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Blockchain technologies to mitigate COVID-19 challenges: A scoping review

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A R T I C L E I N F O

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A B S T R A C T

Background: As public health strategists and policymakers explore different approaches to lessen the devastating effects of novel coronavirus disease (COVID-19), blockchain technology has emerged as a resource that can be utilized in numerous ways. Many blockchain technologies have been proposed or implemented during the COVID-19 pandemic; however, to the best of our knowledge, no comprehensive reviews have been conducted to uncover and summarise the main feature of these technologies.

Objective: This study aims to explore proposed or implemented blockchain technologies used to mitigate the COVID-19 challenges as reported in the literature.

Methods: We conducted a scoping review in line with guidelines of PRISMA Extension for Scoping Reviews (PRISMA-ScR). To identify relevant studies, we searched 11 bibliographic databases (e.g., EMBASE and MEDLINE) and conducted backward and forward reference list checking of the included studies and relevant reviews. The study selection and data extraction were conducted by 2 reviewers independently. Data extracted from the included studies was narratively summarised and described.

Results: 19 of 225 retrieved studies met eligibility criteria in this review. The included studies reported 10 used cases of blockchain to mitigate COVID-19 challenges; the most prominent use cases were contact tracing and immunity passports. While the blockchain technology was developed in 10 studies, its use was proposed in the remaining 9 studies. The public blockchain technology was the most commonly utilized type in the included studies. All together, 8 different consensus mechanisms were used in the included studies. Out of 10 studies that identified the used platform, 9 studies used Ethereum to run the blockchain. Solidity was the most prominent programming language used in developing blockchain technology in the included studies. The transaction cost was reported in only 4 of the included studies and varied between USD 10^{-10} and USD 5. The expected latency and expected scalability were not identified in the included studies.

Conclusion: Blockchain technologies are expected to play an integral role in the fight against the COVID-19 pandemic. Many possible applications of blockchain were found in this review; however, most of them are not mature enough to reveal their expected impact in the fight against COVID-19.

We encourage governments, health authorities, and policymakers to consider all blockchain applications suggested in the current review to combat COVID-19 challenges. There is a pressing need to empirically examine how effective blockchain technologies are in mitigating COVID-19 challenges. Further studies are required to assess the performance of blockchain technologies' fight against COVID-19 in terms of transaction cost, scalability, and/or latency when using different consensus algorithms, platforms, and access types.

Abbreviations: COVID-19, Novel coronavirus disease; DAG, Direct Acyclic Graph; DPoS, Proof of Location; PRISMA-ScR, Preferred Reporting Items for Systematic Reviews and Meta-Analyses extention for Scoping Reviews; SARS-CoV-2, Severe Acute Respiratory Syndrome Coronavirus 2; PoA, Proof of Authority; PoS, Proof of Stake; PoW, Proof of Work; PlBFT, Plenum Byzantine Fault Tolerance; PrBFT, Practical Byzantine Fault Tolerance; USD, United States Dollar.

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Summary table

What was already known on this topic:
- Blockchain has quickly become a trusted ally of healthcare institutions across the globe.
- The main features of blockchain that make it useful in the healthcare field are immutability, decentralization, transparency and traceability.

What this study added to our knowledge:
- Blockchain can play a crucial role in mitigating COVID-19 challenges.
- Blockchain applications are still immature in the fight against COVID-19.

Introduction

Background

Today's hyper-connected world, or the "global village", is challenged with the rise of human disease epidemics and pandemics due to complex interactions among multiple factors including ecological, environmental, and socioeconomic factors [1, 2]. The highly infectious Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2), which causes the novel coronavirus disease (referred to hereafter as COVID-19), has been wreaking havoc around the globe. By the 17th of November 2020, it had infected more than 54 million individuals and claiming the lives of more than 1300,000 individuals [3]. Since December 2019 when COVID-19 was first discovered in Wuhan, China, the virus has spread to 216 countries.

COVID-19 has overburdened and overwhelmed healthcare systems around the world, especially those in resource-limited settings with poor disease surveillance mechanisms. While not a silver-bullet solution, leveraging digital tools and solutions such as artificial intelligence, blockchain, and the Internet of Things, can augment and enhance public-health strategies targeting the fight against COVID-19 [4–7].

