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CURRENT TOPIC

Blockchain Technology in Pharmaceutical Industry: A Review of Recent Research Articles on *PubMed*

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Abstract

Blockchain technology has emerged as a formidable force ready to transform the pharmaceutical business. This study investigated the integration of smart contracts and decentralised apps as potential future possibilities, emphasising their ability to automate crucial operations and strengthen pharmaceutical product integrity, based on the recently published articles in *PubMed* between 2015 to 2023 with “pharmacology” and “blockchain” as search keywords. Recent study backed up the idea that blockchain can improve openness, security and efficiency in the industry. According to research, it has the ability to speed up regulatory approvals while also considerably reducing the risk of counterfeit medications penetrating the supply chain. Furthermore, the ability of blockchain to disrupt existing intermediaries and enable disintermediation may result in a more streamlined and efficient industry. While there are implementation obstacles, the benefits of this technology in medicines are significant. Embracing blockchain promises a future of increased security, transparency and patient-centricity, ultimately changing healthcare. This article explored blockchain application in the pharmaceutical sector with innovations like *Medledger* and chaincodes, addressing drug tracing and supply chain security. It presents a structure for a private network using *Hyperledger Fabric*, showcasing blockchain's potential to enhance transparency, security and efficiency beyond traditional areas.

Key words: Blockchain technology; Pharmaceutical industry; Smart contracts; Decentralised applications (dApps); Drug supply chain.

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Introduction

Blockchain technology is a decentralised, impermeable digital ledger system. It is made up of a number of interconnected blocks, each containing a number of transactions. Since data cannot be modified after it has been recorded in a block, transparency and security are ensured. Blockchain is maintained by a network of computers as opposed to a single authority because it is distributed. In addition to enabling cryptocurrencies like *Bitcoin*, this technology offers a wide range of applications in fields outside of finance, including voting, supply chain management and healthcare. It offers trust, immutability and accountability in data management, making it a disruptive force in industries seeking transparency, traceability and increased efficiency.

Blockchain technology has a lot of potential ap-

plications in the pharmaceutical sector, such as improving transparency, security and traceability across the whole supply chain. However, there are some challenges to overcome, such as regulatory constraints, interoperability issues and the need for sector-wide standards. However, as technology advances, it may totally alter how pharmaceuticals are manufactured, distributed and treated, which would benefit all stakeholders and increase patient safety.

Blockchain technology has the potential to revolutionise several industries, including pharmaceuticals. Blockchain technology has the potential to have a significant impact on the pharmaceutical industry.

This study investigated the integration of smart contracts and decentralised apps as potential future possibilities, emphasising their ability to automate crucial operations and strengthen pharmaceutical product integrity, based on the recently published articles in PubMed between 2015 to 2023 with “pharmacology” and “blockchain” as search keywords.

Increased transparency in the pharmaceutical industry through blockchain technology

Transparency is a cornerstone of trust and integrity in any industry, but it is especially important in the pharmaceutical industry, since the quality and legitimacy of medicines directly touch human lives. Blockchain technology offers a game-changing alternative for increasing openness throughout the pharmaceutical supply chain.

As blockchain technology advances and more firms realise its promise, the manufacture, distribution and consumption of medications may be transformed, benefiting patients and stakeholders across the sector. Although blockchain technology has many benefits for the pharmaceutical industry, there are still obstacles to application, such as interoperability issues, legal constraints and the need for broad industry standards.

The foundation of transparency: distributed ledger system

The distributed ledger system[1] is at the heart of blockchain's contribution to transparency. A blockchain ledger is distributed over numerous nodes or computers, as opposed to traditional centralised databases, which are vulnerable to manipulation or have single points of failure. A network of participants verifies and records each transaction or record, making it extremely difficult to alter or tamper with data without the network's consensus.

This distributed ledger technology ensures that every stage of the supply chain, from the initial acquisition of raw materials to the final delivery of medicines to patients, is properly recorded and made accessible to all important players in the pharmaceutical business.

This indicates that manufacturers, regulators, distributors, healthcare providers and even patients can track the journey of a pharmaceutical product with complete confidence in the accuracy and integrity of the information.

Tracking and verifying the supply chain

The ability of blockchain to offer end-to-end traceability is one of the most significant applications of blockchain in the pharmaceutical sector. Each batch of medication can be branded with a digital signature that records critical information such as the origin of raw materials, the production process, quality control checks and distribution paths using unique identifiers and smart contracts. This data is added to the blockchain in a sequential and unchangeable manner.

