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Quantum Computing in Healthcare

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ABSTRACT

Quantum computing (QC) utilizes the principles of quantum mechanics to novelly process information, rivaling, and positioning itself to transcend the capabilities of classical computing. QC in healthcare is an emerging field that leverages the principles of quantum mechanics to address complex problems that are beyond the capabilities of traditional supercomputers. Quantum computing is poised to revolutionize clinical care by addressing computational bottlenecks and enhancing the precision, scalability, and adaptability of medical workflows. It holds the potential to transform drug discovery, enhance diagnostic accuracy, and enable personalized medicine. This paper focuses on the applications of quantum computing within healthcare.

KEYWORDS: *technology, quantum computing, QC, healthcare, medicine.*

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INTRODUCTION

Quantum computing (QC) represents a paradigm shift in computational power, offering unique capabilities for addressing complex problems that are infeasible for classical computers, particularly in fields like healthcare. Quantum computing has revolutionized traditional computational systems by bringing unimaginable speed, efficiency, and reliability. These key features of quantum computing can be leveraged to develop computationally efficient healthcare applications. The relevance of QC to healthcare lies in its potential to address computational challenges that are currently insurmountable for classical computers. In areas such as drug discovery, genomics, personalized medicine, and radiotherapy optimization, QC could significantly accelerate breakthroughs by providing solutions to problems that require massive computational power, ultimately advancing the field of healthcare [1].

QUANTUM COMPUTERS

A quantum computer (QC) behaves according to the laws of quantum mechanics. Thus, quantum computers are different from binary digital electronic computers based on transistors. A major difference between classical and quantum computing lies in the way they encode data. While a digital computer requires that the data be encoded into binary digits (0 or 1), quantum computers use quantum bits, which can be in superpositions of states [2]. In other words, instead of storing information in bits as conventional digital computers do, quantum computers use quantum bits, or qubits, to encode information. (Qubits are the basic units of quantum information.) In addition to ones and zeros, qubits have a third state called "superposition" that allows them to represent a one or a zero at the same time. Figure 1 shows the comparison between the bit and qubit [3]. The computing power of a QC grows exponentially with the number of qubits it uses.

Quantum computers have the potential to perform certain calculations significantly faster than any digital computers. QC consists of a quantum processor which operates at a very low temperature (a few tens of mK) and an electronic controller which reads out and controls the quantum processors, as shown in Figure 2 [4]. Several forms of physical media (optical fibers and free space) can be used to deliver quantum information. Figure 3 shows a representation of quantum computing [5].

In quantum system, the computational space increases with the size of the system. This enables exponential parallelism which leads to faster quantum algorithms. Unlike classical computer, QC offers massive parallelism within a single piece of hardware.

A typical quantum computer is shown in Figure 4 [6]. The basic building blocks of quantum computers include quantum gates, quantum memories, quantum CPUs, quantum languages, and quantum languages [7,8]:

- *Quantum Gates:* Quantum computers require quantum gates, which are basically different from classical Boolean gates seen in a conventional computer (AND, XOR and so on). A quantum gate acts on superpositions of different basis states of qubits. The quantum gates perform unitary operations on quantum states and lead to quantum circuits. They are particularly important for quantum error correction and experimental quantum information processing. They can be realized by superconductors, linear optic tools, or quantum dots**.** Common quantum gates are CNOT and SWAP.
- *Quantum Memories:* Quantum memories store the quantum systems in a quantum register for information processing. Quantum memories are formulated by n stationary quantum states. Quantum computers are expected to have limited memory.
- *Quantum CPUs:* These use a quantum bus for the communication between the functional elements of a quantum computer. From a computing perspective, quantum CPUs can be approached through quantum adders.
- *Quantum Languages:* These enable us to create an artificial quantum computer to simulate a quantum computing environment. The programming language should follow a functional programming structure, which can compute the process as a whole entity with a proper bounded structure.
- *Quantum Algorithms:* Quantum algorithms are significantly faster than any classical algorithm in solving some problem. Most of the successful quantum algorithms use quantum Fourier transforms in them because they require less hardware. Popular quantum algorithms include Shor's algorithm (since integer factorization is faster) and Grover's search algorithm.

In ambitious attempts to realize practical quantum computers, enormous efforts are still being expended both in designing software (quantum algorithms) and hardware development (physical implementation).

