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Big Data in Healthcare: Transforming Health Information into Actionable Intelligence

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ABSTRACT

Aim: This paper investigates the transformative role of big data in healthcare, focusing on its potential to convert vast, complex, and heterogeneous health-related information into actionable intelligence that can drive clinical and administrative decision-making.

Methodology: A narrative review methodology was adopted, drawing evidence from peer-reviewed research articles published between 2015 and 2025 in reputable databases such as PubMed, Elsevier, and Springer. The literature was screened to identify studies addressing the lifecycle of big data in healthcare, including acquisition, analysis, and practical implementation. Particular emphasis was placed on emerging technologies, AI-driven analytics, and the integration of multi-source datasets, such as electronic health records (EHRs), genomic data, imaging, and real-time patient monitoring.

Results: The synthesis of literature indicates that big data integration has significantly advanced several healthcare domains. These include personalized medicine, where predictive algorithms guide individualized treatment plans; population health management, enabling early identification of at-risk groups; enhanced diagnostics through AI-assisted imaging; hospital resource optimization for cost-effectiveness; and improved design and execution of clinical trials. Notable case studies—such as Flatiron Health and Tempus—demonstrate how data-driven models accelerate oncology research, facilitate biomarker discovery, and improve patient outcomes.

Conclusion: Big data, when supported by structured frameworks, robust data governance, and ethical AI principles, can shift healthcare from reactive to proactive and predictive models. It offers the capability to enhance preventive care, optimize workflows, and improve patient engagement. However, significant challenges remain, including fragmented data silos, lack of standardization across systems, concerns over data privacy and security, and the need for skilled professionals to interpret complex outputs. Addressing these barriers through interoperable systems, stringent regulatory compliance, and cross-sector collaboration will be essential to unlocking the full potential of big data in revolutionizing healthcare delivery and research.

Keywords: Big Data, Healthcare Analytics, Precision Medicine, Electronic Health Records, Machine Learning.

INTRODUCTION

Big data in healthcare refers to the generation, collection, and analysis of vast and complex datasets originating from a multitude of sources within the health sector. This paradigm shift has arisen due to the rapid digitization of medical records, the proliferation of high-throughput biomedical technologies, and the integration of patient-generated data from wearable devices and mobile health applications.(1) A big data in healthcare is characterized not only by its volume, but also by its velocity, variety, and veracity. These four "V's" describe a landscape where clinical, social, environmental, genomic, imaging, and administrative data intermingle, creating unprecedented opportunities and challenges for healthcare systems worldwide.(2) The traditional model of healthcare information management was largely siloed and fragmented, with records existing in disparate formats, scattered across institutions, and often handwritten or incompatible with digital analysis.

The adoption of electronic health records (EHRs) represents one of the most significant milestones in the big data era. Today, EHRs contain a wealth of structured and unstructured data, including demographics, medication lists, laboratory test results, imaging studies, clinicians' notes, and more.(3) Coupled with claims and billing records, as well as increasingly granular data from genomics and wearable sensors, the cumulative result is a continuously expanding "digital footprint" for every patient. As highlighted by literature, the growth in healthcare data volume presents both opportunities and hurdles. On one hand, these data reserves offer potential to revolutionize clinical care, allowing for earlier disease detection, improved risk stratification, and more effective prevention strategies.(4) On the other, the sheer scale and heterogeneity of data pose methodological, ethical, and infrastructure-related challenges. Issues such as data interoperability, standardization, privacy, and security have become central topics in biomedical informatics research, with ongoing efforts to develop frameworks that enable secure, efficient, and meaningful data sharing. (5)

Big data analytics refers to the suite of computational and statistical tools deployed to discover patterns and generate insights from these large-scale datasets. Techniques such as artificial intelligence (AI), machine learning (ML), and advanced statistical modeling are being applied to identify disease risk factors, optimize treatment protocols, predict health outcomes, and assess health system performance.(6) According to systematic reviews indexed in PubMed, these analytic advancements are fueling progress in precision medicine, where interventions can be tailored to individual patient characteristics—genetic, behavioral, and environmental—rather than relying on one-size-fits-all guidelines. Moreover, the integration of big data into health research and public health surveillance has enabled more robust population health management.(7) Large, linked datasets facilitate longitudinal studies on chronic disease trends, monitoring of infectious disease outbreaks, and evaluation of interventions at the community or national level. The COVID-19 pandemic further highlighted the critical role of real-time, data-driven approaches in guiding policy, resource allocation, and clinical decision-making. (8)This review aims to explore the foundational components, analytical techniques, applications, and real-world implementations of big data in healthcare. By highlighting both benefits and challenges, the paper provides a holistic understanding of how big data can be leveraged for better decision-making and improved health outcomes.

