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CURRENT OPINION

Opportunities for Use of Blockchain Technology in Medicine

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Abstract

Blockchain technology is a decentralized database that stores a registry of assets and transactions across a peer-to-peer computer network, which is secured through cryptography, and over time, its history gets locked in blocks of data that are cryptographically linked together and secured. So far, there have been use cases of this technology for cryptocurrencies, digital contracts, financial and public records, and property ownership. It is expected that future uses will expand into medicine, science, education, intellectual property, and supply chain management. Likely applications in the field of medicine could include electronic health records, health insurance, biomedical research, drug supply and procurement processes, and medical education. Utilization of blockchain is not without its weaknesses and currently, this technology is extremely immature and lacks public or even expert knowledge, making it hard to have a clear strategic vision of its true future potential. Presently, there are issues with scalability, security of smart contracts, and user adoption. Nevertheless, with capital investments into blockchain technology projected to reach US$400 million in 2019, health professionals and decision makers should be aware of the transformative potential that blockchain technology offers for healthcare organizations and medical practice.

Key Points for Decision Makers

Blockchain is a new and emerging technology that is currently in its early stages but offers great potential for cost savings in healthcare, while at the same time keeping data secure and accessible.

Projects currently under development include implementation of blockchain in electronic medical records, drug supply chain management, public health, health insurance, and education.

The technology's scalability and data access controls together with the current lack of expert knowledge are important obstacles to overcome for blockchain to revolutionize the practice of medicine.

1 Introduction

There is an ongoing debate among public and professionals alike about Bitcoin, cryptocurrencies, and the potential of this technology to have a revolutionary role in the future of our society. The technology behind Bitcoin and all other cryptocurrencies is called blockchain. In a recent survey conducted by HSBC, 59% of consumers polled have said that they had never heard of blockchain technology. Even if they had heard, 80% said that they do not know or do not understand what it is [1]. There is a visible rise in interest to understand this new technology and this can be demonstrated by Google trends of the search terms 'bitcoin' and 'blockchain', where "blockchain" being a more abstract term significantly lags behind the former in users' search activities [2]. To further analyze awareness of blockchain technology among our population of interest, in 2017, we conducted a paper-based survey among fifth-year students of the Zagreb Medical School, where most surveyed students (75.4%) claimed that they have never heard about blockchain (response rate 49%, from a total of 300 students), with only 3.4% of respondents stating that they were keeping up with the technology. Furthermore, even those students who claimed to know more about blockchain, incorrectly answered survey questions that tested their knowledge of this technology.

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Blockchain is a decentralized database (ledger) that stores a registry of assets and transactions across a peer-to-peer computer network acting as a public registry of ownership and transactions, which is secured through cryptography, and over time, its history gets locked in blocks of data that are then cryptographically linked together and secured. This creates an immutable unforgeable record of all transactions across the network. This record is replicated on every computer that uses the network [3].

Currently, money transfers, stock trades, ownership, and identity are recorded on digital ledgers and require a central authority to verify them to remove uncertainty. In contrast, without the presence of a presiding authority, data could be changed, moved, or deleted (be it money, stocks, or medical information), thus causing the system to become non-functional owing to a lack of trust and increased uncertainty. Institutions (banks, insurance companies, corporations, and governments) have traditionally been entrusted to keep the ledgers updated and secure. Blockchain technology could change this paradigm. There would not necessarily be a need for a central authority to act as an intermediary, as all ownership and transactions could be mathematically verified, approved, stored, and secured on a blockchain and participants in the system would not be able to corrupt or manipulate the ledger. Thus, blockchain-based systems could be much closer to replicating physical transactions as they would eliminate intermediaries. Such systems could also be much cheaper and more streamlined, as they would reduce the need for bureaucratic work. Moreover, because blockchain databases are always online, cryptographically secured, and distributed on every computer using the network, any organization with Internet access would be able to participate.