QUANTUM COMPUTING IN HEALTHCARE

The healthcare sector faces complex challenges that call for innovative solutions to improve diagnostic accuracy, treatment efficacy, and data management. Quantum computing, with its unique capabilities, holds the potential to revolutionize various aspects of healthcare. Quantum computing is a rapidly advancing field with applications in physics, cryptography, material science, logistics, and AI. It is an innovative frontier in technology that leverages the principles of quantum mechanics to process information. Healthcare, in particular, will benefit from QC as the volume and diversity of health data increase exponentially. QC's intersection with medicine began to materialize in the early 21st century, as advancements in both quantum theory and hardware laid the groundwork for practical applications in healthcare. QC promises a revolutionary approach to improving healthcare technologies. Figure 5 shows a representation of QC in healthcare [9], while Figure 6 shows various components of QC in healthcare [9].

The potential of quantum computing in healthcare is vast and varied. Quantum computing has demonstrated its ability to accelerate genomic and molecular analyses, which are foundational to precision medicine. It has potential in drug delivery systems, particularly in designing targeted mechanisms for chronic diseases and oncology. Quantum computing has shown promise in tuberculosis treatment by enabling precise modeling of pathogen dynamics and optimizing therapeutic strategies to counter drug resistance.

APPLICATIONS OF QUANTUM COMPUTING IN HEALTHCARE

The application of quantum computing to healthcare has the potential to completely transform methods used in medical research, diagnosis, and therapy. Figure 7 shows the diverse applications of QC in healthcare, including drug design and molecular simulation, genomics and personalized medicine, medical diagnostics, AI-enhanced healthcare, and Monte Carlo simulations in radiotherapy [9]. Some of these key applications are explained as follows [1,10,11]:

- *Drug Discovery:* Quantum computing holds transformative potential for the field of drug discovery, offering unprecedented capabilities in simulating molecular interactions and accelerating the design of new pharmaceuticals. Quantum computing's ability to address high-dimensional, multi-variable problems makes it a game-changer for drug discovery. QC has introduced powerful algorithms that have the potential to revolutionize drug discovery by enabling more efficient molecular modeling. Traditional methods for simulating molecular interactions and predicting how a drug will interact with biological targets are computationally expensive and time-consuming, especially for complex molecules. Quantum computers can simulate molecular and chemical interactions at an atomic level with unprecedented precision, which is computationally prohibitive for classical computers. This capability accelerates the identification of promising drug candidates for complex diseases like Alzheimer's and Parkinson's, potentially shortening the drug development timeline from decades to years. The enhanced computational power of quantum computers can drastically reduce the time and resources required for drug development, from initial screening to final testing. Figure 8 shows drug design [12].

- *Genomics and Personalized Medicine:* Quantum computing's role in personalized medicine is an exciting frontier, promising to tailor medical treatments to individual patients based on their unique genetic profiles. QC is poised to transform genomics and personalized medicine by enabling the analysis of complex genetic interactions at a scale that is currently impossible with classical computers. Quantum algorithms can model complex interactions more efficiently, identifying patterns and genetic mutations that contribute to diseases like cancer, Alzheimer's, and heart disease. The technology can analyze vast, complex genetic datasets to understand how genes interact and influence disease. This allows for the development of highly personalized treatment plans.
- *Medical Imaging and Diagnostics:* Quantum computing can be used to gain additional insights from medical images and perhaps to diagnose diseases like cancer earlier. It is emerging as a powerful tool in medical diagnostics, particularly through its ability to enhance pattern recognition and data analysis for the early detection of diseases. Quantum principles have the potential to revolutionize medical imaging by enhancing the precision and resolution of imaging technologies like magnetic resonance imaging (MRI). Quantum machine learning algorithms can process and analyze large amounts of medical imaging data (MRI, CT scans) more efficiently and accurately, leading to earlier and more precise disease detection. These advancements not only improve the quality of imaging but also reduce the amount of time required for a scan, potentially lowering patient discomfort and exposure to magnetic fields.
- *Healthcare Research:* Quantum computing research spans a variety of medical specialties, with the most significant focus on radiology and oncology. The integration of QC with AI has the potential to significantly enhance the capabilities of AI models in healthcare. QC is poised to revolutionize healthcare research by offering new ways to solve complex problems that are intractable for classical computers. Quantum algorithms can solve complex optimization problems, such as streamlining hospital resource allocation, optimizing patient scheduling, and improving the design of clinical trials. By simulating patient populations and potential outcomes, researchers can optimize trial designs to be more effective and efficient. Figure 9 shows a healthcare researcher [10], while Figure 10 depicts the dimensions of QC in healthcare [9].
- *Healthcare Systems Optimization:* Modern hospitals are extraordinarily complex operations – coordinating staff schedules, operating rooms, bed assignments, supply chains, and more – and even small inefficiencies can impact patient care. Quantum computing offers new ways to optimize these logistics problems that strain classical systems. Optimizing hospital operations with quantum tools could translate into tangible benefits: shorter ER wait times, fewer delayed procedures, and more efficient use of limited resources like ICU beds.
- *Monte Carlo Simulation in Radiotherapy:* The Monte Carlo simulation is a powerful computational technique widely used in radiotherapy for accurate dose calculation and treatment planning. The stochastic nature of the Monte Carlo method allows it to simulate the complex interactions of radiation particles with matter, providing highly precise models of radiation dose distribution within a patient's body.
- *Clinical Trials:* Quantum computing can transform the design and execution of clinical trials by optimizing complex variables such as patient selection, treatment sequencing, and adaptive randomization. Quantum algorithms like the QAOA and quantum-enhanced machine learning allow more precise matching of patients to trial arms based on genomic or phenotypic data. This results in safer, more effective treatments and faster trial completion, directly

