Review paper

The use of blockchain technology in medicine. Literature review and future perspectives

Zastosowanie technologii blockchain w medycynie. Przegląd piśmiennictwa i perspektywy na przyszłość

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Abstract

Blockchain technology, the backbone of cryptocurrencies such as Bitcoin, is a rapidly growing field with a wide range of potential applications, including in the medical field. The ability to securely and transparently store and share data makes it a promising technology for various applications in healthcare. In this narrative review, we will explore the ways in which blockchain technology is being used in medicine, the potential benefits and challenges of using this technology, and the future directions for research in this area.

Streszczenie

Technologia *blockchain*, będąca podstawą kryptowalut, takich jak Bitcoin, to dynamicznie rozwijająca się dziedzina o szerokim zakresie potencjalnych zastosowań, w tym w medycynie. Możliwość bezpiecznego i przejrzystego przechowywania oraz udostępniania danych czyni ją obiecującą technologią dla różnych zastosowań w opiece zdrowotnej. W niniejszym przeglądzie omówiono sposoby wykorzystania technologii *blockchain* w medycynie, potencjalne korzyści i wyzwania związane z jej użyciem oraz kierunki przyszłych badań w tej dziedzinie.

Introduction

Blockchain IT technology was invented over 10 years ago, and since then it has been used in many branches of industry [1]. It is the backbone of cryptocurrencies (such as Bitcoin or Ethereum); however, the application of this technology is not limited to these assets. It is a rapidly growing field with a wide range of potential applications, including in the medical field. The ability to securely and transparently store and share data makes it a promising technology for various applications in medicine. In this article, we will explore the ways in which blockchain technology (BT) is being used in medicine, the potential benefits and challenges of using this technology in healthcare, and the future directions for research in this area.

What is blockchain technology?

BT is a decentralized, digital ledger that records transactions across a network of computers. It uses cryptography to ensure the integrity and security of the data stored on the ledger. A blockchain is composed of a series of blocks, each of which contains a number of transactions. Each block is linked to the block before it, creating a chain of blocks (hence the name "blockchain"). The first block in the chain is called the genesis block. When a new transaction is made, it is broadcast to the network of computers that maintain the blockchain. These computers, called nodes, then verify the transaction using complex mathematical algorithms. Once the transaction is verified, it is added to the next block in the chain. Once a block is added to the blockchain, the data stored in it cannot be altered. This ensures the integrity of the ledger and prevents double-spending. Each block also contains a unique code called a "hash" that links it to the previous block, making it virtually impossible to tamper with or alter the data stored in the blockchain [2].

Blockchains use a consensus mechanism to ensure that all nodes on the network agree on the state of the ledger. The most commonly used consensus mechanism is called "proof of work" (PoW), which requires nodes to solve complex mathematical prob-

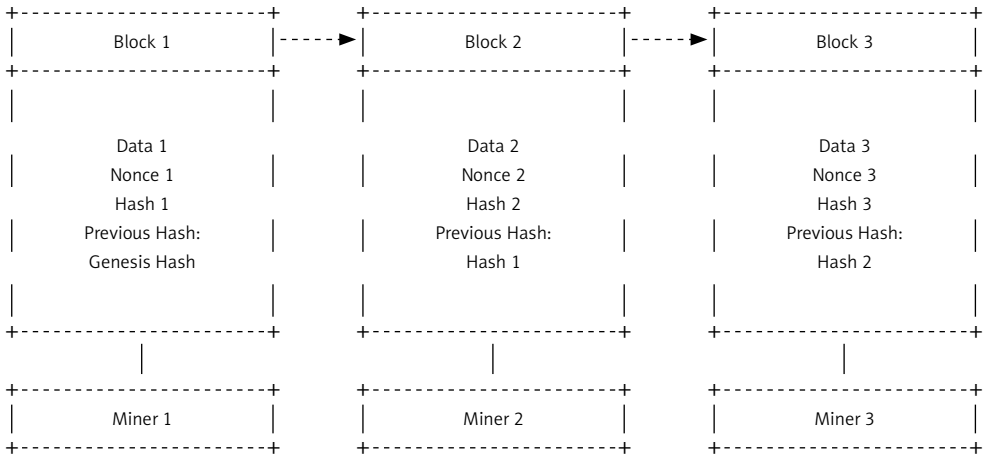

Figure 1. Operation scheme of the PoW Blockchain

lems in order to add a new block to the chain. This is a mechanism invented for the needs of the bitcoin network, and as the network grows, it requires more and more computing power to create a block (the difficulty of mathematical problems is automatically adjusted to the computing power of computers in the network) [1].