As a result, each stakeholder in the pharmaceutical supply chain can now obtain a detailed record of a product's journey. A pharmacist, for example, can scan a QR code on pharmaceutical packaging to instantaneously retrieve a complete history of the drug's creation and distribution. This transparency not only strengthens confidence in the authenticity of the product but also allows for quick action in the event of a recall or quality concerns.

Strengthening regulatory compliance

The pharmaceutical sector relies heavily on regulatory compliance.[2] To assure the safety and efficacy of their products, businesses must follow a plethora of regulations and standards. Blockchain technology has the potential to help streamline and improve compliance processes.

Smart contracts, a blockchain feature, can automate compliance and regulatory processes. When certain circumstances are met, these contracts carry out predetermined activities. For example, if a batch of medication fulfils all quality control norms, the smart contract can immediately activate distribution clearance.

This automation not only decreases the administrative load for pharmaceutical businesses, but it also reduces the possibility of human error or supervision. Furthermore, it gives authorities real-time access to compliance data, allowing for more efficient oversight and faster response to deviations from industry standards.

Facilitating trust in clinical trials

Clinical trials are the foundation of drug development, providing the evidence required to show the safety and efficacy of a new medicine. Transparency and data integrity in clinical trials, on the other hand, have been issues of concern. Blockchain technology has the ability to completely transform this crucial stage of drug development.

Every step of a clinical trial can be recorded in a secure and transparent manner using blockchain. This includes recruiting participants, collecting data and analysing it. The immutability of blockchain means that trial data is unmodified and can be independently validated, building trust in the results' integrity (Figure 1).

Furthermore, blockchain can facilitate safe data sharing and collaboration among trial stakeholders such as researchers, ethics committees and regulatory authorities. This not only speed up the trial process but also makes sure that the highest ethical and scientific standards are a guarantee.

Figure 1: Flowchart for clinical trials security and transparency using blockchain

Enhanced security through blockchain technology

In an era of increased digitisation and interconnection, security has become a top priority, particularly in businesses where lives are on the line, such as medicines. Blockchain technology takes a fresh approach to data protection by employing cryptographic techniques and a distributed ledger system (Figure 2).