2. Big Data in Healthcare: Foundations

Big data in healthcare is best understood through the framework of the '5Vs': volume, velocity, variety, veracity, and value. Volume refers to the vast amount of data generated daily in the medical field, encompassing millions of electronic health records (EHRs), laboratory test results, genomic sequences, imaging files, and sensor readings produced by wearable technologies and connected medical devices.(9) This immense scale of information gathering represents one of the most transformative shifts in modern healthcare, allowing providers and researchers to access an unprecedented wealth of patient and population-level data. Velocity reflects the rapid pace at which healthcare data is created, collected, and transmitted, especially through real-time data streams originating from Internet of Things (IoT) devices such as continuous glucose monitors, remote blood pressure cuffs, and mobile health applications.(10) The immediacy of such data streams supports timely clinical decision-making, remote patient monitoring, and proactive interventions that can prevent deterioration of health conditions. Variety represents the broad range of data formats within healthcare systems.

This includes structured datasets such as diagnostic codes, medication lists, and lab results; unstructured formats like physicians' free-text clinical notes; complex visual formats from MRI and CT imaging; genomic and bioinformatics data detailing genetic variants; and patient-generated health information from fitness trackers, wearables, and smartphone health apps. Managing this diversity requires robust integration and analytical capabilities to harmonize heterogeneous sources into usable insights.(11) Veracity refers to the reliability and accuracy of health data. Ensuring high data quality is essential, as inaccurate, incomplete, or inconsistent records can lead to flawed analyses and risky clinical decisions.(12) Quality assurance processes include validation, standardization, and automated error-checking to maintain integrity across multiple systems and datasets. Finally, value emphasizes the ultimate goal of big data—deriving meaningful insights that improve patient care, optimize healthcare operations, and guide public health policy.(13) When harnessed effectively, big data analytics powered by artificial intelligence (AI) and machine learning (ML) can identify hidden disease patterns, predict future health trends, personalize treatment plans, and allocate resources more efficiently.(14)

The sources of healthcare big data are broad and diverse. EHRs contain structured clinical details such as diagnoses, treatment histories, and patient outcomes. Medical imaging technologies, including MRI and CT scans, provide high-resolution visual data that support specialized diagnostics. Genomic and bioinformatics databases underpin precision medicine, enabling clinicians to tailor therapies based on a patient's unique genetic profile. Wearable devices and mobile health applications contribute continuous streams of patient-generated data, offering real-world, real-time insights into activity levels, sleep patterns, and vital signs. Administrative and insurance claim databases supplement these sources with information for population-level health analysis and economic evaluations.(15) Over the last decade, global healthcare systems have increasingly initiated large-scale efforts to leverage big data.

In the United States, the Health Information Technology for Economic and Clinical Health (HITECH) Act accelerated the adoption of EHR systems, fostering digital interoperability. In Europe, the European Health Data Space initiative aims to enable secure, standardized data sharing across countries to support research, innovation, and policy-making. Milestones in this transformation include the migration of EHR systems to cloud-based platforms, the growing use of AI-powered diagnostics in clinical workflows, and the integration of real-world evidence (RWE) into clinical trials and regulatory decisions.(16) Collectively, these developments mark a decisive shift toward a more data-driven, precise, and patient-centric healthcare model, supported by technological advancement, robust governance, and cross-institutional collaboration.

3. Data Acquisition, Integration, and Management

The acquisition and integration of healthcare data represent critical stages in the big data lifecycle. These processes begin with data collection from a multitude of sources such as EHRs, laboratory systems, imaging archives, biosensors, patient registries, and mobile health applications. Each source produces diverse data formats, necessitating sophisticated techniques to ensure successful integration. Effective integration requires robust interoperability standards. HL7, FHIR (Fast Healthcare Interoperability Resources), and DICOM are some of the widely adopted protocols that facilitate communication between disparate systems. However, fragmentation of healthcare IT systems across organizations still poses a significant challenge.