Recently, however, the growing popularity of consensus-building is "proof of stake" (PoS). The mechanism is selecting validators in proportion to their quantity of holdings in the associated cryptocurrency [3].

The advantages of this consensus mechanism compared to PoW include increased energy efficiency (environmentally friendly), greater decentralization (no need for high computing power), faster transaction processing and a lower risk of "51% attack", i.e. when a device is connected to a PoW network having 51% of the computing power of the entire system, which could result in the possibility of approving blocks containing false information. We presented the operation scheme of the PoW Blockchain network in Figure 1.

The blockchain begins with block 1, which contains data and a randomly generated nonce and hash. The previous hash is set to a special hash called Genesis, which is determined at the beginning of creating the blockchain and serves as the starting point for all subsequent blocks.

Each subsequent block in the blockchain contains data, a randomly generated nonce and hash, and also the previous hash, which points to the hash of the previous block. This creates a chain of blocks, where each successive block is "secured" by the previous block.

Miners, or nodes in the network, are responsible for verifying transactions and adding new blocks to the blockchain. Miners use computational power to find the correct nonce for each new block. When they find the correct nonce, they add the new block to the blockchain and inform the other nodes in the network [1].

Thus, in the blockchain, each new block is "secured" by the previous block, and the entire chain is secured by hashing algorithms and the difficulty in finding correct nonces. This ensures the security and integrity of the blockchain, as well as enabling safe transactions without the need to trust a single, central entity.

In PoS technology, the process of adding new blocks to the blockchain is different. Instead of using computational power to find the correct nonce, validators are randomly selected to validate transactions and add new blocks. These validators are chosen based on the amount of cryptocurrency they hold and their "stake" in the network. This means that the more cryptocurrency a validator holds, the higher are its chances of being chosen to validate transactions and add new blocks. This process is called "forging" instead of mining, and it consumes significantly less energy than PoW [4].

Features of blockchain technology that can be used in medicine

Blockchain technology has many features that can favor its use outside the world of cryptocurrencies [5]. One of these features is immutability: once a block is added to the blockchain, the information it contains cannot be altered or deleted. This feature makes blockchain technology well suited for use in cases where data integrity and transparency are important. Another is decentralization: BT does not rely on a central authority to validate transactions. Instead, it uses a network of nodes to reach a consensus on the state of the ledger. This feature makes blockchain technology well suited for use in cases where trust and security are important [6].

Interoperability is a feature that allows one to create a network that interferes with other networks (data sharing). Smart contracts is another BT technology that allows for the creation of self-executing contracts with the terms of the agreement written directly into the code. This feature makes blockchain technology well suited for use in cases where automa-

tion and efficiency are important. The last one is security. Blockchain technology uses advanced cryptography to secure transactions and ensure the integrity of data stored on the blockchain. This feature makes blockchain technology well suited for use in cases where security is important, such as healthcare and intellectual property. Below, we will present the areas of medicine in which BT can be used thanks to the above-mentioned features [5, 6].

Blockchain and medical records

One key area where blockchain technology is being used in medicine is in the management of medical records. Traditional medical records systems are often fragmented and difficult to access, making it difficult for healthcare providers to get a complete picture of a patient's health history [7]. Blockchain technology, with its ability to create tamper-proof records, has the potential to revolutionize the way medical records are managed [8–10]. For example, a blockchain-based medical records system could allow patients to control access to their own medical information, and make it easy for healthcare providers to access and share this information when needed. This can increase the patient's control over their own health data and improve the continuity of care [11]. BT has the potential to revolutionize the way medical records are managed and shared among healthcare providers. The technology's ability to securely and transparently store and share data has led to numerous proposals and pilot projects for using blockchain in managing medical records [12]. Examples of such projects include Medicalchain [13] or Avaneer Health [14]. The application in Medicalchain is based on a network where a patient can consult a doctor while sharing their medical data. On the Avaneer network, participants can communicate with each other while remaining in control of their own data. Another approach to creating medical records could be to create for each patient an NFT (non-fungible token) – a unique token that is managed by the patient for their privacy [15]. Additionally, using blockchain technology for medical records can improve data security and protect against breaches and hacking. Blockchain's decentralized architecture and cryptographic techniques make it a secure platform for storing sensitive information [8]. Another potential benefit of using blockchain for medical records is the ability to easily share and access information among healthcare providers. A blockchain-based system could enable authorized healthcare providers to access a patient's medical records in real time, improving the efficiency and coordination of care [16–18]. However, there are also some challenges to using blockchain technology for medical records. One major challenge is the lack of standardization and interoperability among different blockchain-based systems, which can make it difficult for healthcare providers to access and share information across different platforms [19]. Another challenge is the need for a secure and efficient method of identifying and authenticating patients and healthcare providers on the blockchain network [20]. In conclusion, while there are challenges that need to be addressed, the potential benefits of using blockchain technology for medical records management make it a promising area for further research and development. More studies are needed to explore the technical, legal and ethical aspects of using blockchain in the healthcare industry.

