Demystifying quantum blockchain for healthcare

Keshav Kaushik | Adarsh Kumar

School of Computer Science, University of Petroleum and Energy Studies, Dehradun, India

Correspondence
Keshav Kaushik, School of Computer Science, University of Petroleum and Energy Studies, Dehradun, Uttarakhand, India.
Email: officialkeshavkaushik@gmail.com

Abstract
The healthcare industry and the battle against the COVID-19 pandemic are two areas where blockchain technology might be useful. In this study, blockchain's significance is examined. Blockchain technology and related procedures will be used in future healthcare systems for collecting sensor data, automated patient monitoring, and safe data storage. Because it can store a large amount of data in a dispersed and secure way and provide access whenever and wherever it is needed, this technology greatly simplifies the process of carrying out activities. The advantages of quantum computing, such as the speed with which patients can be found and monitored, may be fully used with the help of quantum blockchain. Quantum blockchain is an additional resource that may be used to safeguard the veracity, integrity, and availability of stored information. Combining quantum computing with blockchain technology may allow faster and more secure medical information processing. In this research, the authors examine the potential uses of blockchain and quantum technology in the healthcare industry. Quantum technologies, blockchain-based technologies, and other cutting-edge ICTs (such as ratification intelligence, machine learning, drones, and so on) were investigated and contrasted in this article.

KEYWORDS
healthcare and bioinformatics security, healthcare and society, security in business

1 | INTRODUCTION TO QUANTUM COMPUTING

Quantum computing (QC) is a promising computing approach based on quantum physics and its extraordinary events. It is a beautiful synthesis of mathematics, physics, computer science, and computational modeling. It achieves tremendous processing capacity, low energy consumption, and exponential speed above traditional computers by regulating the behavior of tiny physical things such as atoms, electrons, photons, and other minuscule particles. Considering quantum theory is a broader paradigm of science than classical physics, it contributes to a more general framework of computing, QC, that can address problems that classical computing cannot. Unlike regular computers, which use binary bits 0 and 1 to store and process data individually, QC uses their quantum bits, often known as "Qubits." "Quantum Computers" are computers that use QC. QC can quickly penetrate today's encryption techniques, but the most incredible supercomputer presently available takes thousands of years. While QC will be competent in deciphering several of today's encryption techniques, it is believed that they will build hack-proof replacements. Transistors, logic gates, and integrated circuits cannot be used in such small computers. Therefore, atoms, protons, electrons, and ions are used as bits and their rotation and state metadata. They may be layered to make new combinations. Consequently, they may run parallel and efficiently employ memory, increasing their power. QC is the only computing paradigm that defies the Church-Turing thesis, permitting QC to take advantage of the available systems several times greater.
The quantum bit or qubit’s central element of quantum theory depicts elementary particles such as atoms, electrons, and other subatomic particles as computer memory while their regulatory systems act as computer processors. It can have a value of 0, 1, or both simultaneously. It has a million times the processing power of today’s most advanced and powerful. In engineering, producing and managing qubits is a considerable task. The quantum computer’s computing strength comes from its digital and analog nature. Quantum gates have no distortion limit due to their analog nature, yet their digital nature gives a standard for recovering from this significant flaw. As a result, the logic gates and representations used in classical computing are useless in QC. Purely classical computing principles can be used in QC. However, this computation requires a unique way to avoid processing variances and any form of noise. It also requires its technique for debugging issues and dealing with design flaws.

There are three essential properties of QC—superposition, interference, and entanglement. In QC, superposition denotes a quantum system’s capacity to exist simultaneously in two distinct places or configurations. It allows incredible parallel processing with high speed and is quite different from its classical counterparts, with binary restrictions. The QC system stores information in two states at the same time. In QC, interference is comparable to wave interference in traditional physics. Two waves strike in a single environment, leading to wave interference. However, suppose the waves are aligned in the same direction. In that case, it generates standing waves with respective amplitudes added collectively, referred to as constructive interference, or a consequent wave with their amplitudes wiped out, known as destructive interference. Depending on what type of interference, the net wave might be larger or less than the original wave. One of the essential aspects of QC is entanglement. It refers to the close relationship between two quantum particles or qubits. Regardless if they are separated by huge distances, like at opposing ends of the Universe, qubits are linked in a flawless immediate relationship. They are intertwined or characterized by one another.

There are numerous QC applications, but some prominent ones are highlighted in Figure 1. The main applications of QC involve—Cybersecurity, artificial intelligence, financial modeling, logistics optimization, and weather forecasting. Because of the growing number of cyber-attacks that arise along the way all over the world, the internet security environment has become highly susceptible. Even though businesses are implementing the appropriate security frameworks, the procedure for traditional digital computers has become intimidating and unworkable. Figure 1 explains the multiple applications of QC, some of which are as follows:

- **Cybersecurity**—Quantum computers on a large scale will considerably increase computational capability, opening up new possibilities for enhancing cybersecurity. Quantum-period cybersecurity will be able to identify and block cyber-attacks from that era before they do damage. But it could end up being a double-edged sword since QC might also open up new vulnerabilities, such as the capacity to swiftly solve the challenging mathematical puzzles that form the basis of some types of encryption. Businesses and other groups may start getting ready now even if post-quantum cryptography guidelines are still being developed.

- **Healthcare**—Combining quantum and classical computing in the healthcare industry is anticipated to offer significant benefits that classical computing alone cannot provide. A new style of understanding, a highly sought-after set of talents, unique IT architectures, and innovative business strategies are all required for QC. Additionally, technology directly affects security. Considering the sector’s obligations and difficulties about data privacy, security is a topic of special concern for the healthcare industry.

- **Artificial intelligence**—AI and QC are both game-changing technologies, and for artificial intelligence to make substantial strides, QC is a must. Artificial intelligence is constrained by the computing power of conventional computers while producing useful applications on them. Artificial intelligence may benefit from a computing boost from QC, allowing it to handle more challenging issues in a variety of commercial and scientific domains.

- **Financial modeling**—Financial firms that can use QC will probably gain a lot from it. They will be better equipped to assess big or unstructured data collections, in particular. By making offers that are more timely or relevant, for instance, banks might make better judgments and provide better customer service. Where algorithms are driven by real-time data streams, such as real-time share prices, which contain significant random noise, quantum computers are showing promise.

- **Logistics optimization**—Numerous benefits from QC may be realized in the logistics industry. Current CPUs would be complemented by quantum computers, speeding up gadgets using machine learning and AI. Quantum supercomputers would have a significant impact on route planning in logistics. Utilizing QC would improve the utilization of warehouse modeling by examining all feasible routing choices and selecting the most effective one while accounting for all factors.
- Weather forecasting—On a local and a larger scale, QC can help weather forecasting for more sophisticated and precise warnings of catastrophic weather occurrences, possibly saving lives and lowering yearly damage to property. Beyond weather forecasting, keep up with the 1QBit blog and follow us on social media to learn more about the status of QC and its growing effect on a range of sectors. By handling enormous amounts of data with numerous variables efficiently and quickly utilizing the computing power of qubits, and applying quantum-inspired optimization algorithms, QC has the potential to advance conventional numerical methods to enhance tracking and forecasts of weather conditions.

