A Survey On Blockchain and Prescription Tracking: Challenges & Opportunities

Keywords: Blockchain,Prescription Tracking,Healthcare

Abstract: Over the course of the last several decades, prescription drug misuse and diversion has become a major public health epidemic. Concurrently, flaws in contemporary prescription tracking introduce data siloing, security vulnerabilities and a lack of accountability between parties involved. This paper surveys the potential blockchain technology has to enable a more secure, efficient, and complication-free prescription drug tracking infrastructure. To facilitate this discussion we review blockchain's fundamentals and provide background on its use in cryptocurrency, banking, supply chain management, and other domains beyond healthcare. The discussion explores various potential benefits of blockchain in healthcare, such as patient prescription data management, record alteration prevention, stakeholder communication interoperability, and faster medication issue notifications. Furthermore, obstacles persist in areas like user experience, compatibility with existing health IT infrastructures, and the scalability of blockchain. Research opportunities exist in studying onboarding, handling postmortem data, and consent management. We believe this survey will provide blockchain researchers and developers a comprehensive overview of the state of the blockchain in prescription tracking and facilitate further research going forward.

1 INTRODUCTION

As the medical landscape has changed, digital technology has become increasingly embedded into various aspects of healthcare, paving the way for innovations that provide value to hospitals, the medical system, and end users. One innovation is the blockchain, a technology that offers significant potential to disrupt the way healthcare data management and security is currently handled.

Blockchain is a distributed immutable ledger technology that underpins cryptocurrencies like Bitcoin and Ethereum. Since the inception of this technology it has been recognized for its constantly-expanding potential to bring about profound changes beyond its initial use case in the financial sector, with utilization of this technology spreading into a multitude of fields. Healthcare represents one of the more recent areas leveraging blockchain capabilities like decentralization, immutability, transparency, and security for a variety of uses. This paper explores the use of blockchain in medical technology, focusing on the use case of prescription tracking and giving a brief overview of the background and application of this technology in the medical field. We examine the potential of blockchain to provide a powerful solution that could redefine various aspects of healthcare by offering enhanced privacy, facilitating efficient data sharing practices, lowering prescription abuse rates, and ensuring accurate diagnoses and personalized treatment. It provides a comprehensive overview of the current state of blockchain in healthcare and highlights areas in which this technology could be used to further improve the existing healthcare system.

2 BACKGROUND

Blockchain technology, traditionally associated with the realm of finance and cryptocurrencies, is making considerable strides in the medical industry. Blockchain technology has earned a significant reputation by addressing key issues such as inefficiency, transparency, and trust concerns. The two most well known examples of blockchain in the financial industry are the cryptocurrencies Bitcoin and Ethereum, though there are others that have gained prominence as the technology has evolved.

A blockchain is comprised of three fundamental pieces: blocks, hashes, and the network. Each block on the blockchain contains a list of transaction records. Once a block fills up with information, it is sealed with a unique code called a 'hash.' The hash is created from the transaction data and functions as a digital seal. If anyone tries to alter the transaction data, the hash will change, making any tampering evident. The hash is highly sensitive to its input data; a minor change in data, even the altering of a single byte, would alter the hash by over 50% following the byte-change. As a result, hashes can detect minute modifications to input data.

When a new block is created, it carries both its own hash and the hash of the previous block. This process links the blocks together in a chain, with each referencing the prior, hence the name blockchain.

The network is decentralized and distributed among various nodes; each node is a computer participating in the network by running the software required to bring the computer and its computational resources online. These nodes validate new transactions and record them on chain. This decentralization means that no single entity has control over the entire chain, ledger or network, making it secure and robust against fraud and malicious actors.

Proof of Work (PoW) and Proof of Stake (PoS) are two of the most common types of consensus algorithms used in blockchain networks to verify transactions and append new blocks to the end of the chain. They are both used to achieve agreement across the distributed network and between the nodes, but function in distinct ways.

Bitcoin uses a PoW consensus mechanism, also called the Nakamoto consensus. In PoW, miners compete against one another to solve complex mathematical equations, with the first miner able to solve the problem becoming the one who adds the next block to the chain. This process requires a considerable amount of computational power and energy because the difficulty of the puzzles ensures that they cannot be solved quickly. This energy expenditure and computationally-intensive process is used as a 'proof' of the work done to secure the network.

On the other hand, Ethereum, a network that originally used PoW, has now transitioned to a Proof of Stake (PoS) consensus with its Ethereum 2.0 upgrade. In PoS, instead of miners, there are validators who lock some of their Ether as a 'stake.' The validators, with the weight of their vote proportional to the size of their stake in the network, then propose and vote on blocks to be added. Rather than requiring energy and computational power to solve puzzles, PoS relies on the economic value participants have in the network and the risk of losing it to secure the network and come to agreement.

The primary differences between PoW and PoS lie in their resource requirements and centralization potential. PoW consumes large amounts of energy, which has raised major environmental concerns. PoS, as implemented in Ethereum 2.0, is much more energy-efficient but could potentially lead to greater centralization, as those with more financial ability to be involved in the system can stake more and thus gain influence over the rest of the network and the validation of the nodes.

2.1 Current Healthcare System

In an increasingly digitized data-centric world and economy, the healthcare sector finds itself at a critical juncture, grappling with the escalating challenge of effectively managing the vast amounts of sensitive health data being continuously generated. The intricacies involved in the safeguarding of this confidential information from malicious actors, and the preserving of data integrity while ensuring smooth transfer between authorized parties and a myriad of medical entities, have long plagued the healthcare ecosystem. This section discusses the facets of the current healthcare system, including the Health Insurance Portability and Accountability Act (HIPAA), the transition from physical to digitized records, existing prescription monitoring programs, and how blockchain technology can impact these aspects of the healthcare field, enforcing data ownership, record immutability, cross-hospital communications and efficient alert systems.

2.1.1 Health Insurance Portability and Accountability Act (HIPAA)

All healthcare systems, applications, or technologies must adhere to relevant laws. HIPAA is a federal regulation that sets the standard in the United States for protecting private health information from being disclosed without the patient's consent or knowledge. All parties involved in patient information must adhere to HIPAA for healthcare systems. HIPAA can be broken down into four main rules, the Privacy rule, the Security Rule, the Breach Notification Rule, and the Enforcement Rule (Division, 2022) (Association, 2019b) (Association, 2019a) (for Civil Rights, 2021).