Data quality and preprocessing are essential to maintain the reliability of analytics. This involves data cleansing, normalization, deduplication, and transformation. Governance frameworks also play a pivotal role in ensuring that healthcare data are accurate, secure, and used ethically. These frameworks often include data stewardship policies, audit trails, and quality metrics.

Security and privacy are paramount, given the sensitive nature of health data. Compliance with regulations such as the Health Insurance Portability and Accountability Act (HIPAA) in the U.S. and General Data Protection Regulation (GDPR) in the EU is mandatory. Advanced techniques like data anonymization, pseudonymization, and encryption are widely employed to safeguard patient information.

Ultimately, the success of big data in healthcare hinges on building scalable, interoperable, and secure data infrastructures as mentioned below in **Fig-1**vcapable of handling dynamic, high-volume inputs across diverse clinical settings.

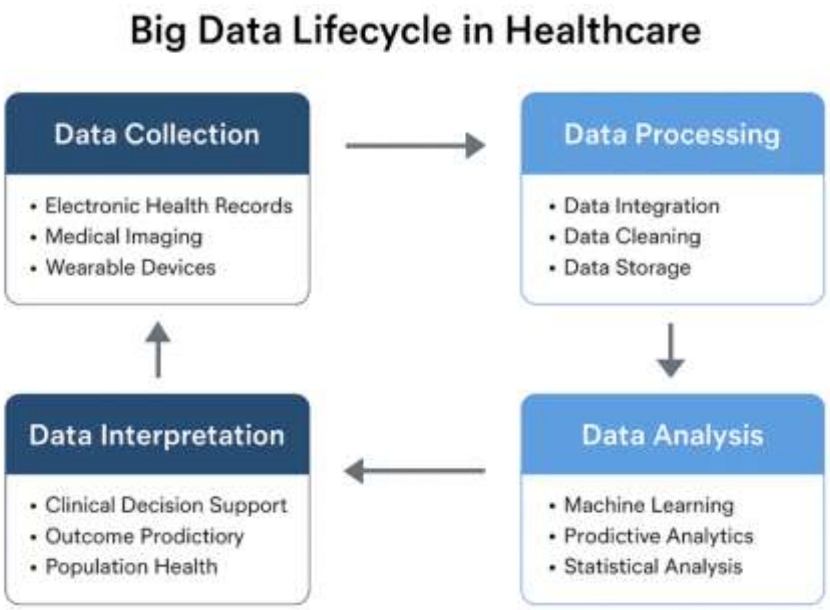

Fig-1: The big data life-cycle in healthcare.

4. Analytical Approaches in Big Data

Big data analytic's in healthcare employs a range of advanced techniques to derive actionable insights from massive datasets. These analytical approaches are foundational in driving innovation, efficiency, and improved clinical outcomes. Machine learning (ML) and artificial intelligence (AI) algorithms enable predictive modeling, disease classification, and risk stratification. Supervised learning models such as logistic regression, decision trees, and support vector machines are used for diagnostic prediction, while unsupervised methods assist in patient clustering and anomaly detection. Deep learning, a subset of AI, has revolutionized medical imaging and genomics by enabling high-dimensional feature extraction and pattern recognition.(17) Predictive analytics utilizes historical patient data to forecast health events such as disease outbreaks or hospital readmissions. Prescriptive analytics, on the other hand, suggests actionable steps to optimize care pathways and resource allocation based on model outputs. Real-time analytics, powered by streaming technologies, allows healthcare providers to monitor patient vitals continuously and respond to critical changes immediately. Integration of decision support systems (DSS) with clinical workflows enhances the speed and accuracy of clinical decisions.(18) Cloud computing and distributed frameworks like Hadoop and Apache Spark facilitate large-scale data processing and storage, enabling scalable and cost-effective analytics. These platforms support parallel processing, fault tolerance, and integration with machine learning libraries. Data visualization tools such as Tableau, Power BI, and custom dashboards are essential for communicating complex data to stakeholders. Interactive charts, heat maps, and visual timelines enhance interpretation and foster data-driven decision-making.(19) Together, these analytical tools and technologies are pivotal in transforming healthcare from reactive to proactive and personalized models as mentioned below in **Fig-2**.