Pharmaceutical formulation and construction are the most demanding tasks in QC. Typically, drugs are created through trial and error, which is pricey, dangerous, and time-consuming. QC, according to studies, might be a beneficial tool for investigating drugs and their impacts on people, potentially saving drug companies a lot of time and resources. Machine learning and artificial intelligence are two of the most critical issues today since new technologies have infiltrated nearly every aspect of human existence. QC can reduce its time to solve complex problems that might otherwise take years on conventional devices. Since accounting professionals manage vast sums, even a minor change in the expected return can significantly impact. Another possible use is algorithmic investing, wherein a computer performs complex procedures to automatically initiate share trades depending on market circumstances, which is beneficial, especially in high-volume transactions. Quantum annealing is a cutting-edge, efficient algorithm that might surpass traditional computers. On the other hand, Ubiquitous QC is prepared to address any computing issue but is not yet commercially accessible.

The article is arranged into nine major sections, in Section 1, QC is introduced followed by quantum blockchain in Section 2. The introduction of Quantum blockchain in healthcare is discussed in Section 3, whereas advanced quantum-integrated technologies like quantum drones, quantum satellites, quantum AI, and quantum ML are highlighted in Section 4. Furthermore, photonic quantum computing for healthcare is added in Section 5. Quantum gates and circuits for healthcare are highlighted in Section 6, and quantum algorithms for healthcare are discussed in Section 7.
Quantum simulation and healthcare, a comparative analysis of QC-based approaches for healthcare are discussed in Sections 8 and 9 respectively. Finally, the conclusion and future directions are discussed in Section 10.

2 | INTRODUCTION TO QUANTUM BLOCKCHAIN

The blockchain is a decentralized distributed hyperledger that stores and shares copies of all activities or digital events. The plurality of involved parties confirms each transaction. It holds every single transaction record. Blockchain the groundbreaking technology transforming many sectors was mysteriously launched into the market with its first advanced form, Bitcoin. Bitcoin is a type of cryptocurrency that may be used to replace traditional money for transacting. Blockchain is the advanced technology that has led to the rise of cryptocurrencies. Quantum blockchain (QB) is encrypted, distributed, and decentralized based on quantum information theory and QC. The data will not be altered after being recorded on the QB. As QC and quantum communication theory has advanced in recent years, more academics have turned their attention to QB exploration. QB Technologies has launched ambitious research, development, and investment programme in the fast-paced blockchain technology field, including cryptocurrency mining and other sophisticated blockchain applications. Quantum's research and development will be focused on cryptography, combining the most sophisticated implementation techniques and functions with QC technologies and AI deep learning to provide a new and innovative perspective on blockchain technology.

The cryptocurrency business began to increase, with a market capitalization of $90 billion last month. Whatever happens next, cryptocurrencies will play an increasingly significant role in the world financial sector. The most challenging aspect of digital cash is ensuring that everybody uses it legitimately. Moreover, it appears that blockchain technology offers a promising alternative. This ensures honesty by employing cryptographic algorithms commonly considered impenetrable, barring brute-force assaults. In this article, the authors examined recent breakthroughs in QB and briefly discussed its benefits over the traditional blockchain. The QB’s architecture and structure are discussed. Integrating quantum technology into a specific area of the broader blockchain is then shown.

Furthermore, the benefits of QB over the traditional blockchain are discussed, as well as its future development potential. This article demonstrates that time entanglement, rather than spatial entanglement, offers a critical quantum benefit. All of the system’s constituent parts have been experimentally realized. Additionally, our encoding approach can potentially influence the past in a non-classical way. The article explores the fundamental problems, hazards, and benefits of putting these technologies into practice from a future perspective. We wrap up our study with an overview of the field’s significant gaps, methodological issues, and suggestions for future research.

A blockchain is a distributed hyperledger that is cryptographically safeguarded from harmful changes. While blockchain systems promise a broad array of applications, they rely on digital certificates, which are susceptible to quantum computer assaults. Although to a lesser degree, the same holds for cryptographic algorithms used to prepare new blocks, implying that parties having access to quantum processing may have a square edge in obtaining mining rewards. Researchers present an exploratory implementation of a quantum-safe blockchain platform for cognitive person identification that leverages quantum key distribution via an urban fiber network as a viable answer to the quantum-era blockchain dilemma. The existing research developments on QC, quantum-safe computing, or post-quantum cryptography, which are essential to quantum connections, are discussed in article, as well as the benefits involved, constraints, future breakthroughs, and research issues related to quantum technologies, as drones, and their systems. This research also includes constructing a categorization system for quantum-related disciplines depending on the rationale of their comprehension and study of each of these disciplines.

This chapter surveys the topic of blockchain systems. The existing systems’ security is predicated on computational outcome expectancy, and many mainstream encryption methods are susceptible to the arrival of full-fledged quantum systems. The authors of this study proposed a unique negotiating process to set the authenticity of a block and allocate a new block in the blockchain infrastructure. Mediation processes based on an expanded probability environment are used to achieve block verification and allocation. A unique QB system is suggested in this study to improve blockchain safety. First, the authors offered a description of QB and discussed its development. In particular, the benefits are outlined in this article. Second, this work created a new cryptocurrency called quantum coin based on the quantum no-cloning theorem. Furthermore, this work claimed to build a unique QB method using quantum entanglement and DDoS.

A brief overview of quantum cryptography and the blockchain system is provided in the article. The foundation and inspiration for fast and secure online communications network-based methods are discussed. The concept is briefly
described to develop a network-based data exchange application using QB technology. QB technology's primary purpose in transmitting data is to create long-term fast, stable network connectivity.

3 | IMPORTANCE OF QUANTUM BLOCKCHAIN FOR HEALTHCARE

Insurance companies and digitally recorded healthcare datasets can assist society in reducing the healthcare ecosystem's high degree of complexity and cost. The general data protection legislation gives data owners the right to know how their data is maintained and used. Nevertheless, healthcare data is transmitted over an open channel, namely the Internet, allowing hackers to carry out nefarious actions such as breaching sensitive data, altering stored data, etc. As a result, maintaining the security and anonymity of participants is a problematic issue for traditional medical systems. Blockchain has evolved as a platform that enhances today's healthcare system's efficiency while ensuring all parties' privacy and security. The authors examine several security architectures used to safeguard health records and implement QC to the typical encryption system in this article, which is inspired by these findings. Then, for healthcare, we offer a blockchain-based architecture that allows individuals to access information from the database depending on their stated roles.