2.1.2 Privacy Rule

The Privacy rule provides individuals with a legal, enforceable right to view and receive copies, upon request, of their health records maintained by their health care providers and health plans (Division, 2022).

2.1.3 Security Rule

"The HIPAA Security Rule requires physicians to protect patients' electronically stored, protected health information (known as "ePHI") by using appropriate administrative, physical and technical safeguards to ensure the confidentiality, integrity and security of this information." (Association, 2019b).

2.1.4 Breach Notification Rule

"HIPAA's Breach Notification Rule requires covered entities to notify patients when their unsecured protected heath information (PHI) is impermissibly used or disclosed—or "breached,"—in a way that compromises the privacy and security of the PHI." (Association, 2019a)

2.1.5 Enforcement Rule

"The HIPAA Enforcement Rule - PDF contains provisions relating to compliance and investigations, the imposition of civil money penalties for violations of the HIPAA Administrative Simplification Rules, and procedures for hearings." (for Civil Rights, 2021)

2.1.6 Electronic Health Record (EHR)

An electronic health record (EHR) is a digital version of a patient's health record. Usually, these include highly sensitive private health information regarding history, diagnosis, and treatment procedures. These records serve as a data store and digital records system for salient patient information such as appointment scheduling, records, billing information, account information, lab test results and treatment updates, building a rich and robust tapestry of a patient's medical journey over the course of their life (HealthIT.gov, 2019). "One recent study demonstrated that although EHR improved the accuracy and speed of access to information, it also had undesirable cognitive effects." (Beasley et al., 2011). This has lead to many healthcare organizations not using EHRs to track patient data, rather keeping paper records. This dichotomy has engendered a measure of hesitancy among institutions providing health services in regards to the widespread adoption of EHRs for patient data management. This results in institutions' continuous use of paper records. The paper records allow for decreased organization of information and efficiency (Saeed et al., 2022). From this complex issue, companies like BurstIQ emerged. BurstIQ started in 2015 and is headquartered in Denver, Colorado. They are a stellar example of real-world application of blockchain technology in the contemporary healthcare system. BurstIQ's primary aim is safeguarding patient data and limiting instances of data siloing. BurstIQ accomplishes this by leveraging blockchain technology's inherent security features, fostering an environment in which patients are granted control, access, and autonomy in their private and personal data.

2.1.7 Prescription Drug Monitoring Programs (PDMPs)

PDMPs refer to the electronic databases containing information on specific prescription drugs dispensed statewide (Sacco et al., 2018). The primary use cases of PDMPs are identifying or preventing drug abuse and diversion; coordinating the identification of prescription drug-addicted individuals, aiding in intervention or rehabilitation services, identifying use and abuse trends to inform public health initiatives, and educating individuals about prescription drug misuse (Sacco et al., 2018). The primary drawback of these systems is their statewide nature, although they do have various other limitations. By tracking prescription data, PDMPs can be utilized to detect patterns indicative of drug misuse and even illegal diversion, such as a patient abusing and obtaining prescriptions from multiple doctors, an issue known as doctor shopping, or a health care provider that may be prescribing very large amounts of controlled substances, whether that prescriber is a statistical outlier or participating in something more malicious like a "pill mill." PDMPs can also assist in the identifying drug-addicted individuals, as their ability to highlight patterns can shed light on individual high prescription use and potentially indicate an addiction issue. Such information can then be used to coordinate intervention or rehabilitation service if needed, helping to support those who are susceptible or suffering from addiction to prescription drugs. As a data-gathering system, PDMPs enable an overview of the broader landscape of prescription drug use and abuse. Using data analytics, public health officials are empowered to identify trends and even localized areas where abuse rates are common and/or high. They can also track whether there is a shift in the type of drug being abused. This information can be helpful in keeping public health initiatives up-to-date and keep them aimed at tackling and addressing these issues. PDMPs allow us to not only keep watch over the drugs that are being used, but also provide concrete data and examples that can support education use cases and campaigns, increasing the impact that these systems have on public consciousness and the prescription drug space. The issue that plagues these systems, however, is a major concern. These systems operate on a state-by-state basis and, as such, they are fragmented and incohesive as there is no overarching database that can store and observe data nationally.

This means that data on prescription abuse is siloed within state lines with a severe lack of interoperability between state PDMPs, as data is not automatically shared. This results in the issue of doctor shopping across state lines going potentially undetected, which allows for the system to be undermined. Other limitations include issues with data timeliness and data accuracy in addition to the current lack of information integration for clinical workflows.

2.2 Blockchain Application in Health Sector

As blockchain has grown and evolved, the technology has continued to expand into many industries, including healthcare. Many see blockchain as a potential solution to numerous problems relating to interoperability, security, and transparency among others.

2.2.1 Patient-Owned Data

Within the traditional healthcare architecture, an overwhelmingly significant amount of control over a patients' health data is handed over to medical corporations and care providers for data handling and storage. Patient information, often highly sensitive and confidential in nature, is stored in cloud-based systems from which it is accessed periodically by physicians or other authorized personnel. One of the odd things about this contemporary system is that the ownership of the patients' personal data does not belong to the patients themselves. Instead, patients desiring to access their own health data are compelled to submit requests for data access to their chosen healthcare providers. However, the advent of blockchain technology promises to revolutionize this current paradigm by shifting the ownership of health data in a fundamental way from ownership by medical corporations to ownership by patients themselves. In a blockchain-based healthcare system, data ownership would reside with patients, safeguarded within their own individual and completely unique wallet identities on the blockchain network. This shift is facilitated by the inherent design principals of blockchain technology, characterized by the usage of public and private key pairs and data encryption. It is this encryption that ensures patients have absolute control over their data, preventing unauthorized access and mitigating misuse or improper data handling by third parties or care providers. In implementing these changes, traditional roles would be reversed: medical professionals, rather than having direct access, would now request access to necessary health data from patients each time the patients seek medical assistance. This model of permission-based access gives patients the power to decide whether to share their health information with a given provider or party on a case-by-case basis, thereby ensuring the delivery of appropriate data and care. Patients are empowered with greater control and autonomy over their data, fostering a patient-centric healthcare model. Additionally the application of this blockchain technology enhances the privacy and security of data transfers and handling (Liu et al., 2020). This transformational shift caused by blockchain technology promises to disrupt and redefine data ownership, offering a more balanced and secure approach to managing personal health data.

