Utilisation of Blockchain Technology for Better Health Outcomes during COVID-19

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Blockchain holds immense potential in the field of healthcare as it can make decrease costs, mitigate inefficient practices and prevent patient data breaches. A blockchain is a continuous digital record of transactions that are anonymous to third party users and can be stored on multiple devices. If implemented in the healthcare sector, blockchains can improve outcomes of activities such as infection control and prevention for better management during a pandemic, and also for safer storage of patient data and electronic health records. The use of this technology can help in sharing cryptographically secured data between multiple users for better data assimilation between multiple organisations, especially during COVID-19. Moreover, this technological innovation can provide affordable patient-centred outcomes by sharing clinical data for the development of precision medicine. Apart from medical data management, it can also be used in drug development and clinical trials by making each step more reliable through time-stamping and recording all data inputs. Blockchain can also help keep a record to supply chain operations within hospitals and maintain records of medical equipment, drugs and other necessary stocks. Although blockchain is a promising technological advancement, it may still face several challenges, especially in low and middle-income countries. The usage of an internet source is essential for this advancement and it will take time for all healthcare bodies to transition to this technology by leaving paper-based data record-keeping approaches.

Keywords: Blockchain, Bitcoin, Cryptocurrency.

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1 Introduction

Blockchain has emerged as one of the most promising technological innovations since its conception in 2008 by Satoshi Nakamoto in white paper (Wright et al. 2019). It can be defined as a shared, decentralised, immutable ledger that stores and records information of transactions across the entire network of computer systems associated with blockchain. Blockchain 1.0, the very first generation of this piece of technology was exclusively used in the financial technology sector to store and protect information about digital transactions, and also in cryptocurrency (Wright 2019). The conception of Bitcoin is one of the most recognisable uses of Blockchain 1.0. Further development of this technology led to Blockchain 2.0, which is digitally used to negotiate contractual terms between parties involved. Thus, Blockchain 2.0 is also identified as a blockchain-based smart contract or just referred to as a "smart contract" (Hu et al. 2018). Currently, Blockchain 3.0 allows further applications in fields apart from finance, such as healthcare, government affairs and the energy sector (Condruz-Bacescu 2019).

Blockchain can be thought of as a network of blocks across the internet that holds the data of transaction records that occurred within the network. A block is made of a head and a body wherein, the head carries the hash of the previous block. The head consists of a timestamp to show the time of the block's publication, a nonce which is an arbitrary number used by miners to change hash values, and a Merkle tree to reduce the effort needed to scrutinise transactions inside a block (Ben Fekih and Lahami et al. 2020). Hence, the blocks form a series of interconnected chains, thereby, deriving the name "blockchain".

This technological advancement has been greatly beneficial in healthcare especially due to the current novel Coronavirus 2019 (COVID-19) outbreak. This pandemic exposed faults in the health systems of countries worldwide and also emphasised the importance of innovation in the healthcare sector. Blockchain's decentralised, tamperproof platforms ensure the protection of medical data, meticulous tracking of fundraising activities and donations, the expedition of clinical trials and drug-safety processes, and patient-data confidentiality (Marbouh et al. 2020). Modification of data in a blockchain is tedious and implausible because modifications in the current hash would automatically generate changes in the other hashes; members of the network would be alerted and therefore, manipulation or deletion of data is not feasible due to the technology's transparent and digitally cohesive nature.