Electronic medical records (EMRs) to improve the performance and dependability of health care have become a common occurrence as medical knowledge advances. However, EMRs are housed separately in medicine and healthcare institutes, posing sharing issues. In addition, extremely sensitive EMRs are vulnerable to tampering and abuse, creating privacy and security risks. From a philosophical city standpoint, the latest advancements of Healthcare 4.0, which uses IoT elements and cloud services to access medical procedures remotely, have piqued the researcher's interest. Frequent medical data monitoring, consolidation, data transfer, information sharing, and data management were the core components of Healthcare 4.0. Protecting patients' sensitive and confidential data from hackers presents various obstacles. As a result, storing, retrieving, and transmitting patient medical data on the cloud necessitates extra security precautions to ensure that authorized user elements of E-healthcare systems do not compromise it. Several cryptographic techniques have been created to provide secure health information storage, transmission, and retrieval in cloud service providers. Table 1 provides a comparative analysis of related work in the domain of quantum blockchain.

4 | ADVANCED QUANTUM-INTEGRATED TECHNOLOGIES LIKE QUANTUM DRONES, QUANTUM SATELLITES, QUANTUM AI, AND QUANTUM ML

Exploring ways to employ QC to speed up the implementation of conventional machine learning algorithms is a crucial objective of QML research. QML is also known as quantum-assisted machine learning or quantum-enhanced machine learning. As QC progresses beyond being a developing and primarily theoretical technology, data scientists and others are becoming increasingly familiar with the application of QC for machine learning and other operations. Nowadays, QC is being tested in real-world settings through a few pilot programmes at major IT firms. The outcome could lead to more real-world and less theoretical QC systems.

For the benefit of those who are not aware, a “drone” is a kind of aircraft that may be controlled by someone other than the pilot but which flies in a manner analogous to that of an aeroplane or pilot. It is common to practice using this term while discussing automobiles. Unmanned aerial vehicles/drones and piloted aircraft may be differentiated from one another by the presence of a human pilot. It is physically impossible for an aeroplane to take off without a person at the controls (the autopilot mode is not distinguishable). Quantum AI and drones can help collect imaging in thermal space, keep an eye on things, and conduct surveillance are some of the uses of this technology. Other possible services include making adjustments to systems and distributing medicine or meals, sanitization and disaster relief force. Quantum drone-based systems with quantum satellites might be significantly improved by combining quantum-based data transfer, social distance measuring, and data collection using AI-based recognition. Quantum drones are useful in environment cleaning and many more applications when enabled with quantum satellites, quantum AI and quantum ML technologies.

A theoretical area called quantum machine learning (QML) is only beginning to take shape. It sits where QC and machine learning converge. QML’s primary objective is to accelerate processes by integrating machine learning with what we have learned about QC. QML theory adopts concepts from conventional machine learning theory and approaches QC through those frameworks. For simulating QML, Xanadu offers PennyLane as open-source software. It blends
| Author                  | Year | A | B | C | D | E | Major findings                                                                                                                                 |
|------------------------|------|---|---|---|---|---|-------------------------------------------------------------------------------------------------------------------------------------------------|
| Chen et al             | 2022 | ✓ | ✓ | ✓ | ✓ | × | The authors developed an Anti-Quantum Attribute-based Authentication for Protected EMRs Sharing with Blockchain to address the issues.           |
| Mirtskhulava et al     | 2021 | ✓ | ✓ | ✓ | ✓ | × | Blockchains are seen as a critical answer for several 5G challenges, including mobile IoT security and the exchange of EHR. The researchers looked at Hashing-based Post-Quantum Authentication as a way to improve blockchain safety. |
| Mahajan et al          | 2022 | × | ✓ | × | ✓ | × | This article thoroughly examines contemporary blockchain-based medical data security solutions, both with and without cloud computing. In this work, we use blockchain to build and analyze several strategies. The study gaps, problems, and future roadmap are the findings of this article, as per the research investigations, which promote rising Healthcare 4.0 innovation. |
| Azzaoui et al          | 2022 | ✓ | ✓ | ✓ | ✓ | × | This study provides a Quantum Cloud-as-a-Service for sophisticated Smart Healthcare calculations that are efficient, scalable, and secure. What sets us distinct is our usage of Quantum Terminal Machines and Blockchain technology to increase the feasibility and anonymity of the proposed model. |
| Fernández-Caramès et al| 2020 | ✓ | ✓ | ✓ | × | × | This article first examines the present state of post-quantum cryptographic protocols and how they may be used for blockchains and distributed ledger technologies. Prospective blockchain researchers and engineers will benefit from this article's comprehensive perspective and practical guidance on post-QB security. |
| Gupta et al            | 2022 | ✓ | ✓ | ✓ | × | ✓ | The authors presented a strategy to withstand a quantum assault by employing lattice cryptography. Furthermore, a trustworthy blockchain system is demonstrated to ensure the trustworthiness of automobiles in batch data verification. |
| Cai et al              | 2019 | ✓ | ✓ | ✓ | × | × | The suggested quantum trademark strategies rely on quantum entanglement characteristics that a solitary signer or multiple signers may use and will enhance the stability of blockchain-based smart contracts against quantum attacks while maintaining a lightweight structure and eliminating the need for a reliable party or arbitrary organization. |
| Iovane                 | 2021 | ✓ | ✓ | ✓ | × | × | In this research, we present a unique negotiation technique for fixing the validity of a transaction and allocating a new block in blockchain architecture. Negotiation processes based on an expanded likelihood framework are used to achieve block verification and allocation. |
| Li et al               | 2018 | ✓ | ✓ | ✓ | × | × | The authors of this study provide an analysis of the contemporary blockchain networks' weaknesses to a quantum attacker and some prospective post-quantum mitigating strategies. |
| Gao et al              | 2018 | ✓ | ✓ | ✓ | × | × | The authors presented a lattice problem-based signature system. The lattice-based delegating method establishes secret keys, while the preimage survey technique authenticates communications. |

Note: A, quantum computing; B, blockchain; C, quantum blockchain; D, healthcare; E, quantum drones.
traditional machine-learning software with hardware and quantum simulators. PennyLane supports a broad range of machine-learning frameworks and a developing ecosystem of quantum hardware. Despite the community’s ongoing efforts to develop fault-tolerant quantum theory, PennyLane and hardware options enable corporate clients to begin utilizing QC right away.

Deep learning and QC can be used together to speed up neural network training. Using this technique, we may accomplish fundamental optimization and create a new paradigm for deep learning. We can reproduce classical deep learning methods on a real, physical quantum computer. As more neurons are added, the computational complexity rises when multi-layer perceptron topologies are used. Performance may be enhanced by using specialized GPU clusters, which also considerably cuts down on training time. Indeed it, though, will rise in comparison to quantum computers.

The hardware of quantum computers is intended to imitate brain networks rather than the software found in traditional computers. Here, a qubit takes on the role of a neuron, the fundamental building block of a neural network. As a result, a quantum system with qubits may perform the function of a neural network and be utilized for deep learning applications at a rate that is faster than any traditional machine learning technique. In other terms, quantum machines have the potential to improve our quality of life and, when properly used, can remove many obstacles to the way we can improve machine learning algorithms.