2.2.2 Immutability

The structure of the blockchain can be compared to an append-only ledger system whereby information, once recorded into the system, becomes linked to the end of the data-structure and permanently unalterable. This essentially means that any data entered into the blockchain cannot be retroactively changed, tampered with, manipulated, or substituted; the only action permitted is the appending of additional information onto the chain. This property of immutability on the blockchain serves to significantly minimize potential instances of human error that may occur once the accurate data has been entered and stored. Within the context of healthcare data, this is extremely important as even minor inaccuracies can have profound impacts on patient care (Bowman, 2013). By insuring that the correct data, once recorded, cannot be altered, blockchain safeguards the integrity of the stored information. Moreover the immutable nature of the blockchain introduces an added layer of accountability in the realm of data recording. Each entry of data onto the blockchain can be unequivocally traced back to its origin, which enables more efficient audit trails and data accountability in health care when needed. Another significant advantage conferred by the immutable nature of blockchain is that there is a deterrent effect against any form of malicious influence or activity. A malicious actor that intends to alter the data for detrimental purposes would be unable to modify any of the existing ledger block, thus preserving the authenticity and reliability of the data. This attribute could potentially serve as a powerful protective measure against fraudulent activities or data breaches, which have become increasingly prevalent and of concern in the digital age. The immutable nature of blockchain systems stands as a pivotal feature when it comes to data protection and reliability, especially for health data.

2.2.3 Cross Hospital Communication

In the contemporary healthcare landscape the systems used for prescription tracking are predominantly centralized, necessitating manual inputs for record updates. However, this process often results in the sub-optimal outcome of many records being out of date (Taylor et al., 2022) and siloed away in a care provider's system. The current limitations underscore the increasingly pressing need for the adoption of new technologies and strategies to overcome the inherent flaws and inefficiencies of the existing systems. The notion of a decentralized healthcare platform presents a significant opportunity to transform this existing landscape by creating a standardized model that facilitates smooth and cohesive communication between healthcare providers, healthcare corporations, and patients. Blockchain technology emerges as a viable solution to this issue that currently plagues the medical system. The decentralized nature of blockchain would allow multiple authorized parties, including healthcare providers, pharmacists and patients, to request and access data and verify information, ensuring trust and transparency in the system. Within the current system, the notification from supply chain members of any issues with medications or treatments can take upward of a few days; however, with blockchain technology that notification speed is exponentially increased as the system becomes more efficient and less centralized, helping to more quickly communicate messages both between patients and providers (Taylor et al., 2022). This extreme increase in communications efficiency and accuracy presents the potential to establish a standard, cross-hospital model in which interactions between healthcare providers and patients are streamlined, helping to facilitate a swift and accurate exchange of information. Establishing this type of system would allow for the impacts of data siloing, common in the contemporary system, to be mitigated, as data would no longer be walled behind care providers' non-interoperable and proprietary systems.

2.3 Increased Efficiency for Communication and Alerts

It is blockchain's previously-mentioned benefits that pave the way for a substantial transformation in the realm of healthcare communication and alerts. By virtue of its decentralized structure, blockchain technology can dramatically enhance the accessibility of data while reducing notification time and communications lag. The current healthcare landscape is often marred and affected by delayed communications (Zhang et al., 2020). This leads to workflow inefficiencies due to a lack of interoperability (Zhang et al., 2020). A blockchain-based system, however, would operate across multiple independent systems. The interconnected yet autonomous operation facilitates near-instantaneous, cross-network communications and access to the stored data for authorized individuals. Such a shift from contemporary systems in data interfacing and retrieval can significantly diminish medical and financial inaccuracies as well as alert-timing for important notifications, and should mitigate administrative bottlenecks (Zhang et al., 2020). The decentralized network structure eliminates a single point of failure or delay. Information can be gossiped and disseminated across the network in real time, ensuring that all relevant parties receive alerts and notifications promptly. This can be critical in a medical context where delays or issues in treatments or medications can have serious consequences. The distributed nature of blockchain facilitates data redundancy as well. Because the data is distributed across all full nodes in the network, a partial system outage would not eliminate notifications passing through the system as redundant data is always available even if a large network percentage is offline.

3 BLOCKCHAIN IN OTHER FIELDS

The healthcare sector is not the only field that is facing a revolution due to the advent of blockchain technology and its disruptive potential. This section delves into the the expansive landscape of the applications of blockchain and its integration into sectors such as banking, where large entities are already integrating blockchain into their daily operations–the original use case of cryptocurrency–the impacts of blockchain on data storage and permanence, and the advent of Decentralized Applications (DApps). Through a comprehensive examination of these domains, this section aims to underscore the broad-ranging applications of blockchain.

3.1 Banking

In the contemporary financial landscape, numerous banking conglomerates and companies, including well known entities such as JPMorgan, Citi, Wells Fargo, US Bancorp, PNC, Fifth Third, and Signature Bank, are harnessing the potential of blockchain technology (Bank of America, 2021). The emerging trend is substantiated by a study conducted by Bank of America, which identified that approximately 21 percent of the banks they have analyzed have incorporated some form of blockchain technology into their operations and platforms. A compelling illustration of this integration is Wells Fargo's WFC Digital Cash platform. This new platform showcases the application of cutting-edge blockchain technology within the banking sector by facilitating the seamless transfer of investor accounts between its various subsidiaries. By utilizing the distributed, immutable, and secure characteristics of blockchain, Wells Fargo has managed to streamline and create a more efficient intraorganizational funds transfer system, thereby reducing time, cost, and complexities that are traditionally associated with such transactions. In a similar incorporation of blockchain technology, Fifth Third Bank has adopted blockchain technology in handling sensitive data, which further underlines the potential to enhance data security, privacy, and control in banking. The inherent features of Blockchain could be instrumental in safeguarding sensitive information against unauthorized access, tampering, and financial fraud, all of which are prominent concerns in the banking sector. Another unique aspect of Blockchain in the financial sector is the promise of enabling real-time settlement of transactions, reducing counter party risk and increasing transparency and transaction speed (Shrimali and Patel, 2022). This feature of blockchain systems has the potential to revolutionize traditional banking processes such as remittances, clearing and settlement, identify verification, and cost efficiency. These cases demonstrate and underscore the growing recognition within the banking industry of blockchains' opportunity for massive disruptive potential.