improving patient outcomes and advancing personalized medicine strategies.

- *Radiation Therapy:* Radiation therapy has been employed for the treatment of cancers; it uses radiation beams to eliminate cancerous cells to stop them from multiplying. Radiography is performed using highly precise computers and involves a highly precise optimization problem to perform the precise radiography operation, which requires multiple precise and complex simulations to reach an optimal solution. Through quantum computing, running simultaneous simulations and figuring out a plan in an optimal time becomes possible, and hence the spectrum of opportunities is very vast if quantum concepts are employed for simulations.

BENEFITS

By unlocking new levels of processing power, QC could accelerate discovery, enhance diagnosis, and deliver more personalized patient care. While quantum computing is not yet ready for direct integration into clinical practice, its ongoing evolution holds tremendous potential for the future of medicine. As the boundaries of healthcare and technology continue to converge, quantum computing stands out as a frontier that could transform what is possible in the field. Other benefits include the following [9]:

- *Data Security and Privacy*: The integration of quantum computing into healthcare promises to revolutionize the way sensitive medical information is secured and managed. In healthcare, where the confidentiality and integrity of patient data are paramount, quantum cryptography can secure the transmission of electronic health records (EHRs) between different healthcare entities. Quantum cryptography can play a vital role in protecting data exchanged during telehealth sessions.
- *Quantum Parallelism:* One of the primary advantages of QC is its ability to revolutionize data processing through quantum parallelism. This allows for the simultaneous processing of information, drastically reducing the time required for complex computations such as molecular simulations in drug discovery. This capability could dramatically shorten development timelines and improve the precision of therapeutic interventions.
- *Predictive Analytics:* Quantum computing's ability to analyze complex datasets could lead to breakthroughs in predictive analytics, identifying at-risk populations and tailoring preventative strategies. This could transform public health approaches, focusing on early intervention and targeted treatments. In spine care, quantum computing enhances predictive analytics by processing complex datasets that traditional methods cannot handle.
- *Big Data Analytics*: The explosion of data within the healthcare sector, especially from genomic sequencing and electronic health records, poses unique challenges in data management and analysis. Quantum computing offers transformative solutions for big data analytics in healthcare by leveraging its inherent ability to handle vast datasets more efficiently than classical computers. Practical implementations and theoretical models provide a glimpse into how quantum computing could reshape big data analytics in healthcare.
- *Epidemiology*: The analysis of large datasets to track disease patterns, outbreaks, and the effectiveness of interventions requires substantial computational resources. Public health and epidemiology involve massively complex systems, which are challenging to model and predict. Quantum computers, with their superior processing capabilities, could dramatically improve the speed and accuracy of data analysis in epidemiological studies.