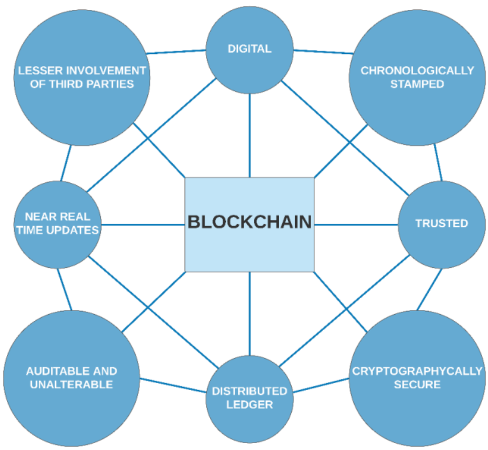

Fig. 1. Key features of Blockchain (Figure designed by author)

In order to tackle the spread of COVID-19, the most immediate steps taken by the Government officials in most countries were social distancing and contact tracing. Case studies and interventions on previous viral outbreaks such as; Ebola virus disease (EVD), severe acute respiratory syndrome (SARS) and the H1N1 influenza pandemic. Blockchain technology is instrumental in combating COVID-19 because it can help keep track of vaccine supply chains, aid in performing contact tracing operations, maintain patient data through electronic health records (EHR) and also allow remote patient monitoring.

2 COVID-19 and Digital Health

Since its first case in late 2019, the severe acute respiratory coronavirus 2 (SARS-CoV-2) has proliferated globally at an unprecedented rate and challenged the capabilities of health systems in most countries. Many unprecedented disruptions due to strict lockdowns travel bans and unexpected health needs have disturbed global economies and healthcare supply chains. However, many governments were forced to ease restrictions to prevent economic downfall, and also to cater to population needs. COVID-19 has caused both direct and indirect complications in health and healthcare. The direct effects include and are not restricted to loss of life, overburdened hospitals, unsafe work conditions and also lack of trust in health systems and administrations in certain countries. Indirectly, the pandemic has increased the risk of mental health conditions among the population, increased socioeconomic gaps in societies and countries, and also decreased doctor-patient interactions due to lockdowns (Kaczorowski and Grande 2021; D. V Gunasekeran et al. 2021).

The pandemic has led current patients in healthcare systems to opt for other modes of consultations to reduce face-to-face clinical appointments. Moreover, since hospitals and other care systems can also serve as potential hotspots for infection transmission, non-urgent appointments, and elective surgeries were postponed, and infection control measures were set up instead (D. V Gunasekeran et al. 2021). Furthermore, healthcare-related workflows and manpower had to be channelised in regions with severe local outbreaks and to also cater to quarantined travellers in hotels or isolation wards (Li et al. 2020; Health, Sinai, and Permanente et al. 2020).

To increase access to healthcare services, improve population health outcomes and strengthen healthcare delivery, many intra and inter-governmental organisations such as the World Health Organization have urged member states to tap into the potential of digital health (Tuckson et al. 2017; Hong et al. 2020; Mann et al. 2020). Incorporation of technological solutions such as artificial intelligence (AI), and machine learning with the support of blockchain, big data and the internet of things (IoT) in healthcare can make efficiently address healthcare challenges, exacerbated by the pandemic (Xie et al. 2010; Hiebert and Werner 2018; D. V. Gunasekeran and Wong et al. 2020). Given the ubiquitous nature of the internet in developed countries, most of the digital health technologies are heterogeneous, and can easily be inculcated into the healthcare systems of high-income countries. For instance, contact tracing during COVID-19 and previous viral outbreaks such as EVD solve two super imposable issues: prevention of the disease, and surveillance of the same. The use of digital health with emphasis on blockchain technology can be implemented in many stages of healthcare ranging from diagnosis to patient engagement.

2.1 Diagnosis

The use of digital innovations to tackle COVID-19 has been actively endorsed by the WHO in order to curb human-centric requirements and channelise resources in a better manner. Many studies have suggested the use of AI-powered tools and applications to screen for COVID-19(Zheng et al. 2020; Buchanan et al. 2020; Shu et al. 2020; Yan et al. 2020).Further studies had also supported the use of blockchain for COVID-19 diagnosis. A low-cost AI-supplemented blockchain application was developed for efficient self-testing and tracking of coronavirus cases and other viral outbreaks in low and middle-income countries (LMICs)(Mashamba-thompson and Crayton 2020). The application requests for the person's identification documents (ID) prior to testing. The user then proceeds to upload results onto the application after testing which is then encrypted onto the blockchain system to enable the transfer of information across the network and alert the needful in case of an outbreak.