5  |  PHOTONIC QC FOR HEALTHCARE

The next major transformation in the medical industry will be led by QC. This technology has several benefits across various industries, particularly in those that impact the health sector. The fusion of quantum theory and quantum technology allows for the processing of massive amounts of data, the creation of simulations, the development of specialized medications, and the molecular manipulation of organs using nanotechnology, artificial intelligence, and particularly QC. A new scientific subject called photonic quantum information has emerged due to recent technological advancements in synthesizing, managing, and sensing individual single photons. This development involves the creation of single photon switching, functional photonic quantum circuits, and innovative optical metrology that goes beyond the capabilities of conventional optics. Although photonics presents unique benefits as a platform for quantum information processing, it faces significant scaling difficulties. While deterministic methods require an unreasonably high number of identical quantum emitters to construct large quantum circuits, nondeterministic techniques incur enormous resource overheads.

We need to make and control a lot of qubits to build a working quantum computer. Although significant advancements have been achieved utilizing trapped ions, superconducting circuitry, and several other technologies, this accomplishment has proven to be challenging. Scalability, or the capacity to combine numerous qubits, is constrained since each qubit in a multi-qubit system gradually loses its quantum features. Decoherence is a phenomenon that arises from interactions between the qubits and their environment. Utilizing photons is one technique to generate scalable structures. We might be onto something here since photons’ quantum states are more resistant to decoherence.

If the Wigner function of a photonic system is a two-dimensional Gaussian function, the system is indeed in a Gaussian state. An operation that would take an ordinary supercomputer more than 9000 years to complete may be completed in only 36 microseconds by a new photonic quantum computer. The brand-new system, called Borealis, is the first quantum computer developed by a startup to exhibit such a “quantum edge” over conventional computers. Borealis is the first computer with a quantum advantage made publicly accessible through the cloud. Theoretically, quantum computers can acquire a quantum edge that permits them to discover solutions to issues that conventional computers have never been able to.

Compared to previous approaches, photonic devices take a very different technique from QC. Even though the creation of qubits still poses a problem, recent theoretical and practical advancements have enhanced its reputation as a scalable solution. We can integrate qubits into photonic states in a wide range of ways, which leaves a lot of opportunity for inventiveness and pave the way for future research and technological advances.

6  |  QUANTUM GATES AND CIRCUITS FOR HEALTHCARE

The state vectors are used by quantum gates, which are analogous to logic gates. The functions of quantum gates are described by Alice and Bob, who also show how they affect the states that describe a single qubit. The NOT gate, the Pauli
gates, and the Hadamard gate are some examples of these gates. Even abstract characters and matrices that aggregate state vectors are used to express the gate functions. Additionally, Alice and Bob provide a brief introduction to a few of the mathematical properties of quantum gates and what occurs when many gates work sequentially on the state, denoting a qubit, a property that frequently recurs in QC. Cardy is interested in how quantum measurements and quantum gates are connected. Alice and Bob make the critical distinctions between measurement tools and quantum gates. These distinctions hint at the substantial conceptual gap between quantum and conventional physics.

Doctors will be able to include a great number of cross-functional data sets into their physician’s risk factor thanks to quantum’s capacity to compute at scale. Thanks to QC, a better match between the procedure and the patient will be ensured by employing additional points of reference when choosing clinical trial participants. Reliability and promptness in diagnosis and treatment are now essential for providing high-quality care. The use of QC might lead to unparalleled processing speed and power. Employing quantum theory, doctors may make correlations and offer a diagnosis or therapy. Including its intelligence, QC has the potential to transform current medicine completely. QC is not far behind when it comes to the detection and monitoring of illness. Chemotherapy is typically administered to cancer patients who do not learn the treatment results for several months. But that is altering now due to developments in QC. Doctors can analyze enormous amounts of data concurrently in parallel, together with all possible combinations of that data, to identify the most accurate trends that characterize it.

It takes a while to fully comprehend how one medicine interacts with others in combination. Given that QC has the computer ability to simulate every scenario, it can dramatically reduce time. Precise clinical imaging and therapeutic procedures may be provided with the use of QC. The viewing of single molecules is made possible by the incredibly accurate imaging produced by quantum imaging devices. A doctor can be helped by machine learning techniques and QC when analyzing therapy outcomes. QC can aid in interpreting the treatment’s results, and machine learning can assist in detecting anomalies in the human body. Light and dark areas can be seen on standard MRIs, and the radiologist must assess the problems. However, quantum imaging techniques can distinguish between various tissue types, enabling more accurate and thorough imaging.

7 | QUANTUM ALGORITHMS FOR HEALTHCARE

Algorithmic medical research is projected to change due to the use of QC in healthcare and life sciences. The US federal government has made it clear that it is dedicated to a future powered by quantum technology and is actively advancing this sector. The diagnosis of illnesses, the creation of medications, the development of methods for individualized medical therapies, and the analysis of medical imagery are some exciting uses of quantum technology. Additionally, quantum technology may significantly advance our comprehension of protein folding. Computational biologists have created excellent algorithms in recent years to simulate the form of proteins. These models help scientists better comprehend the body’s natural systems by demonstrating how protein folding determines biocompatibility. Such algorithms still lack the accuracy required to make the expected advancements in customized treatment, and future quantum computers could alter that.

The amount of data in the healthcare sector is exploding, and healthcare costs are also growing. Big data, advanced machine learning, supercomputers, and cloud services are all used in cognitive computing to assist clinicians in identifying diseases early, enhancing therapy outcomes, and eventually lowering healthcare costs. Quantum algorithms offer the ability to tackle computationally complex issues with traditional computers by performing computations at extraordinarily high speeds. This holds great promise for extracting valuable, decision-level data from medical pictures.

To successfully exploit the potential of superposition, computer scientists create algorithms that can benefit from this condition. You are not alone if you find it challenging to understand all of this. Even the brightest scientists have trouble understanding these ideas, mainly because quantum theory is still primarily an abstract concept. Nowadays, a traditional computer can produce the strategy in a clinically realistic amount of time utilizing a small number of data points. Nevertheless, quantum-inspired algorithms will enable medical technologies to run all conceivable permutations concurrently, utilizing many data points and creating an ideal strategy more quickly.

Among the various varieties of quantum algorithms that might be crucial to the healthcare industry, the breadth of applications of quantum-enhanced machine learning techniques stands out. This is because we are moving closer to a time when the characteristics of health datasets, such as their frequent variability and inequitable distribution, may provide challenging computational challenges for existing AI. For instance, scientists have been exploring how to use
quantum approaches, primarily processes with huge matrices, to accelerate the computationally expensive processes at the core of machine learning and AI modeling.

8 | QUANTUM SIMULATION AND HEALTHCARE

Although quantum simulation is undoubtedly one of the most promising quantum technologies, it is a broad field constantly evolving and where significant breakthroughs occur frequently. Feynman recognized the fantastic nature of entanglement in 1982. He claimed that when the number of quantum objects rises, the size of their Hilbert space grows exponentially with the increase of entangled things, which was one of the shocking deviations from conventional thinking. An intriguing example is a situation when atoms replace electrons in a crystal, or a periodic arrangement, in a standing wave potential formed by laser beams. One, two, or three-dimensional simulations of events are feasible. Quantum statistics play a significant part in laser cooling approaches that allow one to have atoms with thermal energy that is low relative to the potential’s magnitude. Therefore, the atoms’ state—whether fermions or bosons—is crucial. In reality, by choosing the proper isotope of atoms, one may decide whether to have fermions or bosons. Atoms like lithium or potassium are frequently employed for that purpose. Lithium, for example, has two isotopes despite having three electrons. Due to the uniform distribution of nucleons and electrons, lithium 7 is a boson. Considering three plus six is an odd number, lithium six is a fermion. Bosonic atoms can be cooled down to a point where a Bose-Einstein condensate is formed while only experiencing little thermal excitation. It is possible to reduce the many-body system of exchanging atoms to its most basic form. With fermions, however, the thermal element is far more critical, and even the most acceptable cooling methods only result in a non-negligible percentage of the Fermi temperature.