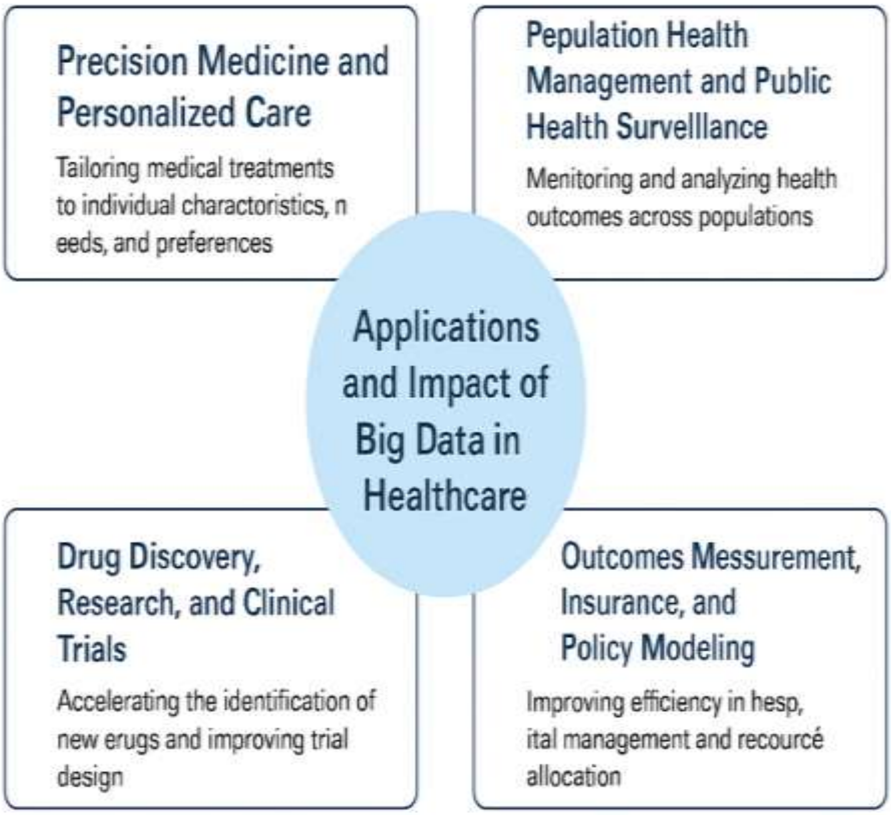

Fig-2: Analytical Approaches in Big Data.

5. Applications and Impact of Big Data on Healthcare

Big data technologies have significantly transformed healthcare delivery, research, and administration by enabling more informed and precise decision-making. One of the most impactful applications is in precision medicine and personalized care, where data from genomics, EHRs, and lifestyle inputs are used to tailor medical treatments to individual characteristics. AI models help identify which therapies will be most effective for specific patients based on their genetic makeup and historical response.(20) In population health management and public health surveillance, big data supports the early detection of disease outbreaks and identification of at-risk populations. Public health agencies leverage data from wearables, mobile apps, and social media to monitor trends in real time, improving epidemic preparedness and policy interventions. Medical imaging and diagnostics have been revolutionized by AI algorithms that analyze scans with greater speed and accuracy.

Tools such as convolutional neural networks (CNNs) are employed to detect tumors, lesions, and anomalies in X-rays, MRIs, and CT scans.(21) These innovations reduce diagnostic errors and enhance radiologist productivity. Drug discovery, research, and clinical trials benefit from the integration of diverse datasets including molecular profiles, biomarkers, and previous trial data. Big data helps optimize trial design, accelerate patient recruitment, and predict adverse events, thereby improving success rates and reducing costs. Hospital operations and resource optimization are also enhanced through predictive analytics. By forecasting patient inflow, resource utilization, and staff requirements, hospitals can improve efficiency and reduce waiting times. Real-time dashboards assist administrators in tracking performance and identifying bottlenecks.(22) In outcomes measurement, insurance, and policy modeling, data analytics plays a vital role in assessing treatment effectiveness, designing value-based care models, and adjusting insurance premiums. As mentioned in **Table-1**, The Governments and insurers use these insights for healthcare financing and strategic planning. Prominent case studies include Flatiron Health's oncology platform, Tempus' AI-driven diagnostics, and SCIO Health's analytics suite, all of which exemplify successful big data integration in diverse healthcare domains.(23)