3.2 Cryptocurrency

Blockchain technology would not exist without cryptocurrency, as it is the reason for the technology's existence. Blockchain is the underpinning infrastructure for cryptocurrencies, starting originally with Bitcoin and Etherieum before branching into the multiple Altcoins that are currently players in the market. Blockchain grants these digital assets numerous attributes that are key for these to function such as trust between anonymous parties on the network. One of the most critical aspects of this trust is transparency. Operating as a distributed ledger, a blockchain records every transaction that takes place across the network, ensuring a traceable and auditable trail of transactions. Each transaction, after validation, is part of a block within the blockchain. The current existing cryptocurrencies have been built to solve existing issues either with contemporary monetary systems or issues that have arisen in other cryptocurrencies, like how Polygon is designed to be a layer two solution built on top of Ethereum to batch transactions together in order to speed up network efficiency. Cryptocurrencies cover a wide range of use cases and utilities, and not all are simply designed to be a digital monetary system like Bitcoin. The Quant Network (Network, 2018), for example, is designed to work as an interoperable blockchain operating system, called Overledger, that will allow for people and organizations to build cross-chain decentralized application with the Quant token serving as a utility token on the network, with holding of the token granting users certain abilities within the network rather than just a financial incentive. Cryptocurrencies have a wide range of impacts and use cases and serve as an example of how blockchain can be used to address certain societal problems.

3.3 Data Storage & Permanence

The advent of Blockchain has also enabled changes in the realm of data storage, owing to its unique properties, all of which have been identified as particularly beneficial for managing and maintaining data (Ali et al., 2018). Blockchain's decentralization is a paradigm shift from the traditional, centralized data storage system and database management that currently makes up the majority of our contemporary systems. Instead of being stored in a single location, data on the blockchain is distributed across multiple nodes in the network, allowing for an increase in accessibility and reducing the vulnerability of a single point of failure. This decentralized method of storage provides more stable and robust protection against data loss and ensures the availability of data even if individual nodes in the network fail. In the case of a blockchain system going down, only one node would have to be online to keep the system functional or to restore ledger functionality once more nodes go back online. The security of data stored on the blockchain is reinforced by the use of cryptographic algorithms and public-private key pairs. Each block of data is linked to the previous block, and any change to any part of the data anywhere on the chain, in any block, would cause an avalanche of hash changes causing tampering to be evident. The immutable append-only nature of blockchain also serves the data storage aspect of the system well as once data has been written to a block it is practically impossible to delete or alter the stored data. This immutability for data storage is a key beneficial aspect of blockchain for use in financial systems, health records, supply chains and other use cases where data permanence is necessary.

3.4 Smart Contracts & Decentralized Applications (DApps)

Smart contracts, essentially self-executing programs that are stored on the blockchain, facilitate automation and enforcement of agreements between participating parties, thereby eliminating the necessity for a trusted third-party intermediary (Khan et al., 2021). These contracts encode the guidelines and consequences related to an agreement between parties like a regular contract, while also automatically enforcing those obligations.

Decentralized applications or DApps represent a novel paradigm in software development that was created with the advent of blockchain technology, where the principles of Blockchain and smart contract development are leveraged to build applications that function on top of decentralized networks. DApps resemble and function similarly to their traditional application counterparts in regard to the user interfaces and functionalities, yet, unlike traditional apps they operate in a decentralized manner, primarily facilitated by the implementation and utilization of smart contracts running on top of the Blockchain. The concept of DApps was popularized and first created mainly by Ethereum due to the network's ability to run smart contracts on the Ethereum Virtual Machine or EVM, the theoretical computer made up of all nodes on the network. This EVM functionality is what allowed Ethereum to support the creation and execution of the smart contracts that led to DApps. (Cai et al., 2018). The key advantage of DApps lies in their enhanced feature set while maintaining a user experience similar to that of traditional apps with which we are all familiar. (Cointelegraph, 2022). DApps leverage the blockchain's properties to provide solutions that are resistant to censorship, tampering and fraud. They open new opportunities for peer-to-peer interactions, allowing direct trustless transactions between parties. The integration of smart contracts that function inside DApps ensures the consistent execution of predefined rules without the need for human intervention or oversight. This automatically reduces the risk of human error and enhances the efficiency and reliability of processes within the application. The utilization of smart contracts and DApps offers a promising avenue for tackling various challenges across numerous sectors, a strong example of that being prescription tracking in healthcare.

4 Blockchain for Prescription Tracking

4.1 Security

The imperative need for secure, transparent, and efficient prescription tracking in the healthcare industry has become increasingly evident amidst the backdrop of rising privacy concerns, opioid crises, data siloing, and interoperability issues. Blockchain technology offers a promising solution to these persistent challenges. This section investigates the potential role of blockchain technology in advancing security in prescription tracking. It discusses the prospects of leveraging Blockchain to increase interoperability, thus enabling a seamless exchange of health information across various systems while ensuring data integrity and patient privacy. Furthermore, it delves into the potential use of Blockchain in the tracking of opioid prescriptions, which could drastically enhance visibility into the distribution of these potent drugs, helping to curb misuse and addiction. Finally, this section sheds light on how Blockchain could fortify the security of patient data by providing an immutable, auditable trail of patient records, thereby mitigating risks of unauthorized access, alteration, and loss of patient data. Through these insights, this section aims to unravel the potential of Blockchain in revolutionizing the security landscape of prescription tracking within the healthcare industry.