Considering traditional approaches cannot predict how proteins and other complicated systems would react to new medications, the creation of new pharmaceutical treatments today entails a lot of experimentation. We now have new chances to create customized quantum simulators that can be made to address these processes thanks to quantum technology. Professor Lodahl will serve as the director of the “Solid-State Quantum Simulators for Biochemistry” facility, also known as “Solid-Q,” and will receive 60 million kroner for his research. The center’s efforts will be focused on implementing and combining two categories of quantum simulation hardware that can calculate the quantum mechanical properties of complex biomolecules.

The director of the other center, “Quantum for Life,” is Professor Matthias Christandl from the Department of Mathematical Sciences at UCPH. To explore intricate biological processes, this initiative intends to create mathematical techniques that may be used for the quantum simulation of proteins. By their very nature, healthcare systems are diverse, with each device using a distinct architecture, technology, and system software. From the perspective of delays and security risks, this variability impacts communication effectiveness.

By utilizing the concepts of quantum physics in novel ways to produce and process information, quantum simulations and computers are opening up transformational possibilities. It is anticipated that such calculations would positively impact several fields, from daily tasks to the discovery of new scientific theories. Such preliminary findings demonstrate that QC and simulations could significantly speed up the deployment of new technologies that are urgently required to meet the growing demands for energy while protecting the environment. Numerous early-stage implementations of QC and simulations have already been evidenced.

Treatment with drugs is required to cure the majority of diseases, preserve health, or stop the future decline. Above all, medication is a highly important factor in the aging population since a significant portion of hospital admissions in this age category are caused by adverse reactions brought on by incorrect drug administration and prescription. Medical professionals must thus use great caution in this area. Authors propose a graph-based system that will enable medical professionals to predict the potential negative effects that a specific drug could have on the well-being of an aging person, based on the patient’s history of drug use, the effects of the drug as explained and the patient’s physiological and genetic predictors.

In this article, the potential of QC for health systems is examined. We investigate application areas where the increased processing speed offered by QC might revolutionize current healthcare systems. We list the essential conditions for applying QC to the healthcare sector. To find security flaws in conventional cryptography systems, the authors conducted a thorough analysis of quantum cryptography from the viewpoint of healthcare systems. We conclude by looking at present issues, their causes, and potential future research areas related to using QC systems in healthcare. The latency and energy conservation constraints for real-time health data collecting and processing can be satisfied by a QC system.
Based on the amazing phenomena of quantum physics and quantum mechanics, QC is a novel form of computing. It is a fantastic fusion of computer science, information theory, arithmetic, and physics.

9 | COMPARATIVE ANALYSIS OF EXISTING QC-BASED APPROACHES FOR HEALTHCARE

Table 2 shows the recent and important QC integrated approaches for healthcare discussed in the literature.

Pros of QC-based approaches for healthcare: The use of QC in healthcare can (i) improve the security of the healthcare system against various real-time attacks, (ii) faster the data processing and availability for