2.2 Treatment and Follow-up

To increase resilience and support for patient treatment and support, consultations through telehealth and telemedicine are used (Torous et al. 2020). Telehealth has been further extended to deliver mental health care and interventions through AI-powered tools for continuous follow-up. Steps such as social distancing and lockdowns have exacerbated the mental health conditions of many, especially groups of people who are considered vulnerable. The feasibility of scalability of these interventions is relatively easy in high-income countries when compared to LMICs. Resources such as internet networks or mobile phones are not easily accessible to everyone in developing countries and with an increased socio-economic gap, having access to them is considered a privilege. Moreover, there is an absence of concrete policies and regulations in place to track and monitor patients using e-health. However, blockchain is a promising technology and holds the potential to expedite and revolutionise steps in healthcare systems, especially for the treatment and follow-up of patients.

2.3 Surveillance

Surveillance using mobile applications has been previously implemented in many outbreaks such as the EVD epidemic in African countries such as Sierra Leone (Danquah et al. 2019; Maganga et al. 2014). Surveillance for contacttracing using mobile applications is common practice during viral epidemics including COVID-19. Digital contact tracing eliminates manual efforts and risks among workers. It is also an economically feasible option because it removes the operations and logistics behind travelling, sourcing of paper, and has the potential to reach niche areas. The most efficient approach for digital contact tracing applications has been blockchain technology; it is a secure source of data transactions and can be implemented across various steps in surveillance (Idrees, Nowostawski, and Jameel et al. 2021). Risks associated with privacy and confidentiality is eradicated because the identity and medical information pertaining to the user remains anonymous. Data integrity is upheld because of hash encryptions along each intertwined chain, while data immutability and time stamping ensures ease in retrieval of information pertaining to the virus or data in an accurate and transparent manner. Smart contact-tracing and surveillance was implemented almost immediately in Wuhan's Hubei Province, the epicentre of COVID-19 to monitor movement and also track contacts of those at risk of upto the third degree using blockchain and big data (Hua and Shaw 2020). Similar surveillance methods using blockchain were implemented in the United Kingdom (UK) through the National Health Service (NHS) application and also in Taiwan (Peek, Sujan, and Scott 2020; Wang et al. 2021). Citizens and travellers in these countries are required to download the necessary application, input their details and also if they have contracted COVID-19 in the past. This allows for effective data management and the safety of citizens.

2.4 Patient Engagement

The pandemic has increased loneliness, stress and many eating, and mental health conditions among people (Pearman et al. 2021). Elderly patients also suffer from comorbidities such as cardiovascular diseases, respiratory illnesses, and are often frail from lack of exercise (Arradelles and Apiol et al.

2017). Such patients require regular monitoring and engagement to discuss a plethora of factors including lifestyle, environment and medical conditions. COVID-19 has made it challenging for doctors to have face-to-face consultations with their patients owing to the risk of infection. Therefore, e-health has played a crucial role in mitigating such difficulties by having video calls with their patients, and also by having AI and machine-learning powered applications to keep track of all information in the system's medical record.

3 Architecture of Blockchain

First described back in 1991, the term "blockchain" was used by a group of researchers to design a tool for attaching digital timestamps on documents to prevent modification of the same. The term truly gained recognition in 2008 when Satoshi Nakamoto created the first cryptocurrency- Bitcoin and listed it on white paper. Blockchain technology holds three core tenets: security, accountability and decentralisation. When used for large scale operations, this piece of technology is also cost-efficient and optimises operations across many industries including healthcare.