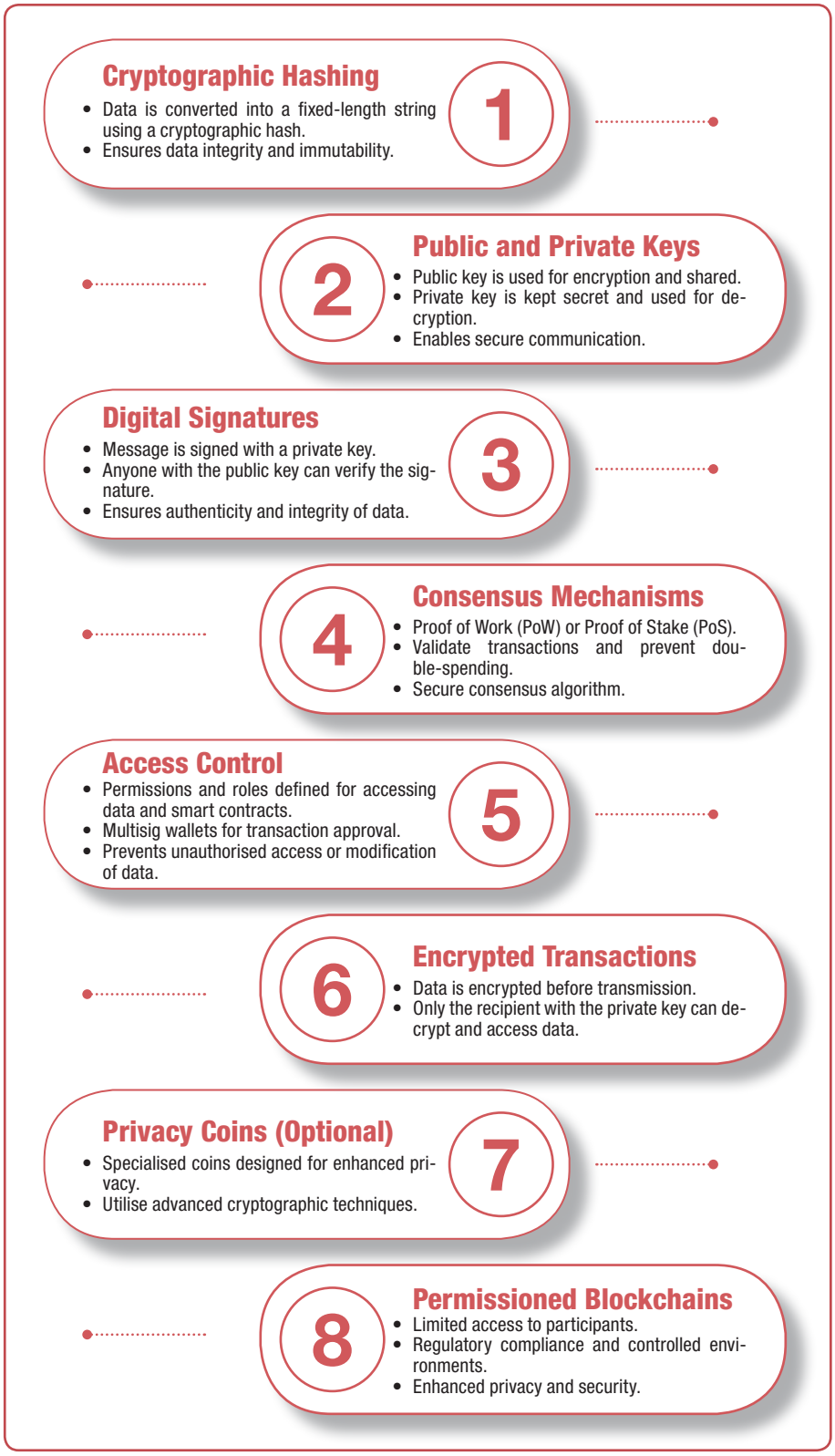

Figure 2: A flowchart about how security and privacy is ensured on blockchain

Cryptographic techniques: the backbone of security

The effectiveness of cryptographic algorithms underpins blockchain security.[3] When data is recorded on a blockchain, it is encrypted and linked to previous blocks using a complicated mathematical method. This technique generates a chain of blocks, each with an unique identity, making data modification or tampering extremely difficult.

A bad actor would need to not only change the data in a single block, but also recalculate the cryptographic puzzle for all following blocks in the chain, to change information on a blockchain. This would necessitate processing power well beyond the capabilities of even the most sophisticated supercomputers. Furthermore, since blockchain is decentralised, obtaining a consensus among all stakeholders in the network is necessary for any changes to be made. This cements the confidence that the integrity of data remains intact and protected.

Countering counterfeit drugs and ensuring patient safety

Counterfeit medications are a major hazard to worldwide public health. They not only endanger patients, but they also undermine trust in the pharmaceutical sector. The transparency aspect of blockchain acts as a major deterrent to the development and distribution of counterfeit medications.

Blockchain ensures that every step in the production and distribution process is recorded and verifiable by enabling end-to-end traceability. This means that a medication's legitimacy may be verified at any stage along the supply chain. If a questionable batch is discovered, stakeholders can immediately track out its source, allowing for targeted recalls and investigations.

Furthermore, by including unique IDs and digital signatures, counterfeit pharmaceuticals can be discovered quickly. These identifiers function as a digital fingerprint, enabling for instant authentication of a product's legitimacy.[4] This not only protects patients, but also builds the reputation of pharmaceutical firms committed to delivering high-quality, authentic pharmaceuticals.

Pharmaceutical firms can ensure the legitimacy and quality of their medicines by protecting the entire supply chain on a blockchain, from raw material acquisition through ultimate distribution. Once a batch of medication is stored on the blockchain, it is nearly impossible to alter or replace it with counterfeit pharmaceuticals without being detected. This sophisticated security mechanism not only protects patients from potentially hazardous pharmaceuticals, but it also protects pharmaceutical businesses' reputation.

Improved efficiency with smart contracts

Efficiency is important in any industry, but it is especially important in the pharmaceutical industry, where quick reaction times and adherence to regulatory schedules are vital. Smart contracts (Figure 3), a game-changing tool for increasing efficiency[5] are introduced by blockchain.

Automating predefined actions

Smart contracts are contracts that execute themselves based on established criteria and situations. These contracts are defined in code and execute automatically when certain criteria are met. Companies may automate a wide range of procedures in the pharmaceutical supply chain by adding smart contracts, from payments and quality checks to regulatory compliance.