4.1.1 Increasing Interoperability

In the realm of healthcare, the application of blockchain technology has been recognized as a promising solution to enhance the interoperability of prescription tracking systems. The decentralization of Blockchain offers a unique format to address the

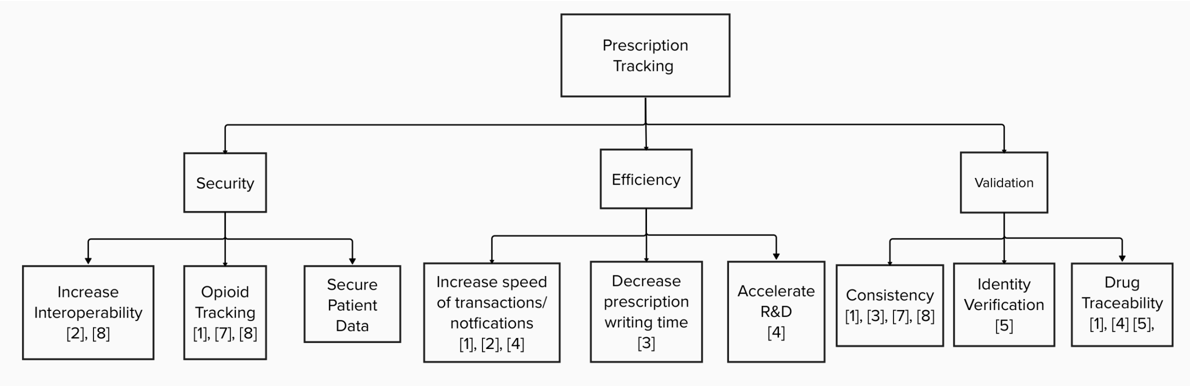

Figure 1: Taxonomy for the closely related topics within the prescription tracking survey paper. Each block contains multiple references that refer to supporting papers and studies for each subsection of each main section.

challenges of data siloing that is commonplace in the healthcare system, enabling a seamless data sharing system across different healthcare providers and stakeholders while further enhancing the overall security of these systems (Saeed et al., 2022), (Beasley et al., 2011). Blockchain technology allows for the creation of a unified and secure platform where transactions related to prescription drugs can be recorded and tracked (Beasley et al., 2011). This platform can be accessed by all stakeholder groups involved in the prescription drug supply chain, from manufactures to providers. This level of access ensures that all parties have a consistent and up-to-date view of all transactions, eliminating the possibility of data incongruities that could compromise interoperable communications or security (Saeed et al., 2022). The transparency and immutability of the network also contribute to improved interoperability. The transparency of the data to authorized partied ensures that all transactions, whether between patient and doctor or communications between hospitals, are visible to all parties involved, thereby promoting accountability and trust between all stakeholders (Saeed et al., 2022). The immutability of these recorded transactions ensures that once a communication is recorded, it cannot be deleted or altered, preserving communication integrity. Relying on a blockchain-based system for data sharing also enables all users of the system to share and store the information in a collective and coordinated manner, eliminating issues that are faced by current systems that are siloed behind state borders without connections to any of the other PDMP systems that are essential to prescription tracking.

4.1.2 Opioid Tracking

In the UK, approximately 1.5 million prescriptions are processed on a daily basis (Schlatt et al., 2023). Between 1999 and 2018, the U.S. experienced a loss of 232,000 lives due to opioid overdose, accompanied by an annual economic toll of $78.5 billion. This figure encompasses costs associated with the criminal justice system, diminished productivity, and the rehabilitation of individuals grappling with addiction (Taylor et al., 2022). Optrak, a decentralized application (DApp) constructed on the Ethereum blockchain, serves as an advanced tool in opioid tracking by employing distributed ledger technology to address four central challenges (Zhang et al., 2020). First, it bolsters interoperability among states by offering an application that streamlines the exchange of prescription information. Second, it counters the vulnerabilities associated with centralized databases by allowing data producers to exercise control over their own information, ensuring that the entire database remains secure even if a single local database is compromised. Third, Optrak integrates a Public Key Infrastructure (PKI)-based identity verification system, supplemented by a registry model through smart contracts. This system employs cryptographic public and private keys that are mathematically linked to encrypt data and verify digital signatures, thereby ensuring secure, authenticated communications (Zhang et al., 2020). Lastly, the DApp enhances the reliability and consistency of information by facilitating instantaneous data updates as they are recorded in local systems, circumventing the need for manual submission of prescription records. This amalgamation of features positions Optrak as a potent solution in the domain of opioid tracking while holding doctors accountable for what they prescribe in a secure manner

(Zhang et al., 2020).

4.1.3 Securing Patient Data

One of, if not the most important aspect of security in blockchain prescription tracking, is that of securing patient data. The integration of encryption and access control mechanisms in blockchain systems helps to provide a robust framework for ensuring the confidentiality, integrity and availability of patient data. SecureRx is one such example of how blockchain systems can help secure patient data. The SecureRx system employs a novel combination of symmetric and asymmetric encryption methods which are instrumental in safeguarding patient data by obfuscating the data when it is in transit and ensuring that the data that is communicated can be transferred and stored in a decentralized manner from party to party under multiple layers of protection (Alnafrani and Acharya, 2021). This dual encryption method approach ensures that only authorized parties and entities can access the data, thereby maintaining confidentiality and integrity of the patient's information within the system. The roll of access control as an aspect of data security cannot be overstated. As proposed in VigilRx (Taylor et al., 2022), an attribute-based access control model that utilized patient attributes to determine access permissions provides a granular level of control over sensitive patient data access. This model ensures that only entities that possess the necessary attributes can access the specific pieces of patient data needed. This not only bolsters the security of the data by limiting access to the data itself, but also ensures that the privacy of the patient is upheld as only entities with the correct attributes and only the correct attributes can access the data (Taylor et al., 2022). By leveraging encryption, access controls, and other security mechanisms, blockchain-based prescription tracking systems can ensure robust protection of sensitive patient data, laying the foundation for efficient and effective healthcare processes (Taylor et al., 2022).

4.2 Efficiency

As healthcare systems grapple with increasing demands and escalating costs, especially in the time after the COVID pandemic, it is imperative that processes across the healthcare sector are efficient and effective. This section delves into the utilization of blockchain technology to increase transaction speeds, reduce latency, decrease prescription time and offer a swifter path from the doctor's office to the patient, improving medical regimens and treatments. In illuminating these aspects, this section underlines the potential of blockchain technology in redefining the efficiency dynamics of prescription tracking, contributing to overall healthcare system performance, and patient outcomes.