Blockchain and drug developments

Blockchain technology has the potential to revolutionize the drug discovery process by improving efficiency and reducing costs. One of its key features, the decentralized and transparent nature of the technology, allows for more efficient sharing of data and resources between researchers and pharmaceutical companies. This can lead to faster and more effective drug development. Additionally, blockchain can improve the accuracy and integrity of data by providing tamper-proof record keeping [21].

One of the problems of clinical trials is the bias of not publishing trials in the case of results that will not meet with interest or their publication is not in the interest of the trial sponsor. If patient results are entered on an ongoing basis in blockchain technology, this ensures full transparency of the database and resistance to any modifications. The database maintained in this way would be publicly available to all interested parties, and the data of successive persons participating in the study would be added in real time. Such a database, due to its decentralization, is also resistant to server or data cloud problems [22].

One example of BT that is created for clinical trials and new drug discovery is Clinical Trials Intelligence built on the Ethereum blockchain [23]. It is a software platform whose goal is to provide the pharmaceutical industry with an entire ecosystem to ensure data analytics functionality, sharing data from other research and ensuring an immutable audit trail based on blockchain technology. A different instance could be a blockchain system that operates across multiple clouds and is intended to make it easier for various institutions to engage in federated data analysis activities [24].

Overall, blockchain technology has the potential to significantly improve the drug discovery process by increasing transparency, reducing costs, and streamlining data sharing. However, it is important to note that blockchain is still a new and rapidly evolving technology and more research is needed to fully realize its potential in the drug discovery field.

Blockchain and supply chains of pharmaceutical products

Blockchain technology has the potential to revolutionize drug supply chains by providing a secure and transparent method for tracking the movement of drugs from manufacturers to patients. Its decentralized nature allows for tamper-proof record keeping, which can increase transparency and reduce the risk of counterfeit drugs. Blockchain can also improve supply chain efficiency by automating the tracking and reporting of drugs throughout the supply chain, which may result in cost reduction [25, 26] and safety of industry [27].

One example of the use of blockchain technology in the discussed issue is the EU-funded innovative research project called PharmaLedger [28]. In this project, information about the package leaflet of a drug is present on the blockchain and updated. The application also provides the possibility of authenticating a given product, which prevents counterfeit drugs. Additionally, it documents the product's supply chain from creation to use, which enables understanding of the geographical demand for a given product and streamlining the delivery process [28].

Another example is the Drug Supply Chain Security Act (DSCSA) implemented by the U.S. Food and Drug Administration (FDA) [29, 30], which requires pharmaceutical companies to track and trace prescription drugs throughout the supply chain. The MediLedger FDA Pilot Project has demonstrated that it is possible to utilize a blockchain-driven solution to adhere to the (DSCSA) guidelines [31, 32].

Overall, blockchain technology has the potential to significantly improve drug supply chains by increasing transparency, reducing costs, and reducing the risk of counterfeit drugs. However, it is important to note that blockchain is still a new and rapidly evolving technology and more research is needed to fully realize its potential in the drug supply chain field.