For instance, if a batch of medication passes all quality control checks, the smart contract can immediately pay the supplier. This eliminates the need for manual intervention, lowering administrative costs and the possibility of human error. Furthermore, smart contracts enable stakeholders to follow progress and respond quickly to any deviations by providing real-time visibility into the state of multiple operations.

Challenges and limitations of implementing blockchain technology in the industry

The use of blockchain technology into the pharmaceutical sector holds enormous promise in terms of better transparency, enhanced security and increased efficiency. This transformational potential, however, is not without its problems

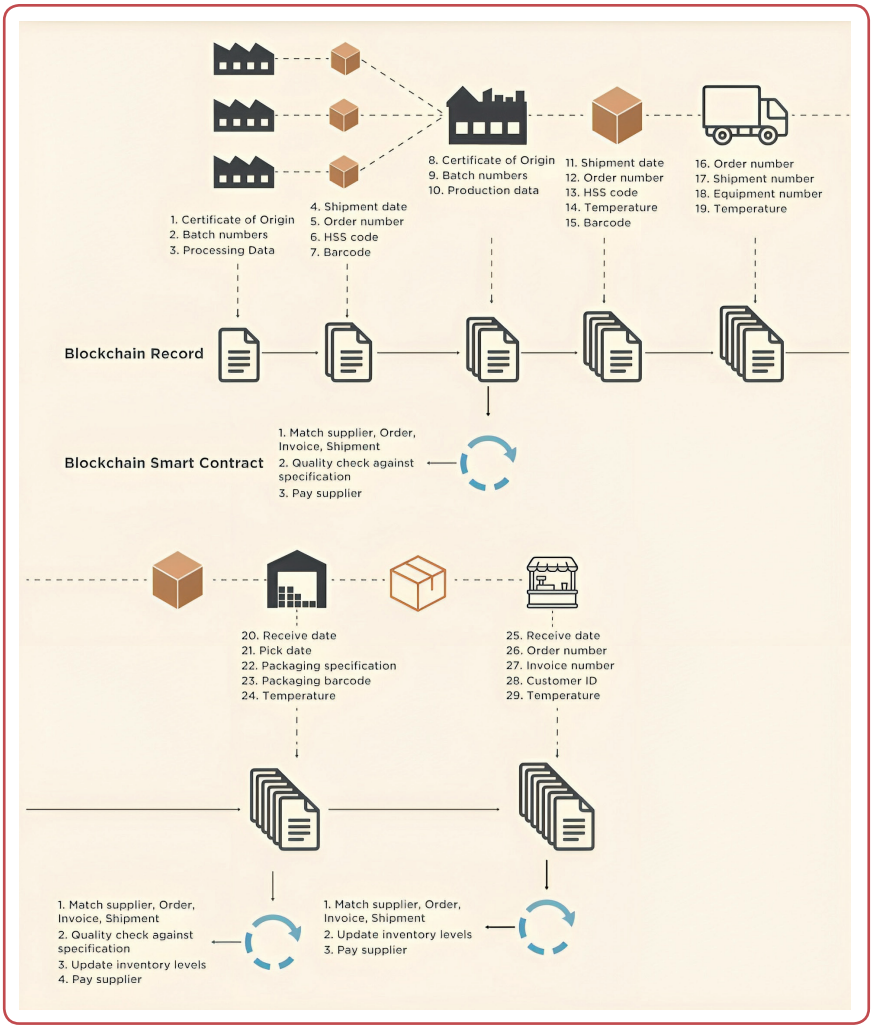

Figure 3: Smart contract workflow

and constraints: the need for standards, data privacy concerns, regulatory constraints. Understanding and addressing these difficulties is critical to realising blockchain's full promise for the industry's and ultimately, patients' well-being.

Need for standardisation

The requirement for standardisation is one of the key hurdles in using blockchain technology in the pharmaceutical sector. The sector operates in a complex ecosystem that includes multiple players like as manufacturers, distributors, regulators and healthcare providers. Each of these entities may have its own set of systems, processes and protocols. A standardised approach that enables interoperability and easy communication between these numerous participants is required for blockchain to be properly implemented.[6]

The full benefits of blockchain, such as end-to-end traceability and real-time information sharing, may remain elusive in the absence of a uniform framework. Furthermore, the lack of standards may result in fragmented and disjointed blockchain deployments, limiting the technology's scalability and overall influence.

Furthermore, standardisation necessitates collaborative efforts from industry leaders, regulatory organisations and technological specialists. Collaboration and consensus-building among stakeholders are essential for developing a coherent framework that can be universally implemented throughout the pharmaceutical supply chain.