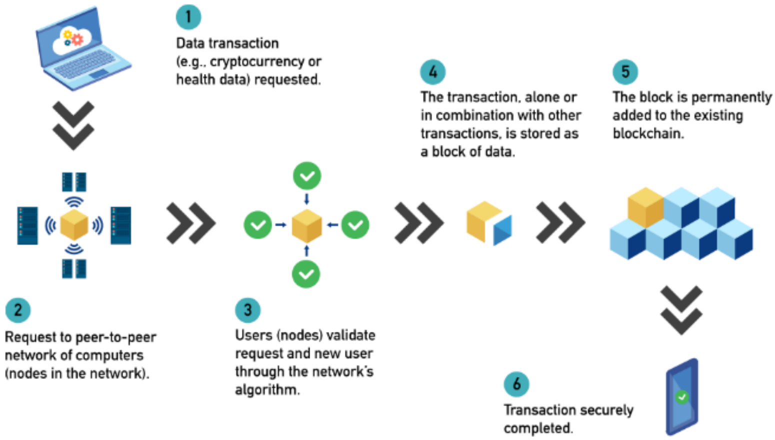

Fig. 2. Overview of Blockchain (Adapted from Vervoort, Guetter, and Peters et al. 2021)

A blockchain is essentially a sequence of blocks that contain specific information stored in a database that is accessible by a group of users within that network. The information stored within this peer-to-peer network is secure, unmodifiable and cryptographically encrypted. Therefore, one member of that network will not be able to modify information without alerting other members since it is decentralised. Therefore, blockchain is a public ledger that consists of a sequence of blocks that are chained together to hold information on transaction records within that network. A transaction within the blockchain system can be defined as the smallest building block within which records, information etc are stored. A block is a data structure that keeps track of transactions within the network that are distributed through nodes. A node can be assumed as a user or a computer within the network that holds an independent copy of the blockchain ledger.

Each block has a header and body in which, the header of each block is linked to the hash of the previous block. Hence, the blocks form a linked chain wherein each block is dependent on the previous one. A hash is a long identification record that consists of letters and numbers, which are unique. The generation of each block hash takes place with the help of a cryptographic hash algorithm. Upon the creation of a new block, a hash is automatically added to it. Any changes made in the hash would affect the block and therefore, hash helps to identify blocks within the structure with accuracy. To indicate the block's time of publishing, block heads contain timestamps. They also contain a nonce, which an arbitrary number is used by miners to regularly change hash values within blocks to work on a mathematical puzzle. Miners are specific nodes that are used for performing block verification prior to their addition to the blockchain structure in order to arrange the blocks into a chain in a specified order. Headers also contain a Merkle tree to reduce the effort needed to verify transactions inside a block. Blockchain transactions are small units of tasks that are stored in public blocks, and scrutinised by most of the network's participants through consensus. Consensus protocol is a set of arrangements and rules to perform blockchain operations. Since all transactions occur within the network and the ledger's copy is maintained by all participants, blockchains are immutable and tamperproof (Ben Fekih and Lahami et al. 2020). Since the ledger is available and accessible to all, blockchain is highly decentralised with each user within the network remaining anonymous. Despite the blockchain type, smart contracts are used for encoding business logic, and self-executing codes within the framework allow processing in a simple manner.

3.1 Types of Blockchain Systems

At present, there are four types of blockchain systems: private, public, hybrid and consortium blockchains (Ray, Dash, and De et al .2020).

- **Private blockchains:** Implemented by single businesses, private blockchains are used as digital solutions to monitor data exchanges between different stakeholders within the company, departments, or even individuals. Upon joining the network after expressing consent, the identity of the members is known in this case.
- **Public blockchains:** Public blockchains on the other hand are completely decentralised wherein, each member in the network has access to everything on the ledger and can also participate in the consensus process.
- **Hybrid blockchains:** A hybrid blockchain is an amalgamation of separate benefits offered by both public and private blockchain systems. The private blockchain runs in the background to monitor and restrict access to the ledger while the public blockchain system runs in the foreground to make the ledger transparent and accessible to other members of the network.
- **Consortium blockchain:** As the name suggests, consortium blockchains are carefully scrutinised networks that are made privy only to certain privileged groups. It is mainly used for conducting audits and also helps in supervising the exchange of information within the database that is synchronised regularly.