Table-1: Impact of Big Data on Healthcare

S.N.	Year	Authors	Country/Region	Data Source(s)	Focus/Impact	Ref.
1	2025	Li et al., 2025,	Jordan	AI and Big Data Analytics	Improved healthcare outcomes	(24)
2	2025	Chatterjee et al., 2020	India	EHR + AI	AI-aided treatment	(24)
3	2024	Sharma et al., 2025	India	Clinical Trials Big Data	Clinical trial efficiency	(25)
4	2024	Tsang et al., 2024	Hong Kong	EHR + AI	AI applications in healthcare	(26)
5	2023	Li et al., 2023, .	China	Medical Imaging	Faster and more accurate diagnosis	(27)
6	2023	Khan et al., 2022	UK	EHR + IoT	Resource optimization	(28)
7	2023	Chao et al., 2023	Global	Health Policy Data	Big Data-driven public health policymaking	(29)
8	2022	Gentili et al	India	Claims Data	Healthcare cost reduction	(30)
9	2024	Tse G et al	Hong Kong	Predictive Models	Personalized care	(31)
10	2024	Wang B et al.	China	IoT Wearables	Advanced IoT technologies and smart nursing systems	(32)

6. Case Studies and Real-World Implementations

Several real-world implementations have demonstrated the tangible benefits and feasibility of integrating big data solutions into healthcare systems across the globe. These case studies provide insights into the impact of data-driven decision-making, clinical support, and operational efficiency. Flatiron Health is a notable example of big data application in oncology. By aggregating and analyzing real-world evidence from electronic health records, the platform provides oncologists with actionable clinical insights. Pharmaceutical companies also use this data to design better cancer therapies and optimize trial outcomes. Flatiron's success lies in its data curation model that ensures high-quality, structured oncology data. Tempus leverages AI and big data to personalize cancer treatment through its platform that integrates genomic sequencing with clinical data.(33) The company partners with hospitals to generate molecular profiles that guide physicians in selecting the most effective therapy. Tempus has also been instrumental in supporting clinical trial enrollment using real-time patient matching.

Data-driven analytics solutions are increasingly being used to support population health management, risk adjustment, and cost reduction in healthcare. By examining claims data, prescription patterns, and clinical records, these analytics tools help healthcare payers and providers identify gaps in care and implement targeted interventions. In clinical settings, advanced big data tools are employed for predictive modeling to identify patients at high risk for hospital readmission, leading to improvements in clinical workflows and more effective resource utilization. Partnerships between healthcare institutions and cloud-based platforms facilitate large-scale integration of genomic and clinical datasets, driving advancements in personalized care.(34) Past large-scale artificial intelligence initiatives in healthcare have aimed to leverage big data to assist in diagnosing and treating complex diseases. While some of these efforts have faced setbacks, they have underscored the critical importance of data quality, interoperability, and clinical relevance in achieving real-world impact.(35) Key success factors across these cases include high-quality data acquisition, seamless integration with clinical workflows, scalability, and clinician engagement. Limitations encountered often stemmed from data fragmentation, regulatory constraints, and implementation costs.

CHALLENGES AND LIMITATIONS

Despite its transformative potential, the integration of big data into healthcare is accompanied by several challenges and limitations that must be addressed to fully realize its benefits. Data heterogeneity and fragmentation remain major obstacles. Healthcare data is often stored in disparate formats across multiple systems, ranging from structured fields in EHRs to unstructured notes and images. The lack of standardization complicates data aggregation and analysis. Interoperability and standardization barriers hinder the seamless exchange of information across institutions.(36) While standards such as HL7 and FHIR aim to bridge these gaps, many legacy systems and proprietary platforms are not fully compliant, resulting in information silos. Security, privacy, and legal/ethical concerns are central issues in big data applications. Health data is highly sensitive and requires strict measures for protection. Compliance with regulations such as HIPAA and GDPR is mandatory, and breaches can lead to loss of trust and legal consequences. Moreover, ethical dilemmas may arise in the secondary use of patient data without informed consent.

