

Review Article



The Role of Cloud Computing in Personalized Medicine

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Received: 09-04-2025; Revised: 26-06-2025; Accepted: 03-07-2025; Published online: 15-07-2025.

ABSTRACT

Cloud computing is reshaping the healthcare industry by offering scalable, flexible, and cost-effective solutions for data storage, analysis, and access to healthcare services. This article critically examines the role of cloud computing in personalized medicine. It highlights the importance of cloud computing for managing large-scale genetic data and individualized patient care, as well as its role in enhancing patient-centric care. It offers several benefits, such as scalability, cost-effectiveness, increased accessibility, and collaboration, which have made it an attractive solution. Personalized medicine or precision medicine, represents a revolutionary approach to healthcare, tailoring medical interventions to individuals based on their unique characteristics such as genetic, lifestyle and environment. Cloud computing has emerged as a transformative force in healthcare industry. The review also addresses the challenges and ethical considerations associated with cloud-based healthcare solutions, such as data privacy and cyber security.

Keywords: Cloud computing, Personalized medicine, Big data analytics, Genomics.

INTRODUCTION

Technology has made great strides in transforming modern industries. It has been advancing and influencing our lives since industrialization and even before that. The cloud is transformative force in the technology era, reshaping how business operates and innovate. Cloud computing is a well-established technology in the industry, providing a faster, cheaper and more agile approach to operating IT architecture.¹

The arrival of cloud computing has proclaimed a transformative era in the digital landscape, fundamentally change how Data is stored, accessed, and processed across various fields, with healthcare being one of the most affected domains. At its core, cloud computing represents a shift from conventional on-building IT Infrastructure to remote, internet-based platforms that provide scalable, flexible, and well-organized data management solutions. This paradigm shift is particularly relevant in healthcare, a sector characterized by its critical need for reliable, secure, and instant access to vast data.²

Cloud computing

Cloud computing is the future of the Next Gen computing systems in the world. A word "cloud" itself relates to any information over and above Earth but near enough to influence the Earth's atmosphere. A report published by Market and Markets estimates the cloud computing market size to increase from \$445 billion in 2021 to \$974 billion by 2026.³

Like many other industries, the pharmaceutical industry has adopted cloud computing for better operations, management of large amounts of data, and collaboration.

The term "cloud computing" is stated by the National Institute of Standards and Technology (NIST) as a "Model

for enabling ubiquitous, convenient, on-demand access to a shared pool of configurable computing resources.⁴

Cloud computing in the pharmaceutical market application refers to using Internet-based technology to accumulate, manage, and access various systems. It brings flexibility, scalability, and cost efficiency by eliminating the need for on-site hardware and infrastructure.

Some of the major players in the competitive cloud computing market in the pharmaceutical industry are Cisco Systems, IBM, Microsoft, Oracle, and Carestream Health.

Key Characteristics of Cloud Computing

- **On-Demand Self-Service:** Through web service interface users can provision computing resources without human interaction.
- **Broad Network Access:** Ability to make cloud available to any device (e.g., mobile phones, tablets, laptops, and workstations) from any location.
- **Resource Pooling:** Grouping and managing a set of resources, such as hardware, software, or virtual machines, to be shared among multiple users or applications.
- **Rapid Elasticity:** Ability of a system to automatically increase or decrease resources on demand.
- **Measured Service:** A metering system that continuously monitors the consumption of resources and generate reports to control and optimize the use of resources e.g., storage, processing, bandwidth, and active user accounts.²

Cloud-based services can be categorized as follows:

- (i) **Software as a Service (SaaS):** SaaS provides users with access to application software and databases. The cloud providers oversee the infrastructure and



platforms that run the applications. SaaS is typically accessed through a web browser and eliminates organizations needing to install and drive applications on their computers or in their data centers. This decreases the cost of software acquisition, maintenance, and support.