4 Uses of Blockchain in Healthcare to Tackle COVID-19

Governments and international organisations are currently spending exorbitant amounts to mitigate further spread of the pandemic by buying vaccines, medical equipment, and restructuring national budgets and expenditure for redirecting it towards healthcare. Additionally, this global threat has made countries realise the importance of data sharing for researchers, policymakers, and other healthcare professionals to design and implement necessary outbreak control strategies (Modjarrad et al. 2016; Whitty et al. 2015).Data sharing is a key tool to keep all stakeholders on the same page and will work only if everyone including citizens understands the concept. Acceptance, understanding and adoption of data sharing are required by citizens for it to work as a credible infection control measure. Key concerns such as accountability, transparency and data access are just some of the concerns that can be voiced by citizens but other concerns such as integrity, confidentiality and other non-functional requirements can be quite challenging for many to comprehend, especially in LMICs (Harst et al. 2020). Citizens primarily rely on the government, reputed journals and print media for information pertaining to COVID-19. Therefore, primary information providers can also educate people about potential interventions, innovations and technological advancements such as blockchain being inculcated in healthcare. Blockchain has many uses in healthcare and COVID-19 has forced national and international health systems and bodies to look at digital tools to decrease reliability on human capital and instead redirect them to work on the frontlines or in community hotspots.

4.1Vaccine passports

Vaccines for COVID-19 were developed in a relatively short time with not much clinical evidence for efficacy still being questionable for some vaccines. Moreover, the world is yet to see the long-term efficacy and study the short-time effects of these vaccines on the body based on real-world evidence (RWE). At the same time, vaccination is also the best step for achieving herd immunity and therefore, reducing the spread of COVID-19(Brown et al. 2021). Therefore, to record contacts, vaccinations status and other relevant medical information, vaccine passports and digital contact tracing applications should be used. Scientific concerns such as limited protection for upper respiratory tract infections when compared to lower respiratory tract infections have been observed from clinical studies (Krammer et al. 2020). On the ethical front, lack of information, vaccine hesitancy and discrimination, and also concerns over privacy have been observed. With the advent of technologies such as blockchain, many of these concerns are eliminated. Moreover, the rollout of vaccines is much more cost-effective, secure and transparent when conveyed to the traditional pen-paper vaccine passports with mobile phones being a ubiquitous resource in developed countries (Mehl, Labrique et al. 2014). Many countries such as Australia had switched to digital contact-tracing applications such as COVID Safe, to trace cases and contracts, and notify people if they have come in contact with those infected by COVID-19 (Thomas et al. 2020). Currently, as most countries are actively aiming to vaccinate citizens swiftly and efficiently, vaccine transports using blockchain can be used for monitoring their status, side effects and other health data while also safeguarding their privacy (Osama, Razai, and Majeed et al. 2021). Moreover, blockchain can also be a crucial tool to share data with many intergovernmental organisations for health data monitoring and management for the formulation of strategies and interventions to tackle coronavirus. Ideally, vaccine passport stores information pertaining to one’s health status, health conditions and risk factors, places of visit, previous records of coronavirus infections and symptoms, and also vaccination status. Upon receiving the vaccine doses, the date, time, location, immediate side effects and the choice of vaccination are also recorded. These pieces of information are useful to understand the efficacy and risk factors associated with vaccines for certain age groups.