CHALLENGES

Despite its immense potential, QC faces significant technological, logistical, and ethical challenges that limit its current application in medicine and healthcare. These challenges include limited hardware capabilities, difficulties with integration into clinical settings, high costs, and concerns over data privacy and algorithmic fairness. Another significant challenge in modern medicine is the sheer volume and complexity of data generated by medical research, clinical trials, and patient records. Other major challenges include the following [1]:

- *High Costs:* One of the major barriers to the widespread adoption of QC in healthcare is the high cost associated with quantum hardware and its maintenance. The infrastructure and operational costs are significant, limiting accessibility to well-funded institutions. The setups necessitate significant investments in infrastructure, cooling systems, and ongoing operational costs, making QC far more expensive than classical computing. For healthcare institutions, many of which already operate under tight budgets, the cost of installing and maintaining quantum systems is prohibitive. Limited availability and high costs restrict access to quantum computers, leading to economic disparities in which only well-funded organizations can benefit.

- *Integration:* While quantum computing holds immense potential for revolutionizing healthcare through its superior computational capabilities, its integration into the healthcare sector is not without significant challenges. This is due to the complexity of quantum systems and the existing healthcare infrastructure. Unlike classical computing systems, which are well-established in hospitals and research institutions, quantum computers require specialized environments, such as ultra-low temperatures and isolated conditions, making them difficult to install and maintain within standard clinical facilities.
- *Hardware Limitations:* One of the primary challenges is the limited hardware capabilities of quantum computers. Current quantum computers (Noisy Intermediate-Scale Quantum or NISQ devices) are prone to errors (decoherence) and difficult to scale.
- *Workforce Training:* QC in healthcare requires a workforce skilled in both quantum mechanics and clinical applications, posing a challenge in training medical professionals. There is a need for professionals skilled in both quantum mechanics and clinical applications to effectively integrate the technology into medical practice.
- *Collaboration:* The complexity and novelty of quantum computing applications in healthcare necessitate collaborations across several disciplines. Building teams that include quantum physicists, healthcare professionals, bioinformatics experts, and computer scientists can foster a comprehensive approach to tackling the challenges at the intersection of quantum computing and healthcare. Collaborations between academic institutions and healthcare industries are crucial for advancing the practical applications of quantum computing in healthcare. In close collaboration with quantum physicists, neurosurgeons could leverage quantum-enhanced algorithms to rapidly integrate preoperative MRI.
- *Error Correction:* One of the key areas driving the future of QC in healthcare is the development of quantum error correction and other hardware innovations. Error correction is critical because qubits, the fundamental units of quantum computers, are highly sensitive to noise and decoherence, which lead to errors during computations. As quantum hardware and algorithms continue to improve, particularly with advancements in error correction and scalability, QC's potential to solve complex healthcare problems will become more apparent.
- *Decoherence:* This is "the loss of information from a system into the environment." Decoherence is a challenge for quantum computing and must be considered when designing the system that supports the quantum computer.
- *Regulation:* Medical devices present a regulatory challenge. Their life cycles often span years. Once certified, they are rarely updated to meet new cryptographic standards, or updates are not possible at all. At the point of certification, there should be requirements for quantum-safe algorithms. Otherwise, devices in daily clinical use could become long-term vulnerabilities. Regulators in the US and EU are considering how to evaluate quantum-powered medical devices and algorithms, recognizing that these might not fit neatly into existing approval processes.

CONCLUSION

Quantum computing (QC) is poised to become a transformative force in the medical field, offering unprecedented capabilities in data processing, problem-solving, and simulation. Although QC for healthcare is still largely in the research and early development phase, its future potential in healthcare is immense. QC promises advances in healthcare, from drug discovery to personalized treatments. The potential of QC to revolutionize healthcare lies in its unparalleled ability to solve complex problems that are beyond the reach of classical computers. From identifying new therapeutic molecules to enhancing diagnostic precision, quantum computers will allow healthcare professionals to develop more personalized and effective treatments.

QC is poised to become a transformative force in the medical field, offering unprecedented capabilities in data processing, problem-solving, and simulation. The timeline for the widespread clinical adoption of QC in healthcare remains uncertain, but experts predict that its integration into mainstream medical research and clinical practice will likely unfold over the next two decades. In the future, quantum computing can be applied to deliver services to the patients who need them the most, when they need them the most. As quantum computing continues to evolve, its applications in healthcare are expected to expand. More information about quantum computing in healthcare can be obtained from the books in [13-19].