Technical limitations such as the need for scalable infrastructure, high-performance computing, and real-time analytics capabilities pose additional hurdles. Many healthcare organizations lack the technical expertise and resources to manage these requirements efficiently.(37) Cultural and organizational resistance to data-driven decision-making may also slow adoption. Clinicians may be sceptical of algorithmic recommendations, especially when transparency or explainability is lacking. Proper training and change management strategies are essential to foster acceptance. In developing countries, challenges are amplified by inadequate IT infrastructure, limited funding, poor internet connectivity, and insufficient policy frameworks.(38) These factors hinder the deployment and scaling of big data initiatives in resource-limited settings. Addressing these challenges requires collaborative efforts from policymakers, healthcare providers, data scientists, and technology vendors to build secure, interoperable, and ethically sound big data ecosystems.

FUTURE DIRECTIONS AND INNOVATIONS

The future of big data in healthcare promises a shift toward more precise, predictive, and participatory models of care, powered by technological and methodological advances. One emerging area is the integration of multi-omics data—genomics, proteomics, metabolomics, and epigenomics—into routine clinical practice. Combining these complex data layers with clinical and lifestyle data can drive truly personalized medicine, allowing clinicians to tailor interventions based on molecular signatures.(39) Explainable AI (XAI) is gaining momentum to overcome the black-box nature of traditional machine learning models. Future algorithms must not only be accurate but also interpretable, trustworthy, and transparent, especially in critical decision-making environments like healthcare. Enhancing interoperability and collaborative data ecosystems is another key goal.

Initiatives like open health data platforms and federated learning aim to allow multiple institutions to collaborate on large-scale analyses without compromising patient privacy or ownership. Regulatory frameworks are evolving to keep pace with technological advancements.(40) Governments and global health organizations are increasingly focusing on ethical AI, equitable access, and standardized data-sharing policies. These frameworks will play a pivotal role in governing the secure and responsible use of healthcare data. The rise of real-time remote monitoring and digital twins—virtual replicas of patients based on real-time physiological and clinical data—offers potential for proactive intervention and simulation of treatment outcomes before actual implementation. Blockchain technology is also being explored for secure, decentralized data sharing. It can enhance trust, data integrity, and traceability in multi-stakeholder healthcare systems.(41) Shortly, big data will be central to value-based care models, predictive public health strategies, and the global effort to deliver personalized, equitable, and efficient healthcare services.

CONCLUSION

Big data has emerged as a trans-formative force in healthcare, offering unprecedented opportunities to enhance patient outcomes, improve operational efficiency, and drive research innovation. By harnessing data from diverse sources such as electronic health records, genomics, wearable, and claims databases, healthcare systems are increasingly shifting from reactive to proactive, personalized care models. This review has highlighted the foundational elements, analytical techniques, real-world applications, and challenges associated with big data in healthcare. From precision medicine to hospital resource optimization, the impact of big data is evident across every domain of care delivery. However, the full potential of big data will only be realized when key challenges—including interoperability, data privacy, ethical AI, and technical limitations—are addressed through coordinated efforts involving clinicians, policymakers, technologists, and patients. As the field continues to evolve, investments in secure infrastructure, collaborative ecosystems, regulatory clarity, and advanced analytic will be essential. Ultimately, big data is not just about information — it is about transforming that information into actionable intelligence that saves lives and empowers healthcare for all.