Data privacy concerns

Data privacy is a top priority in any company, but it is especially important in healthcare and pharmaceuticals, where sensitive patient information is at stake. The intrinsic openness and immutability of blockchain may collide with stringent data privacy requirements, such as the Health Insurance Portability and Accountability Act (HIPAA) in the United States.[7]

While blockchain provides strong security through cryptographic techniques, maintaining patient data confidentiality while reaping the benefits of the technology is a tricky balancing. Some of these concerns can be addressed by permissioned blockchains, which limit access to approved parties. Even with permissioned blockchains, however, ensuring compliance with existing data protection rules and regulations is vital. To address data privacy issues, pharmaceutical businesses and technology specialists must collaborate to create new solutions that protect patient information while leveraging blockchain's disruptive capabilities.

Regulatory barriers

The deployment of blockchain technology in the pharmaceutical industry faces major regulatory challenges. The sector is under to rigorous scrutiny from regulatory organisations around the world, which attempt to assure pharmaceutical safety, efficacy and quality. Integrating a new technology such as blockchain necessitates conforming to and, in certain circumstances, altering current legislation to fit this creative approach.

Regulatory authorities must establish clear rules and guidelines for blockchain implementation. This involves difficulties like record-keeping, compliance and auditability. Regulatory compliance will necessitate open communication between industry stakeholders, technology specialists and regulatory bodies.

Navigating the complex environment of foreign legislation adds another element of complication. Pharmaceutical firms operating across borders must deal with a variety of regulatory constraints, necessitating a global effort to develop a uniform approach to blockchain adoption.

Steinwantder et al[8] emphasise the vital necessity of data integrity in the pharmaceutical business, particularly in the context of process validation. To ensure patient safety and the profitability of industrial enterprises, process validation relies significantly on accurate and trustworthy data. Regulatory authorities, such as the FDA, have issued new standards for handling data in the pharmaceutical industry in response to previous breaches in data integrity.

The authors suggest a technological method for improving data integrity that does not rely on trusted third parties or centralised systems. They employ a strategy that combines traditional software development tools with a new smart contract created on the *Ethereum* network. The case study showed how this approach may efficiently detect data manipulation or result backdating and how regulatory agencies can completely audit the entire data flow from the regulatory report back to the original raw data.

The outcomes of this contribution provide a potential roadmap for the creation of production-ready solutions, such as versioned database systems that interface seamlessly with distributed ledgers. This improvement is projected to improve the dependability of pharmaceutical manufacturing data, protecting both industrial businesses' intellectual property.

In layman's words, this emphasises the need of reliable data in the pharmaceutical sector. It presents a technological solution based on blockchain, which is well-known for its role in cryptocurrencies such as *Bitcoin*. The authors present a method to secure data integrity without depending on traditional middlemen by merging blockchain with existing computing tools. This breakthrough has the potential to significantly improve the reliability of data used in pharmaceutical manufacture, benefiting both firms and patients.

A study by Jia et al[9] addresses long-standing issues in the pharmaceutical sector with medical data sharing, anti-tampering methods and data leak prevention. The issue develops when patients are referred to several hospitals and are unable to provide a thorough medical history due to information exchange limits between healthcare facilities. Instead, for transmitting partial medical information, dependence on easily misplaced paper data such as medical records and test sheets becomes necessary. This raises the possibility of authenticity and impartiality difficulties in medical disagreements.

To address these issues, the article suggests creating a consortium medical blockchain system. This system is built on a Byzantine Fault Tolerance algorithm,[10] which ensures that numerous nodes store and share medical information collectively. This method provides a strong barrier against medical data modification and leakage. The stated issues in medical data administration can be efficiently solved by deploying this solution. Furthermore, when compared to existing

medical blockchain systems, the proposed system has advantages and a broader applicability.

Peng et al[11] address a major issue affecting vaccine production, specifically the necessity for strict oversight to assure the safety and efficacy of vaccines, which are predominantly delivered to young children with vulnerable immune systems. Currently, vaccine production oversight is deemed insufficient because manufacturers have complete control over production data. When vaccines are ready for distribution, these documents are only sent to regulatory agencies for evaluation, leaving possibility for forgeries and modifications.