Financial use for blockchain applications ought to be mentioned first because with Bitcoin, this is currently the main use case for this technology. Bitcoin is a digital currency based on peer-to-peer networking technology and public key (a large numerical value that is used to encrypt data) cryptography. All transactions are anonymous and irrevocable and the usage of a decentralized distributed ledger makes it necessary for all parties to confirm the transactions. Bitcoin was first presented as a theoretical concept in a 2008 paper written by 'Satoshi Nakamoto', and since then has seen a rapid rise in development, adoption, and overall usage as an online transaction currency, reaching an all-time high price of nearly US$20,000 for one Bitcoin in December 2017 [4].

In the Bitcoin protocol, users called 'miners' offer their computing power to verify the blockchain ledger, thus acting as transaction validators, while also simultaneously being incentivized by certain amounts of Bitcoin in exchange for their computing power. Because the distributed ledger in this protocol must be available to all and approved by the majority of users, this could theoretically result in a 51% attack on a blockchain, a situation where a group of transaction validators controls more than 50% of the network's computing power. The attackers would thus gain the ability to reverse transactions, double-spend coins, and halt payments [5]. However, in the case of Bitcoin and similar blockchains, a massive investment in hardware systems would be required to organize such an attack, making any short-term financial gains negligible. Moreover, the resulting blockchain instability could result in the devaluation of the same coins the attackers would try to double spend.

In addition to public blockchains (with Bitcoin being the most representative example), which require no third-party verification, there are other blockchain types that may have even more significance for use in healthcare. With fully private blockchains, write permissions are given only to members of an organization but read permissions can still be public or restricted to some or all participants of the network, thus providing a greater level of privacy. This way, keeping patients' medical records, modifying balances, reverting transactions, and changing the blockchain rules can all be easily achieved by a company or a health organization running their private blockchain. Furthermore, because the validators of a private blockchain are known, there is no risk from 51% attacks [6].

There are also blockchains that fall somewhere in between public and private. These semi-private blockchains are run by a single company or organization, but they grant access to users, typically organizations, that fulfill certain pre-established credentials or criteria [7]. Such systems would be similarly managed to how a company manages its private web applications and their use cases could include: record keeping by government agencies, land titles, public records, healthcare expenditure, and reimbursement data. In the future, these semi-private blockchains could have perhaps the most significant impact on healthcare policy and management.

In her book "*Blockchain, Blueprint for a New Economy*", Melanie Swan defines three phases of blockchain adoption. In her view, we are currently well into the first phase, with online cryptocurrency transactions happening every day. She forecasts that Blockchain 2.0 is not far away with tracking of digital contracts, financial and public records, and property ownership in the blockchain-based systems. However, implementations of this technology go even further. It is expected that Blockchain 3.0 will expand into medicine, science, education, intellectual property, and supply chain applications [8]. There is a rising trend of funding investments into blockchain technology worldwide from year 2014 onwards, thus it is not unreasonable to expect that research of this technology and its reach will continue to expand and even accelerate (Fig. 1).