| Authors            | Year | A | B | C | D | E | F | G | H | I | Proposed approach                                                                 | Future directions                                                                 |
|--------------------|------|---|---|---|---|---|---|---|---|---|----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|
| Ikeda14            | 2018 | ✔ | ✔ | ✗ | × | ✔ | ✔ | ✗ | ✗ | ✗ | Introduced the integration of blockchain and quantum computing.                  | Formal verification and experimentation work can be conducted to evaluate the feasibility. |
| Kiktenko et al12   | 2018 | ✔ | ✗ | ✗ | × | ✔ | ✔ | ✗ | ✗ | ✗ | Introduced theoretical quantum, cryptography and blockchain aspects briefly.     | Formal verification and experimentation work can be conducted to evaluate the feasibility. |
| Chuntanget al10    | 2019 | ✔ | ✗ | ✗ | ✔ | ✔ | ✗ | ✗ | ✗ | ✗ | Quantum, cryptography and blockchain aspects and their integration are discussed. | Practical implementation and formal verification can be extended.                |
| Justinia36         | 2019 | ✔ | ✗ | ✗ | ✔ | ✔ | ✗ | ✗ | ✗ | ✗ | Discussed the details of blockchain technology and its importance to healthcare. | Experimental work integrating blockchain and healthcare can be conducted.         |
| Bhattacharya et al37| 2019 | ✗ | ✔ | ✗ | ✔ | ✔ | ✗ | ✗ | ✗ | ✗ | Blockchain, deep learning aspects are explored for healthcare                    | Quantum computing aspects and their integration can be explored.                 |
| Farouk et al38     | 2020 | ✔ | ✗ | ✗ | ✔ | ✔ | ✗ | ✗ | ✗ | ✗ | Theoretical discussions over the usage of blockchain technology in the large-scale healthcare sector. | This work can be extended to include a quantum computing-based network for healthcare systems. |
| Nandni and Jahnavi17| 2021 | ✔ | ✗ | ✗ | ✔ | ✔ | ✔ | ✗ | ✗ | ✗ | Discussed the importance of cryptography and blockchain integration. Here, the focus is drawn on the strength of the digital signature. | This work can be extended to design quantum gates and circuits for cryptography primitives and protocols use for blockchain in real-time applications. |
| Kumar et al13      | 2021 | ✔ | ✔ | ✔ | ✔ | ✗ | ✗ | ✗ | ✗ | ✗ | A detailed review of quantum drones and networks is conducted. Here, the integration of advanced technologies with quantum drones and networks is elaborated. | This work can be extended to include a mathematical model and the feasibility to design circuits for quantum networks. |
| Singh et al8       | 2021 | ✔ | ✔ | ✗ | ✔ | ✔ | ✔ | ✗ | ✗ | ✗ | The importance of quantum computing for climate change is explored.              | The feasibility to practically integrating quantum computing for environmental solutions can be worked upon. |
| Authors          | Year | A | B | C | D | E | F | G | H | I | Proposed approach                                                                 | Future directions                                                                 |
|------------------|------|---|---|---|---|---|---|---|---|---|----------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|
| Yaqoob et al     | 2021 |   | ✓ | ✓ | ✓ | ✓ | ✓ | × | ✓ | ✓ | Blockchain aspects for healthcare and medical records are discussed               | Quantum computing aspects and their integration can be explored.                   |
| Abd El-Latif et al | 2021 |   | ✓ | ✓ | ✓ | ✓ | ✓ | × | ✓ | ✓ | Quantum and cybersecurity aspects for smart cities and associated infrastructure are explored. | Medical data and its handling using quantum computing aspects can be explored in-detail. |
| Sanka et al      | 2021 |   | ✓ | ✓ | ✓ | ✓ | ✓ | × | ✓ | ✓ | Blockchain aspects for healthcare and medical records are discussed               | Quantum computing aspects and their integration can be explored.                   |
| Qu et al         | 2022 | ✓ | × | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | Quantum computing aspects for securing medical data are discussed. Here, medical data security while processing is focused. Further, the importance of data security for healthcare systems using quantum approaches is discussed. | The feasibility of practically securing healthcare applications and data using quantum computing-based approaches can be explored for all three (processing, transmission, storage) stages of data can be explored. |
| Chen et al       | 2022 |   | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | Security attributes controllable through quantum aspects are discussed.           | More cryptography primitives and protocols and their attributes can be discussed.   |
| Azzaoui et al    | 2022 |   | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | Quantum support to cloud architecture, and its ecosystem are discussed to secure healthcare data in healthcare systems. | Designing quantum computing-based software and hardware architecture to secure cloud infrastructure for healthcare can be worked upon. |
| Charles          | 2022 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | × | The importance of blockchain in the present and futuristic applications (including healthcare) are discussed. | This work can be extended to include quantum computing aspects in blockchain-based systems for securing futuristic applications. |
| Grosu et al      | 2022 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | × | × | This work shows the present and futuristic need for mobile applications and blockchain for the healthcare system. Here, an analysis of mobile devices is conducted in detail. | This work can be extended to discuss the importance of quantum computing for mobile devices or resource-constraint devices useful for healthcare applications and data. |
| Gupta et al      | 2022 |   | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | × | Here, quantum computing and securing the COVID-19 patient data and records are discussed. | A detailed architecture over quantum computing infrastructure specification can be explored for healthcare. |
| Sultana et al    | 2022 |   | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | × | Post-quantum cryptography primitives and protocols for security healthcare records are discussed. | The use of post-quantum cryptography for healthcare to avoid attacks on traditional security mechanisms can be explored in detail. |
| Authors          | Year | A | B | C | D | E | F | G | H | I | Proposed approach                                                                 | Future directions                                                                 |
|------------------|------|---|---|---|---|---|---|---|---|---|------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| Pandey et al     | 2022 | ✓ | × | × | × | × | ✓ | ✓ | × |   | The importance of securing blockchain using non-fungible tokens is explored.       | The importance of quantum computing-integrated tokens for healthcare and other applications can be elaborated. |
| Ahmad et al      | 2022 | ✓ | ✓ | × | × | × | × | ✓ | ✓ |   | Blockchain for a healthcare system with a detailed framework is elaborated.        | The feasibility to improve the scalability of a blockchain network for healthcare can be explored. |
| Zhu et al        | 2022 | × | ✓ | × | ✓ | ✓ | ✓ | × | ✓ | × | A Quantum computing-supported encryption scheme for video conferences is discussed. | This work can be extended to include scenarios where patients and doctors can use this facility to securely exchange medical data and associated treatment. |
| Trenfield et al  | 2022 | × | ✓ | × | ✓ | ✓ | × | ✓ | × |   | The use of digital technologies in different scenarios for pharmacy is explored and discussed. | The evaluation (mathematically or practically) can be conducted for proposed scenarios. |
| Laxminarayana et al | 2022 | × | ✓ | × | ✓ | ✓ | × | × | ✓ |   | Here, the importance of quantum computing in analyzing medical data using machine and deep learning approaches are explored and analyzed. | This work can be explored for more medical records/datasets to analyze and compare the performance with and without quantum computing. |
| Li et al         | 2022 | × | ✓ | × | × | ✓ | ✓ | × | ✓ |   | In this work, a blockchain-based healthcare system is designed to secure data storage and accessibility. In security, a searchable-encryption mechanism is used for the same. | The evaluation of blockchain networks over their scalability, performance and network security can be worked upon for their acceptability on a large scale. |
| Tchagna et al    | 2022 | ✓ | ✓ | × | × | ✓ | ✓ | ✓ |   | A case study to secure medical data for healthcare in a smart city is prepared and discussed. | The practical feasibility to integrate fast computing (like quantum computing) can be explored. |
| Mahajan et al    | 2022 | × | ✓ | × | ✓ | ✓ | × | ✓ |   | Healthcare, quantum computing and cloud infrastructure and their integrated advantages are explored and discussed in detail. | This work can be extended to include security primitives and protocols that integrate three technologies for ensuring full-proof security. |
| Gupta et al      | 2022 | × | ✓ | × | ✓ | ✓ | × | ✓ |   | In this work, quantum computing supported blockchain for efficient authentication in the internet of vehicles is proposed. | The authentication mechanism evaluation against various attacks can be formally conducted and evaluated. |
Table 2 (Continued)

| Authors            | Year | A | B | C | D | E | F | G | H | I | Proposed approach                                                                 | Future directions                                                                 |
|--------------------|------|---|---|---|---|---|---|---|---|---|-----------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| Malviya and Sundram | 2022 | × | ✓ | × | ✓ | ✓ | × | ✓ | × | ✓ | The importance of quantum computing in the smart healthcare system is discussed with its pros and cons. | The analysis can be extended to have in-depth tools and techniques-based analysis for identifying and generating efficient healthcare scenarios. |
| Azzaoui et al      | 2022 | × | ✓ | × | ✓ | ✓ | ✓ | ✓ | × | ✓ | Blockchain and quantum cloud computing are discussed in healthcare                  | Implementation strategies are not explored in detail.                            |

Note: A, quantum blockchain; B, quantum integrated technologies (quantum drones; quantum satellites; quantum AI/ML); C, photonic quantum computing; D, quantum gates and circuits; E, quantum algorithms; F, quantum simulation; G, healthcare records; H, IoT-based services; I, other advanced technologies (cloud computing, serverless computing, cybersecurity, forensics, metaverse, and others).

authenticated users, (iii) improve the security and enhances the healthcare system for every stakeholder, (iv) Smart healthcare scenarios for improving patient handling and patient-centric system design can be easily achievable, and (v) Quantum blockchain-based scenarios can support in few challenge generation, security of challenges for miners, improved security for authenticated users, protection against attacks and many more.

Cons of QC-based approaches for healthcare: The major challenges in the use of QC for healthcare systems include: (i) large-scale use of QC may not be environmentally friendly. (ii) feasibility to arrange QC resources for the healthcare system in real-scenario is a challenging task, especially in developing countries. (iii) Infrastructure to support QC for real-time applications (especially for healthcare) is a daunting task. It is a costly solution as well. Although tools (like Qiskit, Silq etc.) are available for computing for small-scale solutions. To achieve large-scale integration, more Qibit-support machines are required.