REFERENCES

[1]. Batko K, Ślęzak A. The use of Big Data Analytics in healthcare. J Big Data. 2022 Dec 6;9(1):3.
[2]. Ekbia H, Mattioli M, Kouper I, Arave G, Ghazinejad A, Bowman T, et al. Big data, bigger dilemmas: A critical review. J Assoc Inf Sci Technol. 2015 Aug 31;66(8):1523–45.
[3]. Saberi MA, Mcheick H, Adda M. From Data Silos to Health Records Without Borders: A Systematic Survey on Patient-Centered Data Interoperability. Information. 2025 Feb 5;16(2):106.
[4]. Jaiswal SJ, Pawelek JB, Warshawsky S, Quer G, Trieu M, Pandit JA, et al. Using New Technologies and Wearables for Characterizing Sleep in Population-based Studies. Curr Sleep Med Rep. 2024 Jan 2;10(1):82–92.
[5]. Ponnarengan H, Rajendran S, Khalkar V, Devarajan G, Kamaraj L. Data-Driven Healthcare: The Role of Computational Methods in Medical Innovation. Computer Modeling in Engineering & Sciences. 2025;142(1):1–48.
[6]. Jamarani A, Haddadi S, Sarvizadeh R, Haghi Kashani M, Akbari M, Moradi S. Big data and predictive analytics: A systematic review of applications. Artif Intell Rev. 2024 Jun 17;57(7):176.
[7]. Molla G, Bitew M. Revolutionizing Personalized Medicine: Synergy with Multi-Omics Data Generation, Main Hurdles, and Future Perspectives. Biomedicines. 2024 Nov 30;12(12):2750.
[8]. Awotunde JB, Adeniyi EA, Kolawole PO, Ogundokun RO. Application of big data in COVID-19 epidemic. In: Data Science for COVID-19. Elsevier; 2022. p. 141–65.
[9]. Ristevski B, Chen M. Big Data Analytics in Medicine and Healthcare. J Integr Bioinform. 2018 Sep 25;15(3).
[10]. Zhang K, Zhou HY, Baptista-Hon DT, Gao Y, Liu X, Oermann E, et al. Concepts and applications of digital twins in healthcare and medicine. Patterns. 2024 Aug;5(8):101028.
[11]. Pendergrass SA, Crawford DC. Using Electronic Health Records To Generate Phenotypes For Research. Curr Protoc Hum Genet. 2019 Jan 5;100(1).
[12]. Bernardi FA, Alves D, Crepaldi N, Yamada DB, Lima VC, Rijo R. Data Quality in Health Research: Integrative Literature Review. J Med Internet Res. 2023 Oct 31;25:e41446.
[13]. Syed R, Eden R, Makasi T, Chukwudi I, Mamudu A, Kamalpour M, et al. Digital Health Data Quality Issues: Systematic Review. J Med Internet Res. 2023 Mar 31;25:e42615.
[14]. Hanna MG, Pantanowitz L, Dash R, Harrison JH, Deebajah M, Pantanowitz J, et al. Future of Artificial Intelligence—Machine Learning Trends in Pathology and Medicine. Modern Pathology. 2025 Apr;38(4):100705.
[15]. Hong L, Luo M, Wang R, Lu P, Lu W, Lu L. Big Data in Health Care: Applications and Challenges. Data Inf Manag. 2018 Dec;2(3):175–97.
[16]. Ge S, Song Y, Hu J, Tang X, Li J, Dune L. The development and impact of adopting electronic health records in the United States: A brief overview and implications for nursing education. Health Care Science. 2022 Dec;1(3):186–92.
[17]. Cremin CJ, Dash S, Huang X. Big data: Historic advances and emerging trends in biomedical research. Curr Res Biotechnol. 2022;4:138–51.
[18]. Al-Dmour R, Al-Dmour H, Basheer Amin E, Al-Dmour A. Impact of AI and big data analytics on healthcare outcomes: An empirical study in Jordanian healthcare institutions. Digit Health. 2025 Jan 7;11.
[19]. AL-Jumaili AHA, Muniyandi RC, Hasan MK, Paw JKS, Singh MJ. Big Data Analytics Using Cloud Computing Based Frameworks for Power Management Systems: Status, Constraints, and Future Recommendations. Sensors. 2023 Mar 8;23(6):2952.
[20]. Hassan M, Awan FM, Naz A, deAndrés-Galiana EJ, Alvarez O, Cernea A, et al. Innovations in Genomics and Big Data Analytics for Personalized Medicine and Health Care: A Review. Int J Mol Sci. 2022 Apr 22;23(9):4645.
[21]. Kostkova P, Saigí-Rubió F, Eguia H, Borbolla D, Verschuuren M, Hamilton C, et al. Data and Digital Solutions to Support Surveillance Strategies in the Context of the COVID-19 Pandemic. Front Digit Health. 2021 Aug 6;3.
[22]. Serrano DR, Luciano FC, Anaya BJ, Ongoren B, Kara A, Molina G, et al. Artificial Intelligence (AI) Applications in Drug Discovery and Drug Delivery: Revolutionizing Personalized Medicine. Pharmaceutics. 2024 Oct 14;16(10):1328.