4.2 Pharmaceutical Supply Chains

The global vaccine supply chain has been implemented by the WHO through the COVAX programme to ensure equitable distribution of vaccines across countries worldwide. However, within the pharmaceutical industry, there is often a risk of shortage or counterfeit medications in countries worldwide, and this can lead to adverse outcomes for patients. Additionally, many vaccines such as Pfizer and Moderna require cryogenic storage to maintain their efficacy. Therefore, blockchain addresses this problem by verifying compliance with temperature requirements through quality control measures during transportation and storage (Bocek et al. 2017). Blockchain also eliminates corruption within the pharmaceutical industry by safeguarding data pertaining to branded, generic and counterfeit drugs and vaccines by maintaining a secure, traceable and immutable network (Bryatov and Borodinov et al. 2019; Raj et al. 2020). Blockchain can be further used to solve problems associated with drug regulation and standardisation through data sharing.

4.3 Electronic health records (EHRs)

Although EHRs have observed a 46% growth in the past 5 years and even more so due to the pandemic, concerns over data protection are still rampant because many industries still store primary data in content management systems (Roehrs, André, and Righi et al. 2017). Blockchain is an urgent and optimal solution to address concerns over data protection while sharing within a certain network. EHRs collect data on the total health of patients, which goes beyond standard clinical data collected by the provider, and therefore, gives an overall picture of the patient's health (Ben Fekih and Lahami et al. 2020). Blockchain helps in managing EHRs through various applications and software packages. An application called "MedRec" uses blockchain to maintain EHRs by decentralising information and keeps all necessary stakeholders updated with data that is obtained from patients. It uses Ethereum- a blockchain platform to sensitise all patients on information about health and healthcare (Ben Fekih and Lahami et al. 2020). Another similar blockchain application that is used in HER is FHIRChain (Fast Health Interoperability Records + Blockchain)(Zhang et al. 2018). This too uses the Ethereum platform for keeping track of clinical data for efficient healthcare record management while the FHIRChain helps meet patient expectations based on the advice of providers. Lastly, another Ethereum-based platform for companies that struggle to effectively collaborate for data sharing due to its sensitive nature is MedShare(Xia et al. 2017). It aids the network by conducting regular audits, governing data and also provides cloud services between large conglomerates for sharing data. Blockchain holds heavy potential and promise for safeguarding data by increasing security, efficiency and interoperability within large ecosystems for transferring and receiving data, especially during COVID-19 between large biopharmaceutical companies and also between countries and intergovernmental organisations. It also provides the opportunity to collect and store data remotely and also communicate findings between relevant parties without breach of privacy.

4.4 Remote monitoring of patients

Remote patient monitoring involves the collection of patient data through mobile phones and other devices using IoT and blockchain. After data collection, storage, retrieval and sharing across networks is performed by blockchain. Ethereum is used in remote patient monitoring as well wherein interventions are suggested based on real-time monitoring of patients (Griggs et al. 2021). Another application, IoBHealth combines IoT and blockchain to access, manage and store patient data obtained from remote consultations and applications (Ray, Dash, and De et al. 2020). Since vulnerable groups such as the elderly, pregnant women or immunodeficient individuals are at high risk of contracting COVID-19, remote patient monitoring of their health status for their safety is crucial. It prevents the risk of travel, infection and is also an economical option for many since sometimes, people tend to travel great distances to meet their healthcare providers. Lastly, the use of blockchain can also be used in health and healthcare insurance claims. MIStore is a blockchain-based insurance system that ensures secure encryption and immutability of medical insurance data (Zhou, Wang, and Sun et al. 2018)

5 Opportunities and Challenges in the Implementation of Blockchain in Healthcare During COVID-19

5.1 Opportunities

Blockchain is certainly an important technological advancement because it expedites many steps in the healthcare provision system, helps redirect the workforce especially during COVID-19, helps keep track of patients remotely and also provides safety, transparency and immutability to data stored in the interface. However, there are a few shortcomings associated with the implementation of the same. For instance, the internet and mobile phones are not ubiquitous resources in LMICs. Moreover, the scalability and feasibility of blockchain in those countries would be challenging because healthcare providers and patients are still accustomed to practising and receiving health services through conventional methods. Therefore, a plethora of considerations needs to be taken into account for researchers, policymakers and healthcare leaders to make better decisions pertaining to blockchain and how it can be used to combat COVID-19.