REFERENCES

[1] J. C. L. Chow, "Quantum computing in medicine," *Medical Sciences*, vol. 12, no. 4, November 2024.

[2] "Quantum computing," *Wikipedia,* the free encyclopedia https://en.wikipedia.org/wiki/Quantum_computing

[3] https://www.science.org.au/curious/policy-features/rethinking-cybersecurity-quantum-world

[4] B. Patra et al., "Cryo-CMOS circuits and systems for quantum computing applications," *IEEE Journal of Solid-State Circuits*, September 2017, pp.1-13.

[5] "Quantum computing and its applications," https://www.batoi.com/blogs/perspective/quantum-computing-applications-6357d329ccbad

[6] R. Seifman, "Is quantum computing a potential game changer for the health sector?" March 2025, https://impakter.com/is-quantum-computing-a-potential-game-changer-for-the-health-sector/

[7] L. Gyongyosia and S. Imreb, "A survey on quantum computing technology," *Computer Science Review*, vol. 31, 2019, pp. 51-71.

[8] P. S. Menon and M. Ritwik, "Comprehensive but not complicated survey on quantum computing," *IERI Procedia*, vol. 10, 2014, pp. 144 – 152.

[9] N. Jeyaraman et al., "Revolutionizing healthcare: The emerging role of quantum computing in enhancing medical technology and treatment," August 2024, https://www.cureus.com/articles/278342-revolutionizing-healthcare-the-emerging-role-of-quantum-computing-in-enhancing-medical-technology-and-treatment#!/

[10] X. Marin, "Quantum use cases in healthcare & medical research," January 2025, https://postquantum.com/quantum-computing/use-cases-healthcare/

[11] R. U. Rasool et al., "Quantum computing for healthcare: A review," *Future Internet,* vol. 15, no. 3, February 2023.

[12] B. Mesko, "What can quantum computing do to healthcare?" June 2024, https://medicalfuturist.com/quantum-computing-in-healthcare

[13] G. Nagasubramanian, S. R. Kumar, and V. E. Balas (eds.), *Quantum Computing for Healthcare Data: Revolutionizing the Future of Medicine (Advances in Biomedical Informatics).* Academic Press, 2025.

[14] S. Bedi, *Quantum Computing in Medical Sciences (Artificial Intelligence's Books Series Book 20).* MEUINDIA, 2025.

[15] E. Quiroz, *How Quantum Computers Will Change Pharmaceuticals and Healthcare: Transforming Drug Discovery, Precision Medicine, and Healthcare Innovation Through Quantum Computing.* Kindle edition, 2025.

[16] A. Kumar et al. (eds.), *Exploring Intelligent Healthcare with Quantum Computing.* Institution of Engineering and Technology, 2024.

[17] D. J. Monlezun, *Quantum Health AI: The Revolution of Medicine, Public Health, and Global Health by Quantum Computing-Powered Artificial Intelligence.* Academic Press, 2025.

[18] D. Roosan, *Quantum Computing in Medicine: Transforming Drug Discovery, Protein Folding, and Genomics Research Through Artificial Intelligence Integration.* Elsevier Science, 2026.