4.2.1 Increasing Transaction Speeds

In regards to efficiency of blockchain networks, a significant focus has been placed on increasing transaction speed. SecureRx has been instrumental in this regard (Alnafrani and Acharya, 2021). The system leverages the Ethereum network, which is renowned for its smart contract functionality. SecureRx employs a two-layer architecture, where the first layer is responsible for the storing of prescription data and the second layer is used as a method of access control. This system design has been found to significantly increase transaction speeds as the separation of layers allows the system to process transactions more efficiently (Alnafrani and Acharya, 2021). Each layer can focus on the task that that layer was designed for without being slowed down or affected by the other layer and the complex operations that it employs. Moreover, the second layer can be optimized for access control and can handle those tasks as quickly as possible in parallel with the first layer, without having to wait on validation or block creation. The system also utilizes a Merkle Patricia Tree for data storage, which further optimizes transaction speed by enabling efficient data retrieval. A second system advancing research for Blockchain in prescription tracking, called VigilRx, has provided further insights into optimizing efficiency and transaction speeds (Taylor et al., 2022). VigilRx utilizes role-based smart contracts to define allowed actions for different stakeholders in the prescription process. By differentiating users and separating permissions across different smart contracts, actions like prescription filling can be executed in parallel without waiting for blocks to be pushed onto the ledger. This allows the system to process transactions more efficiently (Taylor et al., 2022). VigilRx also establishes patient consent at multiple stages, enabling transparency while not hindering transaction speeds. VigilRx's use of drug codes on-chain further improves efficiency by reducing storage needs. These systems demonstrate reasonable transaction speeds within blockchain-based prescription tracking systems when configured properly.

4.2.2 Decreasing Prescription Time

Not only is system efficiency a major concern, the reduction of time required for writing and processing prescriptions is an extremely important consideration in evaluating blockchain-based prescription tracking systems. Recent research has demonstrated significant time savings using blockchain platforms compared to traditional electronic prescribing methods. The SecureRx system leverages Ethereum's EVM smart contract functionality to enable real-time updating of records, eliminating manual data submission delays (Alnafrani and Acharya, 2021). Experimental testing of the VigilRx framework showed achievement of reasonable transaction speeds when configured based on appropriate decentralization requirements; however, a real-world implementation for validation would be needed (Taylor et al., 2022). The PAGR (Seaberg et al., 2021) blockchain e-prescribing system provides further concrete evidence, with testing resulting in a mean time savings of 108 seconds per prescription compared to the current electronic health record workflows. PAGR integrates access to patient data, insurance eligibility, drug databases, and other resources to minimize disruptions in the prescribing process. Across these projects and studies, optimized data storage, paralleled contract execution, and consolidated system interfaces are all techniques that help to reduce prescription time. While the decreases in time vary across system implementations, blockchain platforms consistently have demonstrated transmission and processing speeds that are improvements over legacy health IT and prescription systems. This becomes significant when scaled nationwide and dealing with massive amounts of prescriptions, especially when over 51 percent of the United States Population is using some form of prescription medication, with that percentage predicted to increase (Kantor et al., 2015).

4.3 Validation

In healthcare, ensuring validity and integrity of data is crucial for accurately tracking sensitive information such as prescriptions. Within this context, blockchain technology emerges as a potential game changer, offering several methods of validation that can enhance security and transparency. This section will delve into three key aspects of validation in blockchain based prescription tracking systems: consistency, identity verification, and drug traceability.

4.3.1 Consistency

The concept of consistency in distributed systems is a critical one, and it has been the subject of extensive research. Within the bounds of prescription tracking, achieving consistency has been approached multiple ways in order to ensure validity of data. Due to the decentralization that blockchain systems offer, they can provide greater consistency compared to traditional centralized databases. The distributed-ledger design of Blockchain's structure ensures that the data in the ledger is replicated across all nodes, ensuring redundancy and eliminating the single point of failure issue (Alnafrani and Acharya, 2021). Each transaction is broadcast to the network and recorded in near real-time as the nodes gossip valid transactions between each other, updating records simultaneously across the platform and eliminating duplication by maintaining a single state across all nodes (Alnafrani and Acharya, 2021). This enables real-time prescription tracking and prevents issues like outdated databases that centralized storage systems suffer from (Beasley et al., 2011). The introduction of smart contracts that blockchain systems have provided allows for further consistency measures. For example, the issuing of prescriptions, prescription type, and other state variables can trigger events to record fulfillment, flag odd prescription patterns, etc., all without human error, preventing tampering and improving consistency (Chenthara et al., 2020), (Seaberg et al., 2021). This type of consensus mechanism also plays a roll in data consistency. In the PAGR system; the consensus is done by a method called Proof of Authority or PoA (Seaberg et al., 2021). The PoA consensus ensures that validation is done only by nodes that have proper authorization on the network. Limiting the nodes that can add and validate transactions restricts the potential for malicious action and error when it comes to data consistency, ensuring that the state of the chain is constant across all nodes and preventing data discrepancies. The PoA model is not the only consensus mechanism that allows for more precise data consistency. Practical Byzantine Fault Tolerance (PBFT) is also used as a mechanism to ensure data consistency (Chenthara et al., 2020). PBFT designates a single node as a primary node that bundles blocks and broadcasts those bundles to the network for voting. These backup nodes also check that the data in the new block is consistent with the previous ledger state for each block added, essentially double-checking that the data is correct at all times. This is important for prescription tracking as even a single inconsistency in the data could cause severe medical consequences.