5.1.1. Feasibility in Research and Practice

The practical uses of blockchain in healthcare are many, especially when used for tackling problems associated with COVID-19. In order to further decrease rates of infection and also help those who have been severely affected by the pandemic, blockchain can be scaled up and implemented in other sectors such as online education, food security and disaster relief, contactless food delivery, management of resources in manufacturing, agriculture and fast-moving consumer goods (FMCGs), and also for tracking donations in non-governmental organisations (NGOs). Although blockchain can store, access and protect data of patient records, drugs and vaccines associated with COVID-19, it can perform more functions such as predicting future outbreaks, analysing infection rates, and monitoring patient safety in infection hotspots with the help of AI and machine learning. It can help in understanding the local and national epidemiology of the disease better in countries so that health ministry's can take appropriate steps incase of subsequent waves of the pandemic. These robust approaches can and should be implemented for countries and even the world as it prepares itself for a potential third-wave. Technical and technological literacy also plays a vital role in the rollout of blockchain-based applications for combating the pandemic. For optimal and successful switch to digital health and blockchain-supplemented applications, clinical and non-clinical staff, researchers and policymakers across intergovernmental organisations and think-tanks must understand the functioning of this piece of technology. Additionally, opinions associated with the volatile nature of bitcoins and therefore by extension, blockchain as well need to be corrected to have an open mind about the same (Abd-alrazaq et al. 2020).

There are differences between public and private blockchain systems and these differences further extend to factors such as performance, cost, and data privacy. Depending on the type of blockchain, health systems ought to carefully monitor and manage their transactions by reinforcing blockchain with IoT (Mhaisen et al. 2020). As mentioned earlier, blockchain-driven applications serve as excellent candidates for contacttracing and are hugely beneficial for health outreach workers, healthcare providers and other important stakeholders. Although this innovation can solve plenty of healthcare problems faced by COVID-19, relevant researchers, policymakers and advisers should still run a risk management analysis on blockchain applications to be better understood the intricacies associated with it and also to make better decisions.

Blockchain may be economical and affordable, there are, however, a few costs associated with its operations as well. Firstly, stakeholders in the network must pay a "gas fee" for the smooth operation of the system. Every code in the application's back-end requires a particular amount of gas for execution. The unit of gas required for each transaction is measured by the Ethereum gas unit (Abd-alrazaq et al. 2020). Gas transaction costs are of two types: execution cost is the first and is associated with costs associated with the change of state in the internal storage and contract. The second is called transaction costs which break down the cost for sending and receiving data for input cost and contract deployment. As the gas price increases, the rate of each block for adding transaction information also increases. As of 2020, the average gas price is equal to 6 Gwei per transaction (Nguyen et al. 2020).

5.1.2. Security

Blockchain guarantees integrity and ensures data protection through crypto graphical encryptions. Information once updated on a blockchain cannot be amended before notifying all stakeholders within that network. Therefore, all patient records are protected and cannot be modified for selfish purposes such as underplaying morbidity rates, ruling other causes of death instead and upholding accountability. Since every stakeholder and member of the network across the ledger is accountable for their actions, data modification and deletion cannot take place because they can be traced back to the node, or the stakeholder's address. Each block within the blockchain infrastructure gets completely encrypted before its addition. Therefore, a hacker would not be able to access and retrieve information due to a block's end-to-end encryption with its previous and subsequent hash. Therefore, all countries should adapt to using algorithms in blockchain for providing privacy to confidential and sensitive data. In order to decrypt and read data, only certain authorised and erudite personnel can access and modify them using "keys" associated with the block. Since all digital transactions in the blockchain network are timestamped and signed, organisations or users would be able to track a modification in the system and find the user based on their public node address. Therefore, one cannot duplicate and delete data without getting caught. Therefore, the blockchain network's ability to self-audit and regulate information ensures credibility and transparency. Lastly, blockchain networks are mostly immune to cyber attacks simply because an attempt at the same would be long, costly and futile for the hacker. For the attacker to access information, they would have to strategically transact large pieces of small transactions to gain control of the network. However, due to the network's decentralised architecture and robust consensus algorithms, its cyber defence is top-notch.