10 CONCLUSION AND FUTURE DIRECTIONS

The use of blockchain technology in the fight against the COVID-19 epidemic as well as in other healthcare systems of a similar kind, has shown to be highly advantageous. The most up-to-date medical care systems include sensor data, which may be used to monitor patients while also protecting their privacy and the confidentiality of their medical records. This technology can store enormous quantities of data in an organized and safe way, enabling users to access that data whenever they wish. This puts it in a class above all other technologies, which puts them in a lower class. Because they may be obtained promptly and conveniently whenever and wherever required, they can be used whenever and wherever it is essential. Patients may be traced down and found using quantum blockchain technology and network in a couple of minutes. In a quantum blockchain, it is feasible to conceal data while ensuring that it is secure and not too complicated to access. It is possible that using technologies like QC and blockchain may make it possible to handle patient data more quickly while maintaining its integrity. Both blockchain technology and quantum technologies have been the subject of a great deal of conjecture. This investigation aimed to determine whether or not there are presently operational medical uses for either of these technologies. Research is being conducted in this field on various technologies, including quantum physics, blockchain, ratification intelligence, machine learning, and drones.

ACKNOWLEDGMENTS

I would like to express my very great appreciation to Dr K. Rajalakshmi and all unknown reviewers for her valuable and constructive suggestions during the exploration of this research work. Her willingness to give her time so generously has been very much appreciated.

CONFLICT OF INTEREST

On behalf of all authors, the corresponding author states that there is no conflict of interest.
DATA AVAILABILITY STATEMENT
Data sharing is not applicable - no new data generated.

ORCID
Keshav Kaushik https://orcid.org/0000-0003-3777-765X
Adarsh Kumar https://orcid.org/0000-0003-2919-6302

REFERENCES
1. Marella ST, Sai H, Parisa K. Introduction to quantum computing. Quantum Computing and Communications. London: IntechOpen; 2020. doi:10.5772/intechopen.94103
2. Top Applications Of Quantum Computing Everyone Should Know About. https://analyticsindiamag.com/top-applications-of-quantum-computing-everyone-should-know-about/. Accessed May 18, 2022.
3. Quantum Computing Applications You Should Know | Built In. https://builtin.com/hardware/quantum-computing-applications. Accessed May 18, 2022.
4. Kaushik K, Dahiya S. Scope and challenges of blockchain technology. Lect Notes Electr Eng. 2022;832:461-473. doi:10.1007/978-981-16-8248-3_38/COVER/
5. Kaushik K, Dahiya S, Sharma R. Internet of things advancements in healthcare. Internet of Things; London: CRC Press; 2021:19-32. doi:10.1201/9781003140443-2
6. Singh M, Dhara C, Kumar A, Gill SS, Uhlig S. Quantum artificial intelligence for the science of climate change; 2021. 10.48550/arxiv.2108.10855.
7. Chugh N, Kumar A, Aggarwal A. Security aspects of a RFID-sensor integrated low-powered devices for internet-of-things. Paper presented at: Fourth International Conference on Parallel, Distributed and Grid Computing, PDGC, 2016:759-763, doi: 10.1109/PDGC.2016.7913223
8. Vashisht S, Gaba S, Dahiya S, Kaushik K. Security and privacy issues in IoT systems using blockchain. Sustainable and Advanced Applications of Blockchain in Smart Computational Technologies. London: CRC Press; 2022:113-127. doi:10.1201/9781003193425-8
9. Kaushik K. Blockchain enabled artificial intelligence for cybersecurity systems. Big Data Analytics and Computational Intelligence for Cybersecurity. Vol 111. Cham: Springer; 2022:165-179. doi:10.1007/978-3-031-05752-6_11/COVER
10. Chuntang L, Yinsong X, Jiahao T, Wenjie L. Quantum blockchain: a decentralized, encrypted and distributed database based on quantum mechanics. J Quantum Comput. 2019;1(2):63. doi:10.32604/JQC.2019.06715
11. Kumar A, de Jesus Pacheco DA, Kaushik K, Rodrigues JJPC. Futuristic view of the internet of quantum drones: review, challenges and research agenda. Veh Commun. 2022;36:100487. doi:10.1016/j.vehcom.2022.100487
12. Kiktenko EO, Pozhar NO, Anufriev MN, et al. Quantum-secured blockchain. Quantum Sci Technol. 2018;3(3):035004. doi:10.1088/2058-9565/aabc6b
13. Kumar A, Bhatia S, Kaushik K, et al. Survey of promising technologies for quantum drones and networks. IEEE Access. 2021;9:1. doi:10.1109/ACCESS.2021.3109981
14. Ikeda K. Security and privacy of blockchain and quantum computation. Adv Comput. 2018;111:199-228. doi:10.1016/bs.adcom.2018.03.003
15. Iovane G. MuReQua chain: multiscale relativistic quantum blockchain. IEEE Access. 2021;9:39827-39838. doi:10.1109/ACCESS.2021.3064297
16. Gao YL, Chen XB, Xu G, Yuan KG, Liu W, Yang YX. A novel quantum blockchain scheme base on quantum entanglement and DPoS. Quantum Inf Process. 2020;19(12):1-15. doi:10.1007/s11128-020-02915-y
17. Nandini C, Jahnavi S. Quantum cryptography and blockchain system: fast and secured digital communication system. Data Engineering and Intelligent Computing. Singapore: Springer; 2021:453-462. doi:10.1007/978-981-16-0171-2_43
18. Singh K, Kaushik K, Ahatsham H, Shahare V. Role and impact of wearables in IoT healthcare. Adv Intell Syst Comput. 2020;1090:735-742. doi:10.1007/978-981-15-1480-7_67
19. Bhavin M, Tanwar S, Sharma N, Tyagi S, Kumar N. Blockchain and quantum blind signature-based hybrid scheme for healthcare 5.0 applications. J Inf Secur Appl. 2021;56:102673. doi:10.1016/j.jisa.2020.102673
20. Kumar A, Krishnamurthi R, Nayyar A, Sharma K, Grover V, Hossain E. A novel smart healthcare design, simulation, and implementation using healthcare 4.0 processes. IEEE Access. 2020;8:118433-118471. doi:10.1109/ACCESS.2020.3004790
21. Kumar A, Ottaviani C, Gill SS, Buyya R. Securing the future internet of things with post-quantum cryptography. Secur Priv. 2022;5(2):e200. doi:10.1002/spy.2.200
22. Chen X, Xu S, Qin T, Cui Y, Gao S, Kong W. AQ–ABS: anti-quantum attribute-based signature for EMRs sharing with blockchain. Paper presented at: IEEE Wireless Communications and Networking Conference (WCNC), April 2022:1176-1181. 10.1109/WCNC51071.2022.9771830
23. Mirtskhulava L, Iavich M, Razmadze M, Gulua N. Securing medical data in 5G and 6G via multichain blockchain technology using post-quantum signatures. Paper presented at: IEEE International Conference on Information and Telecommunication Technologies and Radio Electronics (UkrMiCo); 2022:72-75. 10.1109/UKRMICO52950.2021.9716595
24. Mahajan HB, Rashid AS, Junnarkar AA, et al. Integration of healthcare 4.0 and blockchain into secure cloud-based electronic health records systems. *Appl Nanosci (Switzerland)*. 2022;1:1-14. doi:10.1007/S13204-021-02164-0/FIGURES/8