4.3.2 Identity Verification

Blockchain-based prescription tracking systems have the potential to incorporate greatly enhanced identity verification and authentication compared to traditional centralized methods. Rather than checking for static identifiers like a driver's license or social security number, Blockchain enables identity validation through the use of public key cryptography linked to each user whether they are a patient, doctor, pharmacist, admin or other authorized user (Alnafrani and Acharya, 2021) (Chenthara et al., 2020). Each user holds a unique private key that acts as their personal identifier on the ledger. Any transaction that the user makes, like the prescribing or filling of a prescription, are signed with the private key and can be verified with a corresponding public key (Chenthara et al., 2020). This allows transactions to be cryptographically tied to unique identities, acting as a fingerprint for verification or auditing purposes. Smart contracts can also play a roll in verification of identity as their execution can be limited with role-based permissioning rules to enable or restrict actions on the system (Alnafrani and Acharya, 2021). The Optrack (Zhang et al., 2020) system combines this cryptographic model with biometric forms of identification, as with a large user base a PKI-based infrastructure would incur significant technical challenges to avoid limiting wide-range adoption (Beasley et al., 2011). This creates a robust linkage between identity and keys while still limiting a centralized weakness with verification failure that can happen with a centralized structure. The immutability of blockchain systems also enables comprehensive audit trails of all users interacting with prescription records, improving accountability (Seaberg et al., 2021). Any access or transactions can be immutably traced back to the specific public key identities that initiated them. While widespread interoperability of identities remains a challenge for blockchain health systems, cross-referencing and linking identities across institutions is far more feasible due to the globally-shared ledger that could be implemented utilizing a blockchain system (Alnafrani and Acharya, 2021). These features make a blockchain-based prescription tracking platform substantially more accountable than the current methods.

4.3.3 Drug Traceability

Medical enterprises are actively probing the potential of integrating supply chain tracking methodologies for drug traceability that have proven to be useful in other sectors like retail, luxury goods, and logistics. The goal of these integrations is to establish a detailed and precise monitoring system that oversees the transfer of raw materials, components, and finished products from their points of origin through all stages of production and distribution and ultimately to delivery to the end consumer or patient (Close et al., 2018). In this context the implementation of blockchain technology could revolutionize and streamline supply chain management protocols in healthcare, particularly in the context of prescription tracking. The inherent transparency, immutability, and traceability in blockchain systems make blockchain technology an ideal tool for providing comprehensive visibility across all stages of the supply chain, offering stakeholders the ability to track pharmaceutical goods. Utilizing this technology within supply chain management can ensure a stakeholder's accountability at each stage from beginning to end. From manufacturers sourcing raw components, to the shipping companies that control the shipping environments and need to keep conditions stable for medications to remain safe, to wholesalers, retailers, hospitals and pharmacies, and patients. It allows every transaction and each movement of goods to be recorded and stored in a transparent, redundant, and immutable manner, which can significantly reduce counterfeit products, theft, improper handling or storage of goods, and other forms of misconduct within the supply chain. Moreover smart contracts could also automate certain processes, making operations more efficient and less prone to human errors. For instance, a smart contract could contain code that would automatically validate transactions based on predefined conditions such as whether the product has been stored under the correct conditions, or whether it has been dispatched and received on time during shipping. This not only improves efficiency but also enhances the trust and reliability of the system. The end-to-end permanent traceability facilitated by the Blockchain in supply chain management could also be pivotal in recalling and notifying users or suppliers of defective or unsafe products. In the event of a recall, the tracking capabilities of a blockchain-based system could rapidly identify affected batches and their locations, thereby minimizing the risk to patient safety. As promising as these applications of Blockchain are, there are challenges and issues that need to be addressed. One of these critical concerns is the rampant and increasingly serious problem of fake prescriptions. Tracking pharmaceuticals globally presents a formidable challenge due to the prevalence of counterfeit drugs. These illegitimate products, often nearly indistinguishable from authentic medication, are distributed by unscrupulous manufacturers, posing serious health risks as patients are unable to easily discern their authenticity (Benita K et al., 2020).. In recent years, the production of counterfeit drugs has escalated, contributing to an estimated annual death toll ranging from 100,000 to 1,000,000 individuals globally (Zakari et al., 2022). Blockchain-based prescription tracking systems can help address this through the end-to-end traceability of drugs (Zakari et al., 2022). Distributors and pharmacies update locations on-chain as authentic drugs are moved (Beasley et al., 2011). Meaning that each unit can be tracked and assigned a unique identifier allowing authentication from dispensation and preventing counterfeits from entering the system (Chenthara et al., 2020). This counterfeit prevention would limit the amount of people that could get a hold of fake products and thus push more users towards the proper tractable drugs. While blockchain-enabled tracking offers significant benefits for prescription monitoring, there are still major challenges and opportunities that blockchain offers.

5 CHALLENGES & OPPORTUNITIES

5.1 Challenge 1: Onboarding

The field of prescription tracking presents numerous challenges and opportunities, with user onboarding being a prominent hurdle. The limited adoption of blockchain technology can be attributed to existing technological barriers, particularly the complexity of user creation in Web3 compared to the prevailing standards in current applications. For prescription-tracking systems based on blockchain, patients, healthcare providers, and pharmacists will all need to be onboarded. This may require downloading apps, creating digital wallets, managing cryptographic keys, and learning new interfaces. There is a steep learning curve associated with these steps, which could hinder adoption (Shrimali and Patel, 2022). In addition, those who are not technologically savvy may struggle to set up blockchain-based accounts and understand the basics of how the system works. They will need more hand-holding and training resources. Even users experienced with technology may find the onboarding process frustrating if the UI/UX design is not intuitive. To promote widespread adoption, researchers should explore ways to simplify and optimize the onboarding user experience across different stakeholder groups. This could involve creating standardized protocols, developing natural language chatbots for assistance, providing educational resources, and iterating the UI through user testing. Making onboarding seamless will be critical for transitioning from current systems to next-generation blockchain prescription tracking.

5.2 Challenge 2: Data Regulation Compliance

A significant challenge includes complying with HIPAA regulations and standards, which is crucial for any application handling sensitive medical data. Achieving this compliance is critical for the blockchain prescription tracking systems under discussion, prior to release. In particular, the decentralized nature of blockchain ledgers conflicts with HIPAA's strict confidentiality rules around patient prescription information. Additional privacy controls would need to be built into tracking systems to restrict data visibility in line with regulations. HIPAA also requires specific patient consent procedures before sharing medical data that could be difficult to implement given blockchain's inherent verifiability. Furthermore, HIPAA demands rigorous access controls, auditing, and encryption that blockchain's native security may not fully provide, necessitating extra mechanisms in tracking systems. Overall, accommodating HIPAA's expectations for comprehensive medical data privacy and security represents a major technical and procedural challenge in developing regulatory-compliant blockchain prescription tracking. Innovative solutions will be needed to enable the benefits of transparency and verifiability from blockchain tracking while still upholding HIPAA's patient protections.