- (ii) **Infrastructure as a Service (IaaS):** Service provider leases its infrastructure or makes an infrastructure that can be used to deliver any kind of public or private service. IaaS is highly flexible and scalable, making it ideal for workloads that are temporary, experimental, or change unanticipated.
- (iii) **Platform as a Service (PaaS):** A dedicated platform is created to provide any specific kind of service. PaaS proposed a development and deployment environment in the cloud, it allows users to develop, run, and manage applications without the complexity of building and maintaining the underlying infrastructure typically associated with the process.³

Key Applications of Cloud Computing In Healthcare:

- Electronic health records and medical data management
- Telemedicine and remote patient monitoring
- Healthcare analytics and decision support
- Medical billing and revenue cycle management
- Cyber security and compliance

1. Cloud Computing in Personalized Medicine

Cloud computing delivers computing services—inclusive servers, storage, databases, networking, software, analytics, and intelligence—over the internet ("the cloud") to offer intense innovation, flexible resources, and economies of scale. Users pay only for their cloud services, helping less operating costs, run infrastructure more competently, and scale as business needs change.

In healthcare, cloud computing is not just a technical innovation but a catalyst for enhancing patient care, improving research capabilities, and streamlining operations. It facilitates telemedicine, real-time patient monitoring, and electronic medical records (EMR) management, thereby improving accessibility and quality of care. Additionally, the scalability of cloud services enables healthcare providers to adjust resources based on demand, ensuring the efficient use of computational and storage capabilities while adhering to stringent data protection and privacy regulations.

Personalized healthcare refers to the customization of medical treatment based on individual patient characteristics, such as genetic makeup, lifestyle and environmental factors.⁵

The advent of personalized medicine marks a ideal shift in healthcare, tailoring treatment and prevention strategies to individual patient profile. At the forefront of this revolution

is cloud computing, a technological advancement that has become increasingly vital in managing the vast data sets and complex computational processes intrinsic to personalized medicine.⁴

Development in genomics, proteomics, and data analysis have make easier the identification of biomarkers and treatment targets, leading to the evolution of personalized diagnostics and therapies in different medical fields. Personalized medicine holds promise for lowering both financial and time costs while enhancing patients' standard of living and potentially extending their life spans. It represents an outlook to improve treatment results by identifying the genomic makeup responsible for causing diseases in person. Personalized medicine goals to innovate healthcare delivery by giving precise and targeted therapies.

Personalized medicine is revolutionizing patient care by enabling more accurate diagnoses, targeted therapies, and prevention strategies, fundamentally altering healthcare delivery in the process.

Personalized medicine holds potential across different dimensions of healthcare. It increases diagnostic accuracy by pinpointing genetic markers linked to distinct illnesses, thereby enabling earlier intervention and improved outcomes. Additionally, it streamlines treatment selection tailored to individual patients, increasing therapeutic effectiveness and enhancing patient satisfaction.³

Techniques used in personalized medicine:

Genetic Information

Personalized medicine often include analyzing a person's genetic makeup to know how their genes influence their health, disease risk, and response to treatments. This might involve genetic testing to identify variations in genes that may predispose someone to certain diseases or affect their response to medications.

Tailored Treatment Plans

Based on this genetic information and other factors such as environmental exposures and lifestyle choices, healthcare providers can develop personalized treatment plans that are more effective and potentially safer than generic treatments. For example, certain cancer therapies can be targeted to specific genetic mutations present in a patient's tumor, leading to better outcomes and fewer side effects.

Preventive Strategies

Personalized medicine also emphasizes preventive strategies based on an individual's unique risk factors. By identifying genetic predispositions to certain diseases or lifestyle factors that may increase risk, healthcare providers can recommend personalized interventions to reduce the likelihood of developing these conditions.⁶



2. Applications of cloud computing in personalized medicine

- **Storage and management of data:** EHRs are a digital version of medical records that contain information about a patient's past, current, or future physical or mental health or condition.⁷ Cloud based EHRs allow healthcare providers to store, access, and share patient records in real time.

Analyzing and interpreting the large amount of data generated in personalized medicine is a significant challenge. Advanced computational techniques are required for Integrating genetic, clinical, and environmental data to make actionable treatment recommendations.

Cloud platforms ensure the availability of computational resources required for running complex algorithms and AI models that drive personalized treatment plans.

- **Big data analytics:** Cloud computing supports AI-driven diagnostics, predictive analytics, and personalized medicine by processing large-scale healthcare datasets efficiently. This helps in early disease detection and treatment optimization.