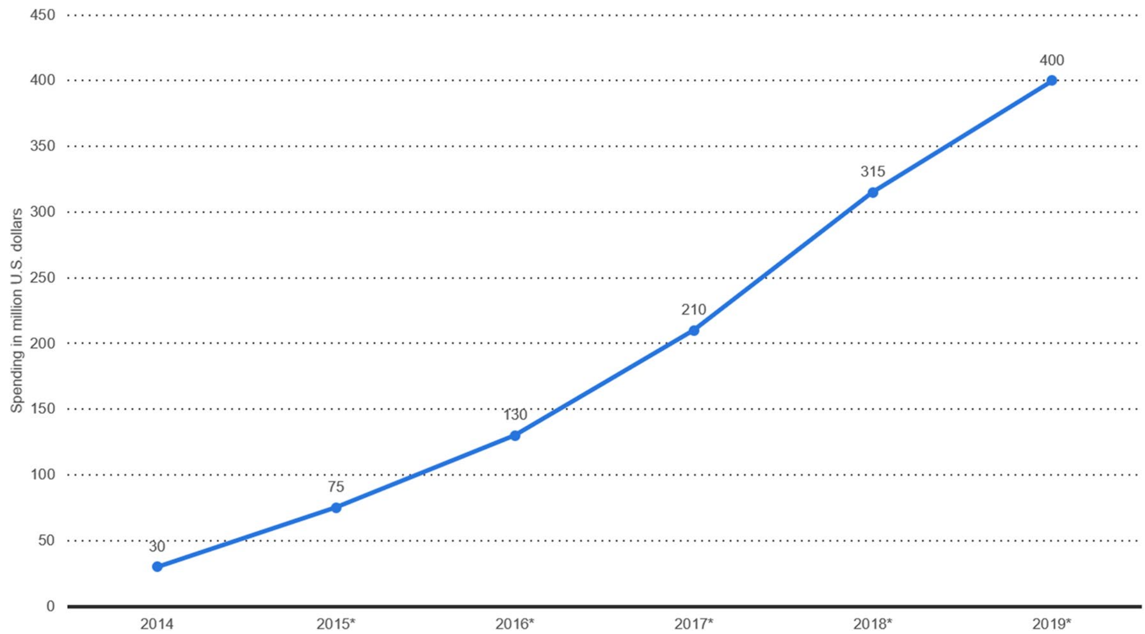

Fig. 1 Capital market investments into blockchain technology worldwide. Asterisk forecasts from 2014 to 2019 (in million US$). Survey period: 2014–15. Publication date: September 2015. Source: statista.com

2 Application of Blockchain Technology in Healthcare

2.1 Electronic Health Records

There are certain strengths of implementation of blockchain technology in healthcare organizations. The most obvious advantage is managing patient electronic medical records. Today, patient information is stored securely in many places, scattered among many institutions, hospitals, and insurance providers, without full access to a shared patient database [9]. Health records stored in a blockchain could allow patients to make their structured data available to researchers, for example in exchange for a determined cryptocurrency fee [8]. Such patient electronic health record databases would make entries tamper proof, while empowering patients to grant access to their electronic health records to third parties at their own will [10]. Moreover, patients would not need to carry a collection of papers containing their medical history and diagnostic procedure results with them every time they seek consultation from a different healthcare provider. Healthcare providers could easily access all the medical data on a patient, regardless of the time and institution in which the healthcare services were performed. Because patients could be involved in the management of their own health records, they would become more engaged with their own healthcare. All of these factors have the potential to reduce storage costs and boost efficiency, possibly by even integrating automatic insurance payment systems by utilizing smart contracts (self-executing contracts with the terms of the agreement between parties directly written into lines of a code) built as a layer upon blockchain [11].

2.2 Public Health

In their survey conducted in 2016 (Fig. 2), Credit Suisse demonstrated that cost savings could be made by hospitals, the pharmaceutical industry, and insurance companies by implementation of blockchain technology [12]. Anonymous and encrypted medical data could be used by the pharmaceutical companies to optimize and boost personalized drug development. Large pools of anonymized patient data could be used to guide public health policies for entire populations and this would permit easier allocation of resources to where they are needed most. Moreover, the Centers for Disease Control and Prevention, the leading national public health institute of USA, is already investigating how blockchain might be used to effectively share medical data between different organizations. In the case of a crisis or pandemic, sensitive personal patient information must be shared with many institutions and time is of the essence. Presently, because many of the processes have to be performed manually, valuable time is unnecessarily lost. Blockchain has the potential to keep the data secure and private, while at the same time allowing healthcare authorities to move it and share it as fast as possible [13].