5.3 Challenge 3: Integration with Legacy Systems

For prescription tracking blockchain solutions to be viable, they will need to integrate and share data with existing health IT systems like electronic health records, e-prescribing platforms, and pharmacy management systems. Most patient prescription records are currently managed through these legacy systems. Siloed blockchain platforms that lack interoperability result in adoption barriers and fragmented data (Taylor et al., 2022). Technical challenges exist in enabling cross-compatibility between decentralized blockchain networks and conventional client-server systems. Additional complexity arises from integrating disparate legacy systems across different healthcare providers, pharmacies, and health institutions. Beyond technical integration, challenges include aligning data standards, vocabularies, and interfaces between different systems. Overcoming these barriers is key for blockchain prescription tracking to integrate into existing health IT infrastructure. Taking an API-based approach along with standardized data models can aid integration. However, designing blockchain tracking that seamlessly works with legacy systems will be critical for wide adoption.

5.4 Challenge 4: Blockchain Bloat

As blockchain-based prescription tracking systems scale, the large volume of transactions can result in "blockchain bloat" - a massive growth in the size of the ledger. Each transaction, prescription record, and timestamp stored on-chain contributes to blockchain bloat. This presents scalability challenges as the ledger grows larger, requiring more storage and computing resources to maintain decentralized nodes. Excessively large blockchains can slow transaction confirmation times and overall network performance. For prescription tracking, the volume of daily prescriptions could quickly bloat an immutable ledger's size to an unmanageable degree. Technical solutions like sharding, off-chain storage, and lighter consensus protocols may mitigate bloat. However, managing the ledger growth through optimized data storage and pruning of non essential data will be an ongoing challenge. The decentralization and permanence that provide security also contribute to high data overhead. Balancing scalability and security as prescription tracking blockchains expand will require novel approaches to minimize bloat.

5.5 Opportunity 1: Machine Learning Utilizing Prescription Tracking Data

The increasing adoption of electronic health records and e-prescribing provides vast amounts of prescription data that can be leveraged through machine learning techniques. By applying machine learning algorithms to prescription records on the blockchain, researchers can uncover patterns and insights related to prescription practices, medication adherence, and patient outcomes. For example, neural networks could analyze a patient's prescription history along with demographic data to predict the likelihood of adverse events or poor adherence. Prescription data combined with lab results may also allow earlier detection of adverse drug events. Researchers could utilize neural networks to develop and validate machine learning models that utilize blockchain-system data to detect doctors acting maliciously or areas that are susceptible to misuse and utilize these models to address these issues.

5.6 Opportunity 2: Researching Ease of Onboarding for Users

Adoption of any new technology relies heavily on how easy it is for users to onboard and utilize the system. For blockchain-enabled prescription tracking solutions, researchers should focus efforts on studying the user experience during onboarding and training. Surveys, interviews, and usability testing can provide insights into the learning curve and barriers faced by different end-user groups like patients, physicians, and pharmacists. Specifically, research should identify obstacles in the onboarding flow, areas of confusion in the user interface or training materials, and where users need additional support to adopt the technology. By pinpointing UX pain points in the onboarding experience, developers can refine the solution to be more user-friendly and intuitive for mainstream adoption. Overall, human-centered research studies on the onboarding process will be key to understanding and overcoming adoption barriers as blockchain prescription tracking solutions are rolled out. The goal should be to minimize the disruption experienced by users and ensure that Web 3.0 is as close to Web 2.0 ease of access as possible in order to ensure a smooth transition to optimized prescription tracking.

5.7 Opportunity 3: Researching How to Handle Patient Data After Death

An important consideration that need to be accounted for in a prescription tracking system is how the patient data should be handled after the patient is deceased. The current heathcare privacy law HIPAA, only applies for 50 years after an individual passes. However, prescription data records on the blockchain ledger will still exist long after. This presents an ethical dilemma, how should a patient's sensitive prescription data be handled and managed after a patient's death, especially when there is no patient to access the associated wallet? Further research is needed to develop policies and protocols addressing the postmortem handling of blockchain-based prescription data. Key issues to investigate include data access by relatives, executors, and researchers as well as anonymization or nullification of records. By proactively addressing this emerging issue, researchers can guide the responsible use of immutable blockchain records when patients pass away. This will balance privacy and ethics with the benefits of maintaining data provenance. Establishing evidence-based guidelines will help uphold public trust as blockchain solutions expand in healthcare.

5.8 Opportunity 4: Researching Consent Management for Patients

Blockchain-enabled prescription tracking systems introduce new complexities around consent management and data sharing. Patients may want to restrict access to certain prescription records for privacy reasons. However, the immutable nature of Blockchain ledgers makes removing or modifying data difficult. Further research should explore solutions to manage patient consent preferences within the architectural constraints of blockchain. This could include cryptographic methods of masking or encrypting selective prescription data based on a patient's preferences. Usability studies could identify optimal interfaces for patients to easily control consent and data sharing. Machine learning may also have a role in enabling dynamic, context-aware access controls. Developing flexible consent and permissions models will be critical for decentralized blockchain ledgers storing sensitive prescription information. With proper consent management, patients can retain autonomy over their medical information, even as it is shared across stakeholders on an immutable ledger. This helps build trust and alignment with ethical data use standards.

6 CONCLUSIONS

In conclusion, this paper has provided a comprehensive overview of the potential for blockchain technology to transform prescription tracking in healthcare. Through an in-depth analysis, we have demonstrated that Blockchain's inherent properties of decentralization, immutability, transparency and security, could address many of the persistent challenges faced by current prescription monitoring systems. Blockchain shows promise in improving security through enhanced identity verification, interoperability, and protection of patient data. It also offers pathways for greater efficiency, including faster transaction speeds and reduced prescription times. Validation methods leveraging blockchain such as drug traceability, access controls, and consensus algorithms further strengthen the reliability and accountability of prescription data. While onboarding complexity, integration with legacy systems, and blockchain bloat present obstacles, opportunities exist in machine learning, UX research, consent management, and post mortem data handling. We hope that the background data, applications in healthcare and prescription tracking, and the challenges and opportunities provided in this survey can help researchers and developers understand and expand the use of Blockchain in the medical field.

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