5.2 Challenges

Although blockchain is a promising technological innovation, there are, however, a few challenges associated with it especially while combating outbreaks such as COVID-19. Computer scientists and engineers with specialisations in cybersecurity, application development, finance and business development are required for building blockchain platforms. Large information technology (IT) conglomerates such as IBM are working towards building a skilled blockchain workforce and bridging the gap between supply and demand by providing training, conducting workshops and facilitating online courses (Guimarãesa et al. 2020).

5.2.1 Data Privacy and Mining Concerns

Although difficult, blockchain technology can be exposed to data breaches since the entire network is transparent and decentralised, and all public keys are known by all members of the network. However, this problem can be solved by amalgamating two approaches: mixing solution and anonymous solution (Angelopoulos, Damianou, and Katos, et al. 2020). In anonymous service, transaction graph analysis is prevented by unlinking payments origins for transactions while in mixing service, multiple input addresses are made anonymous to multiple output addresses while transferring funds (Angelopoulos, Damianou, and Katos, et al. 2020).

Another issue faced by blockchain networks is selfish mining because even the creation of a small set of hashes is sufficient to dupe the network. These miners create private chains which are longer in length than public chains by creating private branches without broadcasting them(Abd-alrazaq et al. 2020). Selfish miners mint more in revenue because host miners spend time and resources building futile chains. In order to combat this problem, a built-in scheme allocates a particular time interval by which each block must be created and accepted.

5.2.2 Scalability and Legality

If the number of transactions in a blockchain network increases, there is an automatic increase of traffic in the network and hence, become bulky since each node can also store and accept a certain number of transactions with limited block size and a specific time interval. Every day, there is only an increase in transactions and are monitored real-time. Therefore, certain transactions can be delayed, especially if they are small because miners would opt for transactions with higher fees (Abd-alrazaq et al. 2020).To tackle this problem, VerSum as a solution can be used where expensive computations with large input data are subcontracted by clients with small transactions, and the results are then run over multiple servers to verify individual results (Hooff, Kaashoek, and Zeldovich et al. 2014).

Using blockchain for tackling healthcare problems associated with COVID-19 raises many legal concerns because laws and policies related to database management, distribution, privacy and decentralisation differ from country to country and organisation to organisation. Many laws and policies need to be resolved and many stakeholders associated with these decisions must reach a consensus in order for introducing regulations in digital health services, data sharing and mining, and also in health policy. They must also accommodate the fact that LMICs are not as digitally advanced as high-income countries, and should make appropriate policies.

6 Discussion and Conclusion

There are a plethora of opportunities to implement blockchain in health and healthcare systems both nationally and globally to ensure economical, safe and easy analysis of healthcare data to fight COVID-19. Prior to the ongoing pandemic, it was estimated that the UK's National Health Service (NHS) would face a £30 billion funding shortfall by 2020 if overall healthcare expenditure is not curtailed (Prokofieva and Miah et al. 2019). Similarly, the USA's healthcare expenditure was also projected to cross $5.5 trillion by 2025 (Prokofieva and Miah et al. 2019). Many processes within the healthcare sector are inefficient and about 20-30% of total healthcare spending can also be linked to poor outcomes. With the use of blockchain, many of these overhead costs can be eliminated while also redirecting doctors and other front-line workers at infection hotspots and communities for better overall population health outcomes. Blockchain can also be further branched out to tackle other infectious diseases such as tuberculosis (TB) and malaria in LMICs. Digital literacy and increased sensitisation of blockchain are needed for people to clearly understand its benefits and shortcomings. Lastly, more training, outreach programs and courses related to blockchain need to be provided for both clinical and non-clinical audience to comprehend.

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