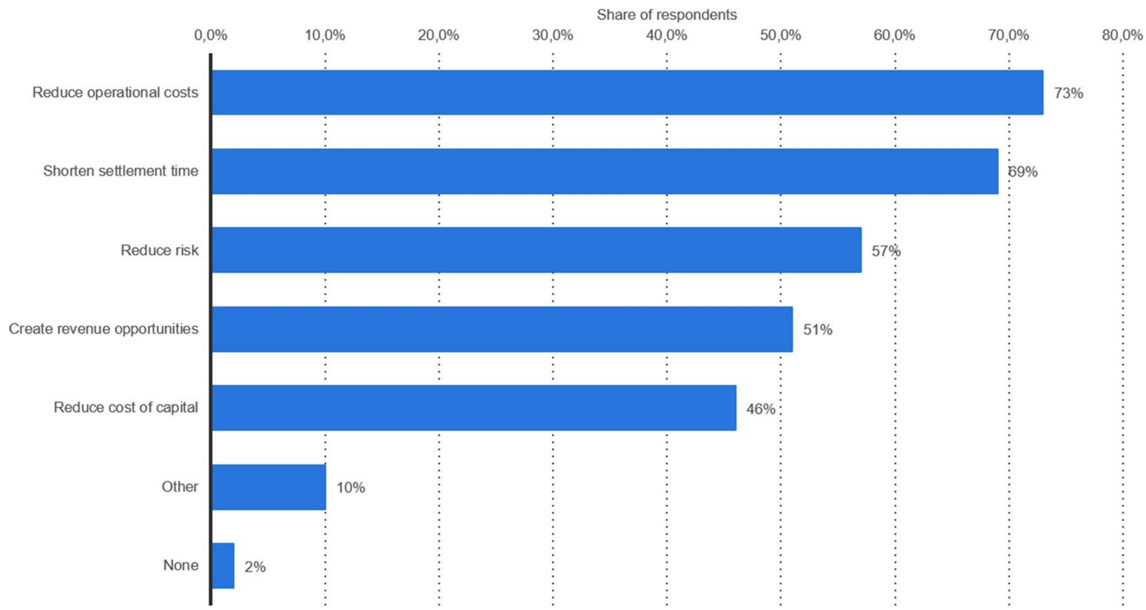

Fig. 2 Leading benefits of blockchain technology worldwide, as of 2016, percent of survey respondents. Survey period: 2016. Publication date: August 2016. Source: statista.com, Greenwich Associates 2016 Blockchain Adoption Study, Credit Suisse research

2.3 Education

Medical education is another field where blockchain introduction could offer benefits. Even before graduation from medical schools, this technology could be used to store and track student achievements throughout the curriculum and document competencies acquired through a range of different clinical settings and specialties, thus acting as a digital record system for every participant. Additionally, because medical education is a process of lifelong learning, records on this digital ledger could continue to grow, archiving every conference attended, every article written, and rates of successful treatment for every patient encountered or procedure performed. Medical practitioners could then decide if they would like to share this information and, in this way, verified certificates and diplomas could be issued more easily, with the process also being more cost effective and tamper proof. Worker mobility would increase greatly, while unnecessary paperwork and approvals would be minimized [14]. The Massachusetts Institute of Technology has already started a pilot program in the summer of 2017 on 111 graduates, which involved issuing digital diplomas to their smartphones (in addition to traditional paper certificates) that they could easily share with anyone—potential employers, friends, and institutions [15].

2.4 Health Insurance and Procurement Policies

Procurement policies are also an aspect of healthcare management that could be considerably improved through blockchain implementation, as this technology would ensure that the supply of goods is transparent, verifiable, and more efficient. All prices, legal tendering requirements, and previous practices by certain suppliers could be easily checked. By introducing smart contracts, transactions could be carried out automatically and over the Internet whenever the prerequisite conditions have been met.

An unchangeable shared ledger is ideal for recording sensitive information, which have a high throughput, typically require an intermediary, and are relatively stable. In a project developed by the Massachusetts Institute of Technology Media Lab and Beth Israel Deaconess Medical Center called MedRec, patients' data remain stored locally, while permissions for data access, data storage location, and audit logs are contained in a blockchain. The project thus enables patients to have control over who can access their data and under what conditions, ensuring more streamlined health insurance and faster and more secure access for participation in biomedical research [16].

Smart contracts are programs that make use of blockchain and cryptocurrency (such as on the Ethereum platform) that execute automatically and independently of their creators and exactly as previously established [17]. In September 2017, a leading French insurance group Axa®, started offering parametric flight delay insurance based on the Ethereum platform called fizzy™, which uses smart contracts connected to global air traffic databases. As soon as a flight delay is detected, a compensation is initiated immediately and securely, thus avoiding the need for additional paperwork [18]. A similar program could be achievable in health insurance, removing the need for verification of medical records and significantly streamlining the process.