The authors propose a unique approach based on a two-tiered blockchain architecture[12] to address these inadequacies in centralised management. The first tier includes confidential data specific to vaccine manufacturing companies, such as production records and hash values. The following tier includes public data, such as manufacturing record hashes and vaccine information. This system incentivises vaccine companies to report production records as soon as possible without worry of jeopardising their privacy. Furthermore, because of the blockchain's tamper-proof characteristics and timestamps, it discourages organisations from tampering with or falsifying records.

The authors propose a consensus approach for multi-node collaboration to improve time efficiency. The principal supervising node is in charge of sorting services and guaranteeing the blockchain replica's accuracy. Ordinary supervisory nodes can temporarily substitute the primary node and help with data recovery in the event of data loss. Furthermore, review nodes are responsible for giving complete and accurate blockchain copies to other nodes, avoiding the time and resource waste that is frequent in traditional blockchain systems.

In addition to addressing concerns about time efficiency, the authors offer a mechanism for reducing vaccine data redundancy within the blockchain. To evaluate if a block can be pruned, the technique uses timestamps and vaccination validity periods. This determination is also aided by information exchange with vaccine institutions. These ingenious methods collectively facilitate efficient spatiotemporal supervision of vaccine manufacturing.

This approach is deemed innovative given the scarcity of research in the subject of vaccine production monitoring. The suggested blockchain-based system has the potential to transform how vaccine production is monitored, ensuring increased safety and reliability in this essential area of healthcare.

Tseng et al[13] introduce the concept of using blockchain, which is known for its trust-building characteristics, outside of the *Fintech* sector. The *Gcoin* blockchain is proposed as the foundation for transparent drug transaction data flow. This method intends to shift the medication supply chain's regulatory model away from inspection and examination and toward a more complete surveillance net model.

Under this new approach, every organisation in the medication supply chain can actively participate, working together to prevent counterfeit drugs and protect public health, particularly patient health. This novel use of blockchain technology has great promise for improving transparency and security in the pharmaceutical business.

The research by Mackey et al[14] demonstrates blockchain technology's potential to revolutionise healthcare by providing a secure and transparent digital ledger system for data management. It highlights that the applicability of blockchain goes well beyond cryptocurrency, particularly in the context of healthcare. Various healthcare stakeholders are currently investigating how blockchain might streamline operations, reduce costs, improve patient outcomes, ensure compliance and increase the usage of healthcare-related data.

However, the authors emphasise the significance of building blockchain solutions with a thorough understanding of the actual needs of healthcare, taking into account consumer, patient, provider and regulatory viewpoints. Addressing the particular issues that healthcare faces in comparison to other sectors of the economy is critical. The authors suggest the concept of a "fit-for-purpose" health blockchain, which refers to a blockchain system that is specifically designed to satisfy the unique needs and demands of the healthcare business.

The paper brings together a broad collection of professionals who are actively involved in the design, development and implementation of

blockchain solutions in healthcare to share insights into this topic. Their diverse perspectives and expertise contribute to a thorough grasp of how blockchain might be used to generate good change in the healthcare sector.

Mackey et al[15] analyse Japan's changing demographic landscape, which is marked by an aging population and dropping birth rates. This demographic shift poses significant problems to Japan's internationally regarded universal health coverage (UHC) system. A surge in national public health expenditures, increased demand for healthcare services, an urgent need for elder and long-term care, a scarcity of healthcare experts and disparities in healthcare accessibility between rural and urban areas are among the predicted concerns.

Blockchain technology has emerged as a potential answer to some of these issues. The authors underline, however, that for blockchain to be effective in Japan, it must be envisioned, constructed and deployed in a way that conforms with the country's centralised UHC-focused public health system.

The technology should also be flexible enough to accommodate Japan's particular national health and innovation regulations, which include a regulatory sandbox system. Lessons learned from blockchain adoption in the commercial sector and in other nations should also be incorporated into the deployment strategy. The position addresses both the possible benefits and drawbacks of implementing blockchain technology in Japan's healthcare system. It emphasises the importance of blockchain solutions being carefully localised and integrated to ensure they suit Japan's specific healthcare landscape and legislation.

Potential future directions

Smart contracts

Smart contracts are a significant innovation in blockchain technology that has far-reaching consequences for the pharmaceutical business. These self-executing contracts can automate crucial procedures because they are governed by preset code. They can, for example, supervise regulatory compliance checks to ensure that each procedure corresponds to set standards. This automation speeds up procedures, increasing efficiency and lowering the likelihood of human error.