25. El Azzaoui A, Sharma PK, Park JH. Blockchain-based delegated quantum cloud architecture for medical big data security. *J Netw Comput Appl*. 2022;198:103304. doi:10.1016/J.JNCA.2021.103304

26. Fernandez-Carameas TM, Fraga-Lamas P. Towards post-quantum blockchain: a review on blockchain cryptography resistant to quantum computing attacks. *IEEE Access*. 2020;8:21091-21116. doi:10.1109/ACCESS.2020.2968985

27. Gupta DS, Karati A, Saad W, Da Costa DB. Quantum-defended blockchain-assisted data authentication protocol for internet of vehicles. *IEEE Trans Veh Technol*. 2022;71(3):3255-3266. doi:10.1109/TVT.2022.3144785

28. Cai Z, Qu J, Liu P, Yu J. A blockchain smart contract based on light-weighted quantum blind signature. *IEEE Access*. 2019;7:138657-138668. doi:10.1109/ACCESS.2019.2941153

29. Gupta DS, Karati A, Saad W, Da Costa DB. Quantum-defended blockchain-assisted data authentication protocol for internet of vehicles. *IEEE Access*. 2022;71(3):3255-3266. doi:10.1109/TVT.2022.3144785

30. Gao YL, Chen XB, Chen YL, Sun Y, Niu XX, Yang YX. A secure cryptocurrency scheme based on post-quantum blockchain. *IEEE Access*. 2018;6:27205-27213. doi:10.1109/ACCESS.2018.2827203

31. Takeuchi S. Photonic quantum information: science and technology. *Proc Jpn Acad Ser B Phys Biol Sci*. 2016;92(1):29-43. doi:10.2183/JPJAB.92.29

32. Bartlett B, Bartlett B, Bartlett B, Dutt A, Fan S. Deterministic photonic quantum computation in a synthetic time dimension. *Optica*. 2021;8(12):1515-1523. doi:10.1364/OPTICA.424258

33. Romero-Alvarez J, Alvarado-Valiente J, Garcia-Alonso J, Moguel E, Murillo JM. A graph-based healthcare system for quantum simulation of medication administration in the aging people. *Lecture Notes in Bioengineering*. Cham: Springer; 2022:34-41. doi:10.1007/978-3-030-97524-1_4/Cover

34. Sultana T, Mazumder R, Su C. Post-quantum signature scheme to secure medical data. *IEEE Access*. 2019;7:138657-138668. doi:10.1109/ACCESS.2019.2941153

35. Li CY, Chen XB, Chen YL, Hou YY, Li J. A new lattice-based signature scheme in post-quantum blockchain network. *IEEE Access*. 2019;7:2026-2033. doi:10.1109/ACCESS.2018.2886554

36. Gao YL, Chen XB, Chen YL, Sun Y, Niu XX, Yang YX. A secure cryptocurrency scheme based on post-quantum blockchain. *IEEE Access*. 2018;6:27205-27213. doi:10.1109/ACCESS.2018.2827203

37. Malviya R, Sundram S. Exploring potential of quantum computing in creating smart healthcare. *Open Biol J*. 2022;9(1):56-57. doi:10.2174/18749670219010056

38. Justini A. Blockchain technologies: opportunities for solving real-world problems in healthcare and biomedical sciences. *Acta Inform Med*. 2019;27(4):284-291.

39. Bhattacharya P, Tanwar S, Bodkhe U, Tyagi S, Kumar N. Blindsign: Blockchain-based deep-learning as-a-service in healthcare 4.0 applications. *IEEE Trans Netw Sci Eng*. 2019;8(2):1242-1255.

40. Farouk A, Alemadi A, Ghose S, Mashatan A. Blockchain platform for industrial healthcare: vision and future opportunities. *Comput Commun*. 2020;154:223-235.

41. Yaqoob I, Salah K, Jayaraman R, Al-Hammadi Y. Blockchain for healthcare data management: opportunities, challenges, and future recommendations. *Neural Comput Appl*. 2021;34:1-16.

42. Abd El-Latif AA, Abd-El-Atty B, Mehmood I, Muhammad K, Venegas-Andraca SE, Peng J. Quantum-inspired blockchain-based cybersecurity: securing smart edge utilities in IoT-based smart cities. *Inf Process Manag*. 2021;58(4):102549.

43. Sultana T, Mazumder R, Su C. Post-quantum signature scheme to secure medical data. *Rhythms in Healthcare*. Singapore: Springer; 2022:34-41. doi:10.1007/978-3-030-30752-4_1/Cover

44. Bartlett B, Bartlett B, Bartlett B, Dutt A, Fan S. Deterministic photonic quantum computation in a synthetic time dimension. *Optica*. 2021;8(12):1515-1523. doi:10.1364/OPTICA.424258

45. Romero-Alvarez J, Alvarado-Valiente J, Garcia-Alonso J, Moguel E, Murillo JM. A graph-based healthcare system for quantum simulation of medication administration in the aging people. *Lecture Notes in Bioengineering*. Cham: Springer; 2022:34-41. doi:10.1007/978-3-030-97524-1_4/Cover

46. Ur Rasool R, Farooq Ahmad H, Rafiq W, Qayyum A. Quantum computing for healthcare: a review big data for development view project secure and adversarially robust ML view project. doi:10.36227/techrxiv.17198702.v2

47. Malviya R, Sundram S. Exploring potential of quantum computing in creating smart healthcare. *Open Biol J*. 2022;9(1):56-57. doi:10.2174/18749670219010056

48. Justini A. Blockchain technologies: opportunities for solving real-world problems in healthcare and biomedical sciences. *Acta Inform Med*. 2019;27(4):284-291.

49. Bhattacharya P, Tanwar S, Bodkhe U, Tyagi S, Kumar N. Blindsign: Blockchain-based deep-learning as-a-service in healthcare 4.0 applications. *IEEE Trans Netw Sci Eng*. 2019;8(2):1242-1255.

50. Farouk A, Alemadi A, Ghose S, Mashatan A. Blockchain platform for industrial healthcare: vision and future opportunities. *Comput Commun*. 2020;154:223-235.

51. Yaqoob I, Salah K, Jayaraman R, Al-Hammadi Y. Blockchain for healthcare data management: opportunities, challenges, and future recommendations. *Neural Comput Appl*. 2021;34:1-16.

52. Abd El-Latif AA, Abd-El-Atty B, Mehmood I, Muhammad K, Venegas-Andraca SE, Peng J. Quantum-inspired blockchain-based cybersecurity: securing smart edge utilities in IoT-based smart cities. *Inf Process Manag*. 2021;58(4):102549.
53. Tchagna Kouanou A, Tchito Tchapga C, Sone Ekonde M, et al. Securing data in an internet of things network using blockchain technology: smart home case. *SN Comput Sci*. 2022;3(2):1-10.

**How to cite this article:** Kaushik K, Kumar A. Demystifying quantum blockchain for healthcare. *Security and Privacy*. 2023;6(3):e284. doi: 10.1002/spy2.284