Advanced machine learning methods such as deep learning and platforms for cognitive computing are future of data-driven analysis of biomedical big data. Encouraging advancements in such areas will be indispensable for future innovation in healthcare and Personalized Medicine.⁸

Recent reports also showed that big data analytics in the form of a cryptosystem allow healthcare workers to enable improvement in healthcare, mainly to detect any medical conditions by using any clinical images of the patients. The cryptosystem was found to be very secure against cyber attacks and other interferences and has a very strong key sensitivity.

- **Interoperability and data sharing:** Cloud platforms facilitate global collaboration among researchers, enabling the sharing of medical insights and accelerating advancements in personalized healthcare.
- **Telemedicine and remote monitoring:** Cloud computing significantly enhances patient-centric care in healthcare. It facilitates advanced services like telemedicine and supports complex data management. Telemedicine encompasses the use of electronic information and communication technologies to provide and support healthcare when distance separates participants. This connects patients with genetic counselors and precision medicine specialists, ensuring that individuals receive care tailored to their unique health profiles.
- **Drug discovery and precision medicine:** Researchers use virtual space and computing power from existing

commercial or not-for-profit cloud service providers to access, store, and analyze data via different application programming interfaces. Cloud services are alternate options for need of larger data storage.

Genomics and proteomics studies help identify disease-specific biomarkers and drug targets. Techniques like CRISPER and RNA sequencing allows researchers to validate these targets before developing drugs.

Unlike traditional "one-size-fits-all" drugs, precision medicine focuses on designing drug tailored to specific genetic mutations.

Cloud computing enables remote patient monitoring and virtual clinical trials, reducing costs and improving patient recruitment.

Real world evidence from wearable devices and electronic health records are analyzed in cloud to improve drug development.

- **AI in Precision Medicine:** AI-driven precision medicine is transforming healthcare by enabling personalized treatment plans tailored to individual patients. Traditional medical treatments often follow standardized protocols, but AI analyzes genetic data, medical history, and lifestyle factors to recommend customized therapies.

Machine learning models identify patterns in patient data to predict disease susceptibility, allowing for early intervention and preventive care. Cloud computing provides a robust infrastructure for securely storing and processing electronic health records (EHRs), genomic data, and medical imaging files. AI-powered cyber security measures, such as anomaly detection and encryption, protect patient data from cyber threats and unauthorized access.⁹

3. Applications Of Cloud Computing In Pharmaceuticals

Pharmaceutical companies all over the world are tapping into the possibilities that are inherent to cloud computing. They are using it in different areas, such as designing clinical trials and track-and-trace management. There are numerous possible ways of application, all of which can boost efficiency in some way. During COVID, cloud-based tools allowed pharma companies to capture and share clinical data between research teams both quickly and securely. Vaccines were delivered worldwide in record time, saving millions of lives.¹ Common applications of cloud computing in pharmaceutical industry include the following:

- **Clinical Trials:**

The clinical trial design process also advantages significantly from cloud adoption by pharmaceuticals. The conventional clinical trial model is difficult and taxing for patients. Cloud computing can be a valuable tool in designing clinical trials, as it can help to well organize the process of patient recruitment for the various sites. Instead of holding data



and information across multiple organizations, the data can be stored in the cloud. Many clinical trials are still designed with life sciences companies in mind, requiring patients to make regular hospital visits without compensation for their time and efforts. Cloud computing is helping to change this by enabling decentralized clinical trials, which offer an innovative solution to the issues of the traditional clinical trial model

● **Drug Discovery:**

In drug discovery and development, cloud computing let for safe research and development collaborations between research teams. It simplifies data transfer from laboratory equipment and can able scientists to analyze results and generate outcomes faster.

AstraZeneca, which depends on cloud solutions to accelerate drug research and development, will likely get products to market faster than any company that has resisted this digital transformation.

● **Supply Chain Management:**

Digitalization of data collection in supply chains and moving it to the cloud provides companies with real-time insights into the state of a supply chain, helping them foresee shortages, reduce mistakes, forecast demand, and enhance compliance checks and traceability. Pharma companies can benefit the most from acquiring cloud computing in supply chain management, especially those producing complex drugs, such as vaccines and cell therapies, which require particular manufacturing processes, storage, and transportation conditions.