Furthermore, smart contracts may supervise quality assurance procedures, ensuring that products fulfil stringent quality standards before moving further down the supply chain. This automation ensures that every product meets the highest quality standards, enhancing patient safety. Furthermore, smart contracts can make payments between stakeholders more seamless and secure. This not only simplifies financial transactions but also reduces potential conflicts, given the conditions of the contract are coded and automatically executed upon meeting the criteria.

Decentralised applications (dApps)

Another intriguing path for the pharmaceutical business is decentralised applications, or dApps. These blockchain-based applications work without the need for a central authority, giving a level of transparency and security unrivalled by traditional systems.

dApps can promote secure and transparent communication between stakeholders in the pharmaceutical industry. They can, for example, provide smooth communication among producers, distributors and regulatory organisations. These interactions may be recorded and validated in real time using blockchain, ensuring the validity and integrity of medicinal medicines throughout their entire lifecycle.

dApps' openness and security have the ability to transform supply chain processes. They create a trust layer between stakeholders, reducing the possibility of counterfeit medications and ensuring that every product meets the highest quality and safety standards.

Potential future implications for the industry: disrupting traditional intermediaries

Impact on intermediaries

Blockchain's distributed ledger architecture has the potential to reshape the roles of traditional

pharmaceutical intermediaries. Intermediaries have historically played an important role in checking and confirming transactions, assuring compliance and validating data integrity. However, with blockchain, the necessity for third-party interference may be greatly reduced.

The immutability and transparency of blockchain records establish trust in transactions and data. This means that stakeholders can directly check information on the blockchain, removing the need for intermediaries. This transformation could have far-reaching consequences for how pharmaceutical transactions are performed. It has the ability to reduce costs, boost operational efficiency and reduce potential points of failure or inefficiency associated with traditional intermediaries. Furthermore, enhanced transparency can boost stakeholder trust, eventually enhancing patient safety and the integrity of pharmaceutical operations.

Potential for disintermediation

The decentralised structure of blockchain allows for direct peer-to-peer contacts, which has the potential to reshape numerous areas of the pharmaceutical value chain, particularly the distribution process. Stakeholders can follow the complete route of pharmaceutical products from production to delivery by employing blockchain's immutable ledger. This openness not only protects the authenticity and integrity of medications, but it also fosters trust among participants. As a result, certain intermediaries that normally oversee or support these transactions may be avoided.

Reduced reliance on middlemen may result in a more nimble and efficient supply chain. However, while disintermediation can provide significant benefits, it can also provide obstacles. Established intermediaries may need to adapt or find new roles as the ecosystem evolves. Furthermore, considerable thought and regulation will be required to ensure that the shift to a more decentralised ecosystem takes place in a controlled and secure manner, eventually enhancing patient safety and the integrity of the pharmaceutical sector.

Finally, the incorporation of smart contracts and decentralised applications in the pharmaceutical business has the potential to completely transform operations. Smart contracts streamline operations and reduce the chance of errors by automating important processes ranging from regulatory compliance checks to quality assurance procedures. Decentralised apps encourage transparent interactions among stakeholders, ensuring authenticity and integrity throughout the lifecycle of a product.

Furthermore, the impact of blockchain on pharmaceutical intermediaries could lead to a more efficient supply chain, with transactions validated directly on the blockchain. Disintermediation, particularly in the distribution process, has the ability to reduce the risk of counterfeit pharmaceuticals. However, in order to preserve patient safety and industry integrity, this change must be properly managed. By embracing these technology innovations, the pharmaceutical business will usher in a new era of efficiency, transparency and eventually, patient well-being. *Medledger*, clinical research, patient data management and supply chain management are some of real example of blockchain technology implementation in the pharmaceutical industry.

MedLedger

Uddin et al[16] conducted study on the vital issue of counterfeit pharmaceuticals, which constitute a substantial danger to the pharmaceutical industry, particularly in developing nations. According to the World Health Organization (WHO), around 10 % of pharmaceuticals produced in these locations are counterfeit, putting human lives in danger. The growth of online and Internet-based pharmacies has challenged medicine supply chain security even further.

To address this, the study recommends the *Medledger* system, which is powered by blockchain technology and uses the *Hyperledger Fabric* platform with smart contracts known as "chaincodes". This technology creates a safe and efficient framework for performing transactions inside a private and permissioned distributed network of pharmaceutical stakeholders. It significantly decreases dependency on centralised authorities and middlemen, hence improving operating efficiency and safety. It also reduces the possibility of data tampering within the *Medledger*.