[23]. Ramezani M, Takian A, Bakhtiari A, Rabiee HR, Fazaeli AA, Sazgarnejad S. The application of artificial intelligence in health financing: a scoping review. Cost Effectiveness and Resource Allocation. 2023 Nov 6;21(1):83.
[24]. Ramezani M, Takian A, Bakhtiari A, Rabiee HR, Fazaeli AA, Sazgarnejad S. The application of artificial intelligence in health financing: a scoping review. Cost Effectiveness and Resource Allocation. 2023 Nov 6;21(1):83.
[25]. Sharma P, Sharma P, Sharma K, Varma V, Patel V, Sarvaiya J, et al. Revolutionizing Utility of Big Data Analytics in Personalized Cardiovascular Healthcare. Bioengineering. 2025 Apr 27;12(5):463.
[26]. Tse G, Lee Q, Chou OHI, Chung CT, Lee S, Chan JSK, et al. Healthcare Big Data in Hong Kong: Development and Implementation of Artificial Intelligence-Enhanced Predictive Models for Risk Stratification. Curr Probl Cardiol. 2024 Jan;49(1):102168.
[27]. Li M, Jiang Y, Zhang Y, Zhu H. Medical image analysis using deep learning algorithms. Front Public Health. 2023 Nov 7;11.
[28]. Khan S, Khan HU, Nazir S. Systematic analysis of healthcare big data analytics for efficient care and disease diagnosing. Sci Rep. 2022 Dec 26;12(1):22377.
[29]. Chao K, Sarker MNI, Ali I, Firdaus RBR, Azman A, Shaed MM. Big data-driven public health policy making: Potential for the healthcare industry. Heliyon. 2023 Sep;9(9):e19681.
[30]. Gentili A, Failla G, Melnyk A, Puleo V, Tanna GL Di, Ricciardi W, et al. The cost-effectiveness of digital health interventions: A systematic review of the literature. Front Public Health. 2022 Aug 11;10.
[31]. Tse G, Lee Q, Chou OHI, Chung CT, Lee S, Chan JSK, et al. Healthcare Big Data in Hong Kong: Development and Implementation of Artificial Intelligence-Enhanced Predictive Models for Risk Stratification. Curr Probl Cardiol. 2024 Jan;49(1):102168.
[32]. Wang B, Shi X, Han X, Xiao G. The digital transformation of nursing practice: an analysis of advanced IoT technologies and smart nursing systems. Front Med (Lausanne). 2024 Nov 29;11.
[33]. Chao K, Sarker MNI, Ali I, Firdaus RBR, Azman A, Shaed MM. Big data-driven public health policy making: Potential for the healthcare industry. Heliyon. 2023 Sep;9(9):e19681.
[34]. Batko K, Ślęzak A. The use of Big Data Analytics in healthcare. J Big Data. 2022 Dec 6;9(1):3.
[35]. Maleki Varnosfaderani S, Forouzanfar M. The Role of AI in Hospitals and Clinics: Transforming Healthcare in the 21st Century. Bioengineering. 2024 Mar 29;11(4):337.
[36]. Hassan S, Dhali M, Zaman F, Tanveer M. Big data and predictive analytics in healthcare in Bangladesh: regulatory challenges. Heliyon. 2021 Jun;7(6):e07179.
[37]. Ayaz M, Pasha MF, Alzahrani MY, Budiarto R, Stiawan D. The Fast Health Interoperability Resources (FHIR) Standard: Systematic Literature Review of Implementations, Applications, Challenges and Opportunities. JMIR Med Inform. 2021 Jul 30;9(7):e21929.
[38]. Sokol K, Fackler J, Vogt JE. Artificial intelligence should genuinely support clinical reasoning and decision making to bridge the translational gap. NPJ Digit Med. 2025 Jun 10;8(1):345.
[39]. Mohr AE, Ortega-Santos CP, Whisner CM, Klein-Seetharaman J, Jasbi P. Navigating Challenges and Opportunities in Multi-Omics Integration for Personalized Healthcare. Biomedicines. 2024 Jul 5;12(7):1496.
[40]. Sadeghi Z, Alizadehsani R, CIFCI MA, Kausar S, Rehman R, Mahanta P, et al. A review of Explainable Artificial Intelligence in healthcare. Computers and Electrical Engineering. 2024 Aug;118:109370.
[41]. Mennella C, Maniscalco U, De Pietro G, Esposito M. Ethical and regulatory challenges of AI technologies in healthcare: A narrative review. Heliyon. 2024 Feb;10(4):e26297.