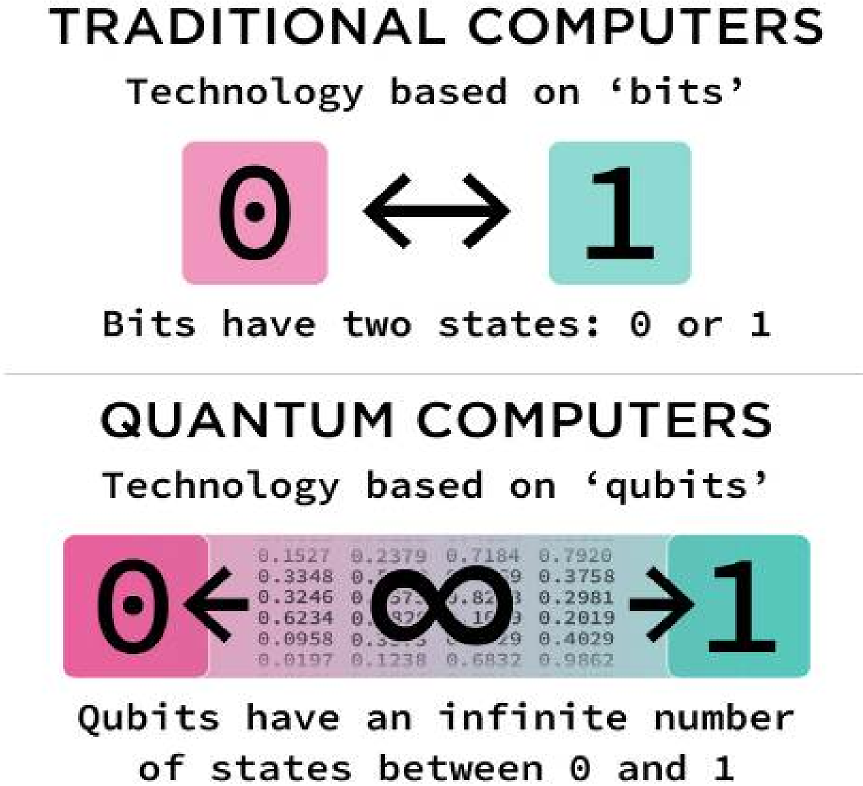

Figure 1 The bit and the qubit [3].

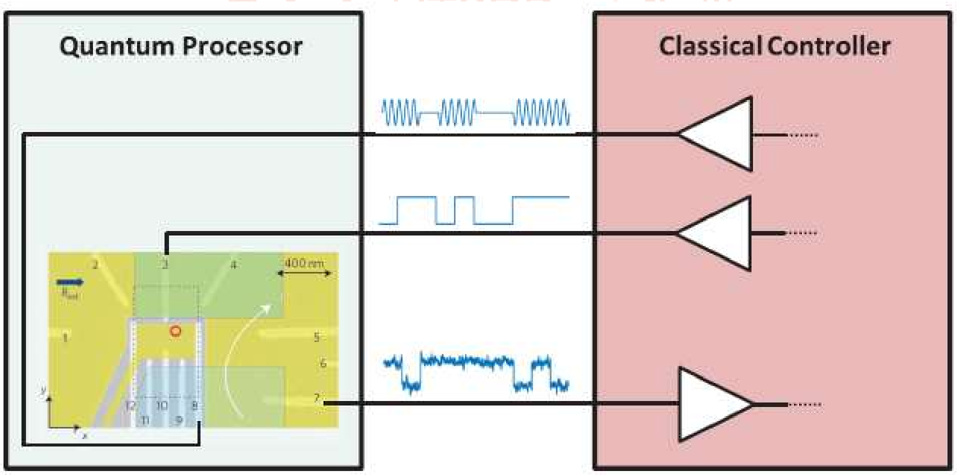

Figure 2 Quantum processor and classical electronic controller [4].

Figure 3 A representation of quantum computing [5].

Figure 4 A typical quantum computer [6].

Figure 5 A representation of QC in healthcare [9].

Figure 6 Various components of QC in healthcare [9].

Figure 7 Diverse applications of QC in healthcare [9].