Blockchain and telemedicine

Blockchain technology has the potential to revolutionize the telemedicine industry by providing secure and transparent patient data management. Its decentralized nature allows for the creation of tamper-proof electronic health records (EHRs) that can be easily shared among healthcare providers. This can improve continuity of care and reduce the risk of medical errors. Additionally, blockchain can facilitate secure and efficient communication between patients and healthcare providers through telemedicine consultations. One example of blockchain technology being used in telemedicine is the MediBloc Project, a platform for creating and managing decentralized EHRs. MediBloc allows patients to control access to their own medical records, which can increase patient engagement and improve data privacy [33]. Another example is "Doc.com" [34] which allows patients to connect with healthcare providers remotely through secure and encrypted video consultations.

BT-based solutions could prove useful in situations where patient isolation is required (such as epidemics), as well as in cases of chronic disease monitoring [35], where health status data (such as continuous glucose monitoring in diabetes) could be stored in a blockchain network and then machine learning algorithms could be adapted to specific clinical situations to adjust treatment (such as insulin dosage).

Blockchain and personalized medicine

Personalized medicine, also known as precision medicine, is an approach to medical treatment that takes into account an individual's specific characteristics, such as genetics, environment, lifestyle, and health history. By considering these factors, personalized medicine seeks to tailor medical care to each patient's unique needs and circumstances, with the goal of improving treatment outcomes and minimizing side effects. This approach represents a shift away from the traditional "one-size-fits-all" approach to medical care [36].

Blockchain can help with personalized medicine in a few ways. One example could be data obtained through wearable devices (such as smart watch-derived data – SWDD). The use of blockchain technology can change the paradigm of data ownership in the case of a person producing SWDD; such data could then be shared with third parties such as scientists or pharmaceutical companies with consent [37]. It can also help with data management of patients. Personalized medicine relies on the collection, analysis, and sharing of large amounts of patient data, including genetic and medical information [38]. On the other hand, smart contracts can be used to automate certain aspects of patient care, such as medication dosages or treatment plans. This can improve efficiency and reduce the risk of errors [39]. Also, the application of blockchain technology in metabolomics and proteomics will enable the creation of transparent and up-to-date databases of new discoveries in this field. On the other hand, proteomics can offer important insights into the unique differences in protein expression and function that contribute to diseases, thus enabling the development of personalized treatments that are customized to meet the specific needs of each patient [40]. Overall, blockchain technology has the potential to transform personalized medicine by improving data management, accuracy, and automation, while also promoting collaboration and innovation in research and development.

Limitations

While blockchain technology has the potential to bring significant benefits to the field of medicine, there are also some limitations to consider. Blockchain technology is still in its early stages, and its scalability

remains a major challenge. Blockchain networks are slow and can only handle a limited number of transactions per second. This could be a significant limitation in medical settings where time is a critical factor [33, 41]. New scalability solutions continue to emerge, such as sharding, which relies on data partitioning, or ZK-rollup, which involves moving most computations off the main chain [42]. The fundamental issue with scalability solutions is that they should not compromise security and decentralization.

Although blockchain is a secure and transparent way to store and share data, there are still concerns about privacy. Medical data are highly sensitive, and patients may be hesitant to share their data on a public blockchain network. There is also a risk of de-anonymization, where an individual's identity could be linked to their medical data. The use of blockchain in medicine raises legal and regulatory concerns, such as data ownership, liability, and informed consent [43–45]. There is also a need for standardization and interoperability between different blockchain networks and medical systems. To effectively use blockchain technology in medicine, healthcare providers and other stakeholders need to have a strong technical understanding of how blockchain works. This could be a barrier to adoption, especially for smaller healthcare providers who may not have the necessary resources or expertise. Overall, while blockchain technology has the potential to revolutionize the field of medicine, its implementation needs to be carefully considered and evaluated to ensure that it meets the unique needs and requirements of the healthcare industry.

Summary

The blockchain technology market has grown dramatically since the creation of the Bitcoin network. Most people associate this technology only with cryptocurrencies and market speculation related to them. Indeed, the Bitcoin network alone in November 2021 reached a capitalization of $ 1.3 trillion dollars. The development of the technology began with the financial markets, but undoubtedly its extrapolation to other branches of life is under way, and medicine will be one of them. The features of BT that stimulate its adaptation in other fields are the same as those that attracted people to use the Bitcoin network: decentralization (which is related to trust), automation, impossibility to change the stored information, audience of data flow and resistance to hacker attacks. In our opinion, this technology combined with artificial intelligence may significantly affect the work of medical staff and patients in the coming years.

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Conflict of interest

The authors declare no conflict of interest.

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