2.5 Biomedical Research

Blockchain could help accelerate biomedical research, while also eliminating data falsification, selectivity of reporting, and fabrication, all extensive problems in today's science [19, 20]. Study data would be time stamped and publicly transparent. Even before the beginning of a clinical trial, all plans, consents, protocols, and possible outcomes could be stored on a blockchain. This way, underreporting of undesirable results of the studies would be prevented. Smart contracts could also be used to link together several phases of a clinical trial, thus only if all steps were followed and the methodology used was correctly validated, would the trial progress to the next phase, thereby ensuring transparency and trust in clinical trials [21]. Furthermore, pharmaceutical companies and research institutes could use blockchain stored DNA data to conduct advanced searches to find subjects of interest for potential genomic studies [22, 23].

2.6 Drug Supply Chain Management and Quality Control

Some pharmaceutical companies have already started implementing blockchain in drug supply chain management because counterfeit medicines are a major public health problem and a danger for the safety of patients, particularly in the developing countries [24]. Although the incidence is lower in the developed world, it is estimated that counterfeit drugs cost the European Union pharmaceutical industry around €10.2 billion or 4.4% of sales each year and result in a direct loss of around 40,000 jobs [25]. Additionally, there has been a 400% increase in the number of counterfeit drugs from 2005 to 2010 in Europe alone [26]. Blockchain systems could be used to record the movement of pharmaceuticals and for their authentication throughout the supply chain. Every manufactured item could be marked by a unique code and blockchain could be used to check the authenticity of the code and the product [27]. Publicity of a blockchain ledger would enable everyone to verify if the product identification number is authentic. This could be a large step in an exhausting battle against the easy availability of counterfeit drugs and medical products.

Finally, to provide a better insight into whether blockchain is fit for use in a particular system or environment, Dr. Adrain McCullagh proposed the so-called *FITS model* (an acronym for Fraud, Intermediary, Throughput and Stable data) [28]. First, blockchain is best used if there is a high probability of *fraud* in transactions. While financial and business industries will likely be the first to adopt this technology, healthcare systems and drug supply chains in particular remain vulnerable to fraud and corruption and are thus expected to take advantage of this technology in the near future [29, 30].

Although there is presently very little proof of concept and an obvious lack of literature regarding healthcare use cases of blockchain, there are already several prototypes built by startup companies. One such project, built by Chronicled, Inc. uses near-field communication technology embedded adhesive seals that are verified on a blockchain to ensure product identification. BlockVerify employs similar technology by using blockchain verification tags for anti-counterfeiting purposes [31].

3 Discussion

Utilization of blockchain as it exists today is not without its weaknesses. Currently, the technology is extremely immature and lacks public or even expert knowledge, making it hard to have a clear strategic vision of its potential future uses. Today, there is little proof of concept and few pilot projects and prototypes that demonstrate blockchain feasibility or practical applications. One could foresee performance and expenditure issues emerging in the developing parts of the world. Cost issues could also be present, at least in the very beginning, in the developed parts of the world because the implementation and electricity costs could offset any savings made by reducing the bureaucracy and boosting the efficiency of healthcare, achieved through more efficient time management and personnel costs. However, by decreasing the need for manual documentation processing and through implementation of smart contracts systems, by which only valid insurance claims would be processed and fulfilled, as well as lowering (or preventing) the potential for fraud and corruption, blockchain technology could likely yield significant cost savings within several years of its implementation.

Although Internet access is today considered a human right, even a temporary outage in hospitals or other healthcare institutions utilizing blockchain technology would cause system-wide disruptions [32]. The security of public blockchain technology is primarily based on the fact that all transactions are authentic and leave a trace, but it can be debated whether the patient data are private enough despite encryption because linking enough data together could reveal the owner and their private information. Similarly, the security and availability of today's blockchain networks are also undermined by the fact that some of them have major issues with scalability in relation to the volume of data being processed [33]. For example, the current set-up of the Ethereum blockchain requires that every transaction is verified by every single validator on the network, a fact that makes this network considerably slower depending on the data load. There have been suggestions of possible solutions and some are being currently implemented with an aim of increasing significantly the data throughput and the blockchain's overall capacity [34].