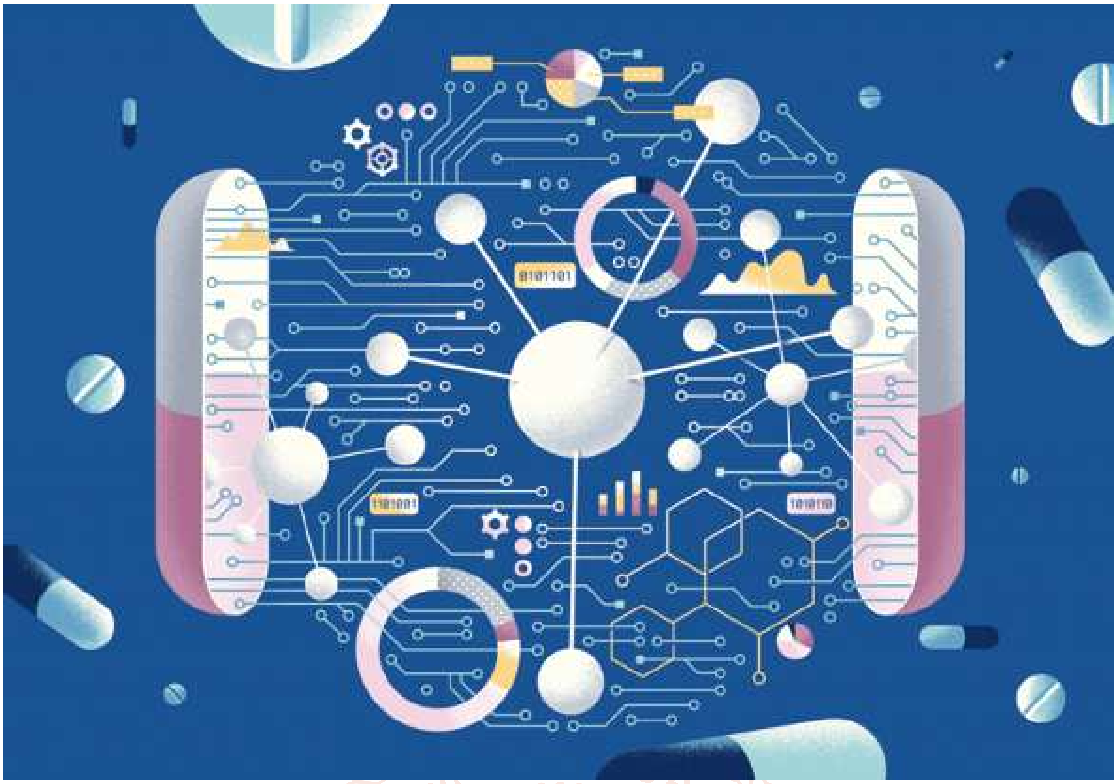

Figure 8 Drug design [12].

Figure 9 A healthcare researcher [10].

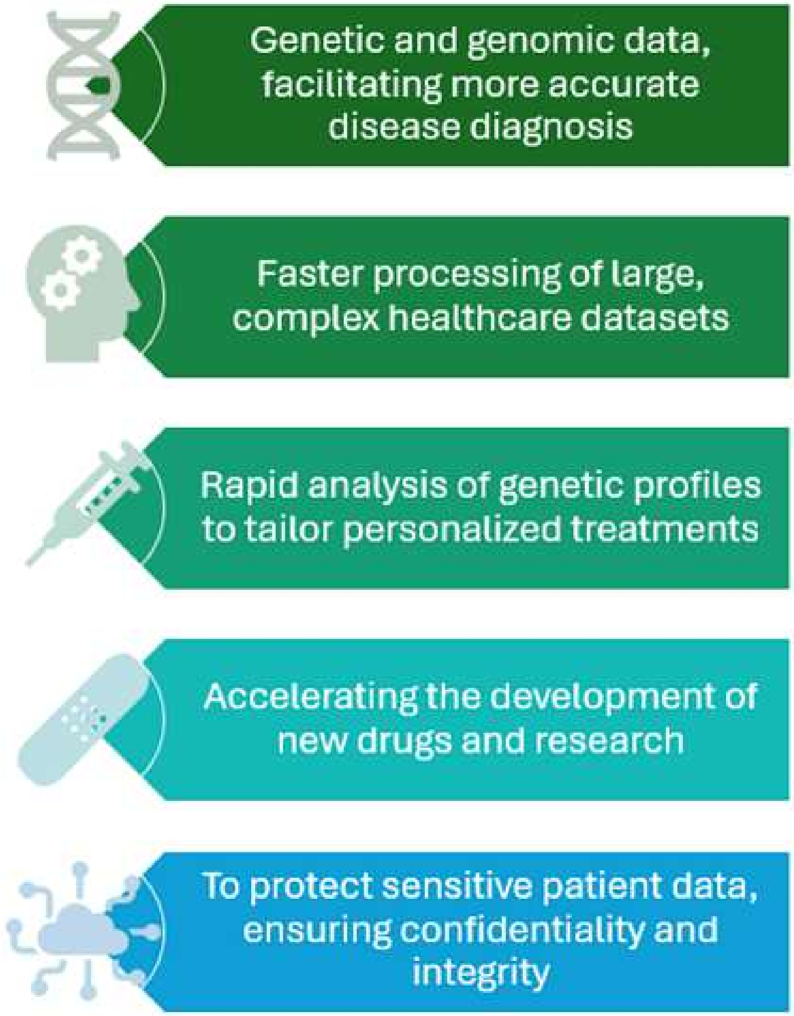

Figure 10 The dimensions of QC in healthcare [9].