Chaincodes[17] manage and organise interactions among actors in the drug supply chain ecosystem, which are represented by sequence diagrams. The system keeps a complete and immutable record of all activities, events and transactions on the *Medledger* blockchain. It also incorporates

peer-to-peer decentralised file systems like as IPFS, Swarm and filecoin[18] to improve transparency and traceability. While the research is encouraging, it does admit some implementation issues related to the *Hyperledger Fabric* architecture. The paper continues by suggesting future research topics and open problems that could help to develop medication traceability solutions further. Overall, the planned *Medledger* system is an important step toward securing pharmaceutical supply chains and protecting public health. Some of the world's major pharmaceutical corporations, including *Pfizer* and *Roche* are now using the platform.

Clinical research

Blockchain technology is being utilised to increase clinical trial transparency and integrity. For example, the US National Library of Medicine's *ClinicalTrials.gov*[19] website is investigating the use of blockchain technology to increase the accuracy and completeness of trial data.

Another example is the Clinical Research Blockchain Platform, which *IBM* and *Boehringer Ingelheim* are developing.[20] This platform promises to improve clinical trial data security and privacy while simultaneously making it easier for researchers to access and evaluate the data.

Patient data management

Blockchain technology is being used to improve patient data management in the healthcare business. *EncrypGen's*[21] is one example. Patients can use this platform to securely store and share their genomic data with researchers and healthcare practitioners. Another example is the *Patientory* platform,[22] which is being utilised to improve patient data sharing and management among healthcare providers.

Supply chain management

IBM Blockchain for Pharmaceuticals. IBM has collaborated with pharmaceutical companies such as *Pfizer* and *Merck* to develop blockchain-based supply chain management solutions. These platforms improve the transparency and traceability of the pharmaceutical supply chain, minimising the risk of counterfeit pharmaceuticals and increasing the chain's overall effectiveness.[20, 23]

Chronicled. Chronicled, a blockchain company, has developed a platform that employs blockchain technology to provide pharmaceutical companies with end-to-end supply chain visibility. It enables firms to monitor and verify products at every stage of the supply chain, from manufacturing through distribution to final consumers.[17, 24] This helps to reduce the risk of acquiring counterfeit pharmaceuticals while also enhancing supply chain processes.

Conclusion

Blockchain technology has the potential to transform the pharmaceutical sector by providing solutions that improve transparency, security and efficiency. The integration of smart contracts and decentralised apps holds great promise for automating crucial operations and maintaining pharmaceutical product integrity. Furthermore, the ability of blockchain to disrupt existing middlemen and encourage disintermediation may result in a more streamlined and efficient industry. Recent research articles highlight the substantial progress made in utilising blockchain's potential for the benefit of the pharmaceutical industry. As the industry evolves, adopting blockchain technology will be critical in crafting a more secure, transparent and patient-centric future.

Critical processes in pharmaceutical operations can be automated through the integration of smart contracts and decentralised apps, resulting in enhanced efficiency and integrity. The potential for blockchain to disintermediate existing intermediaries and disrupt the sector could transform the industry, enabling a more streamlined and secure supply chain.

Recent research studies, such as those discussed in this article, give solid proof of blockchain's disruptive impact on the pharmaceutical industry. Several studies show how blockchain improves transparency, security and traceability, solving critical issues like counterfeit pharmaceuticals and data integrity. As the industry evolves, adopting blockchain technology will be critical in crafting a more secure, transparent and patient-centric future. However, navigating implementation obstacles and legal issues is critical to ensuring a smooth transition to a blockchain-powered pharmaceutical industry. By doing so, the industry will be able to realise the full potential

of this breakthrough technology, eventually benefiting patients, stakeholders and the general public.

The review article is extremely important in today's climate because of its extensive examination of blockchain technology's impact on the pharmaceutical business. It addresses major concerns in global healthcare, such as counterfeit medications, supply chain integrity and regulatory compliance. The paper provides a transformational approach to addressing these difficulties by suggesting creative solutions such as smart contracts and decentralised applications. This review article delivers relevant insights and ideas that can potentially change the industry and defend public health in an era when trust, openness and efficiency are paramount in pharmaceutical operations.

Ethics

This study was a secondary analysis based on the currently existing dataset from the *PubMed* and did not directly involve with human participants or experimental animals. Therefore, the ethics approval was not required in this paper.

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Conflicts of interest

The authors declare that there is no conflict of interest.

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Data access

The data that support the findings of this study are available from the corresponding author upon reasonable individual request.

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