Blockchain technology adoption in healthcare has some specific additional problems concerning the management of large quantities of patient data, should that data be stored on the blockchain itself. To operate flawlessly, such a system would require a significant amount of resources and computing power. There is, however, a possibility of storing the encrypted patient data 'off-chain', while the information about that data and its accessibility are both stored on the blockchain. In such a scenario, it is debatable whether the blockchain is even needed if its implementation is based on an off-chain data storage solution. The reason for that is the fact that most of the guarantees for durability and immutability of blockchain stored data are lost with this approach, as the data are stored in a traditional manner. However, there are still benefits that remain despite all the mentioned constraints, with the main benefit being easy interoperability and the possibility of sharing the data between different healthcare stakeholders.

Technical complexity of cryptography is also something to be mindful of because it may have negative effects on the adoption of this technology. Elderly patients have problems navigating the healthcare system even today, thus to ask them to participate in managing their own medical health records is likely not going to be met with a large amount of enthusiasm [35].

Threats facing the blockchain technology are a world of unknowns, thus most cannot now even be predicted. One of the predictable threats is certainly the privacy concern, which is associated with a risk of unauthorized access to the data, either by the government or any profit-oriented entity (hackers, organized crime, businesses). This risk is real because an extremely large database of personal and medical data could rely on blockchain technology. It is estimated that on the Ethereum blockchain network, over a million of smart contracts currently carry more than $US3.2 billion worth of value and there have been so far several hacker attacks and software bugs causing significant financial losses. For example, in November 2017, $US150 million became inaccessible to users of the service Parity, as a result of poor coding in the underlying smart contract [36–38]. Such problems could be mitigated by greater dedication to software quality, security, and truthful public communication about the advantages of blockchain systems. It will also depend on the motivation of software companies to invest in rigorous blockchain development and to prove the soundness, scalability, and security of the underlying technology. As blockchain data can only be accessed by means of a private key, there is also a real threat of compromising personal keys and unauthorized access. Central national or international authorities in cases like these would be necessary, which in a way would increase the risk of a security breach by providing third-party institutions with sensitive information from the start. Regardless, any incidents must be detected and resolved quickly, and controls should be put in place to slow, stop, or reverse the execution of consequent fraudulent transactions or data transfers. There also should be a means of obtaining a proof of identity in a reasonable time. None of these measures currently exist. In addition, even if all security measures are in place and transactions are invalidated, the data that were breached once would remain available publicly forever. Private or semi-private blockchains could mitigate this risk to a certain degree.

Finally, encryption keys in blockchain use cases are beyond important. Migrating to such a system would demand increased patient and staff education about this vital use prerequisite. Even today, 25 years after the Internet became mainstream, many people are still struggling with realizing the importance of the use of a strong password, their memorization, and safekeeping.

4 Conclusion

Although blockchain technology is certainly in its infancy, we are already seeing progress regarding its implementation in everyday life, particularly in banking and financial industries. There are many important obstacles to overcome for blockchain to reach its full potential and be applied in healthcare, the most important issues being the technology's scalability and data access controls. Some of the greatest advantages that application of this technology in healthcare could bring are access to a large pool of anonymized healthcare data that could be used for personalized drug development, rationalization of healthcare and health insurance costs, as well as improvement of public health policies. In addition, private health information could be in patients' hands, empowering them to be in control of what information institutions receive and keep, under what circumstances, and for how long. Together with data availability about healthcare providers, this type of patient involvement could bring forth a new era in healthcare.

For this technology to move forward and fulfill the mentioned expectations of Swan's Blockchain 3.0, many more production deployments, detailed proof-of-concept applications, as well as research articles focused on the technical benefits and limitations of blockchain technology should appear. Currently, the technology is not ready for broad-spectrum implementation and many of the potential projects are perhaps waiting for the foundation and infrastructure to be reliable with most of the basic problems solved. However, if in the following years these difficulties are overcome, we believe that new concepts, use cases, and monetary interests by many stakeholders will arise even more rapidly than today.

In conclusion, the academic literature is still considerably deficient regarding potential blockchain uses in healthcare systems. Health professionals and decision makers should become aware of the transformative potential that this technology presents for the practice of medicine.

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Compliance with ethical standards

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