● **Regulations:**

Cloud technology helps life sciences companies navigate extremely regulated industry without the need to collect physical dossiers. The data submitted to the cloud lets regulators perform instant analysis and speed up approvals. The regulatory submission process has become much quicker and easier. The regulatory bodies can now access company data directly from cloud servers and trace drug safety in real-time. Cloud computing could also give rise to a risk to healthcare organization's ability to act in accordance with regulations.

● **Pharmacovigilance:**

Traditional pharmacovigilance leads to time-consuming manual reporting. Cloud computing makes real-time monitoring possible, allowing early detection of drug safety signals. Real-time monitoring of a drug's location extraordinarily decreases the possibility of errors and prevents counterfeiting.¹

4. Challenges and Ethical considerations:

The ethical considerations of cloud computing in personalized medicine are multifaceted, involving patient autonomy, data privacy, and regulatory compliance.

Comprehensive legal framework to address data privacy concerns in the Big Data era is necessary. This framework

would ensure that sensitive health information is protected while being utilized for personalized medical treatments.

There should be delicate balance between leveraging epigenetic information for healthcare and maintaining patient privacy and consent.

Comprehensive legal frameworks, the ethical management of epigenetic information, balance between data utility and privacy and robust legal and ethical governance in the application of cloud computing within personalized medicine are crucial.¹⁰

Challenges:

- **Data Privacy and Security:** Personalized medicine heavily depends on gathering and analyzing delicate patient data, including genetic information. Make sure that the privacy and security of this data is crucial to maintaining patient trust and compliance.
- **Ethical Concerns:** Personalized medicine raises ethical questions concerning utilization of genetic data for decision-making.
- **Interdisciplinary Collaboration:** Successful execution of personalized medicine requires collaboration between researchers, healthcare providers, policymakers, and technology experts. Bridging the gap among these disciplines can be difficult but is crucial for progress in the field.
- **Data Interpretation:** Analyzing and interpreting the large amount of data generated in personalized medicine is a significant challenge.
- **Liability:** The data stored on the servers might be the intellectual property of an individual, company, or community. E cloud service provider may have the luxury of locating its servers in the location of their choice. But the ultimate responsibility for protecting the data rests upon the service provider itself.
- **Data protection:** on an inter jurisdictional platform, the cloud-based data must conform to several data protection laws applicable to data exchange between the service provider and end-user.⁶

5. Data security:

Data security in personalized medicine, when paired with cloud computing become crucial. Efficient cyber tools are needed to store data with high security. Cyber security plays an important role in not only securing data from malware, vulnerabilities, or cyber-attacks but also identifying and mitigating risks.¹¹

DNA sequence matching needs to be secured, encrypted genetic data should be managed to ensure patient data confidentiality Developing secure and reliable systems to protect sensitive health data in cloud computing environments is important.



6. Future prospects:

Personalized medicine is universally recognized as a important component of the future of healthcare. It stands for a paradigm shift towards tailoring medical treatments and interventions to the individual characteristics of every patient. In future, imaging a personalized approach, individuals may get their whole genomic information at birth, integrated into individual medical records. This data would empower physicians and clinicians to prepare effective healthcare strategies based on individuals' predispositions to various diseases.

The involvement of cloud computing in personalized medicine is rapidly making progress, marked by promising advancements. The growing use of big data analytics in cloud computing is expected to revolutionize patient care, guide hypothesis formulation, and the generation of more effective treatment models.¹²

CONCLUSION

The integration of cloud computing into personalized medicine represents a significant stride in healthcare, offering innovative solutions for patient-specific treatment and efficient data management. It provides essential on demand utility computing, pivotal for handling large-scale genetic information and individualized patient data. The arrival of the Big Data era in life sciences, intensify the scope and accuracy of personalized medicine. Challenges in data security, privacy, and ethical considerations highlight the need for robust governance and adherence to standards. The continued evolution of cloud computing in healthcare promises significant advancements but requires careful navigation of its complexities for its full potential to be realized.

Source of Support: The author(s) received no financial support for the research, authorship, and/or publication of this article

Conflict of Interest: The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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