Blockchain, a distributed ledger containing information on transactions and the foundation of the cryptocurrency Bitcoin, has recently received widespread interest and attention in many industries beyond its original application of cryptocurrency [8], including healthcare [9–14]. Since its inception back in 2008, blockchain has offered several key features including decentralization, transparency, immutability, and auditability [15]. At its core, blockchain offers "the promise of a trustworthy way to record shared data" through a decentralized immutable ledger [16].

The European Parliamentary Research Service considers blockchain to be one of the 10 most vital technologies to mitigate COVID-19 challenges [17]. Potential applications of leveraging blockchain technology to combat COVID-19 include monitoring disease outbreaks via secure and imputable ledgers in a distributed manner. Additionally, blockchain technology can potentially be used for contact-tracing purposes, patient information-sharing across heterogeneous systems, and medical supply chain management [18].

Research problem and aim

Although many blockchain solutions have been proposed or implemented during the COVID-19 pandemic, to the best of our knowledge, no comprehensive reviews have been conducted to uncover and summarize the main blockchain solutions to augment public health efforts against COVID-19. Therefore, this research aims to bridge this gap by exploring blockchain technologies proposed or implemented to mitigate the COVID-19 challenges as reported in the literature. The findings from this study may be useful to policymakers, health system leaders, and informaticians considering using blockchain technology to their armoury to fight COVID-19.

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Methods

We undertook a scoping review of literature related to blockchain technologies used to combat COVID-19. We followed the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) to conduct this review [19]. The following subsections summarise the methods used in this review.

Search strategy

We searched 11 databases on the 25th of August 2020: MEDLINE (via Ovid), EMBASE (via Ovid), PsycInfo (via Ovid), Scopus, Web of Science, IEEE Xplore, ACM Digital library, Arxiv, MedRxiv, BioRxiv, and Google Scholar. These databases were probed using search terms related to the target technology (e.g., blockchain and block chain) and the target disease (e.g., COVID-19, 2019-nCOV, and novel coronavirus). The search strings used to search each database are shown in Appendix A. To identify other relevant studies that could be added to this review, we checked the reference list in the included studies (i.e., backward reference list checking) as well as examined studies that cited the included studies (i.e., forward reference list checking).

Study eligibility criteria

To be included, studies had to focus on blockchain technology implemented or proposed for any purpose related to the COVID-19 pandemic such as contact tracing, medical supply chain management, secure certification, patient information-sharing, immigration, and emigration procedures, and donation tracking. We excluded studies that discussed or reviewed the theoretical potentials of blockchain in the COVID-19 pandemic.

We restricted our search to English studies published after the emergence of COVID-19 (i.e., December 2019). While we considered peer-reviewed articles, dissertations, conference proceedings, proposals, and preprints, we excluded other types of publications such as reviews, conference abstracts, editorials, and commentaries. No restrictions were imposed on the country of publication, study design, and measured outcomes.

Study selection

In the first phase of the study selection, Alaa Abd-Alrazaq (AA) and Mohannad Alajlani (MA) independently sifted through the retrieved publications based on their titles and abstracts. In the second phase, the full text of studies that passed the 'title and abstract' screening were read by the two reviewers (AA & MA) independently. Any disagreement between AA and AM in either phase was resolved through discussion and consensus. The interrater agreement (Cohen's kappa) was 0.89 and 0.95 in the first phase and second phase, respectively.

Data extraction and synthesis

The data extraction form was developed and pilot tested by 3 included studies (Appendix B). Data related to characteristics of the included studies (e.g., country and year of publication) and blockchain technologies (e.g., type of blockchain, consensus mechanism, and platform) was extracted by the two reviewers (AA & MA) independently. The reviewers achieved high interrater agreement (0.98) and resolved disagreements through consensus. We narratively synthesised the extracted data by describing characteristics of the included studies and blockchain technologies identified in these studies. Microsoft Excel was utilised for data extraction and data synthesis.

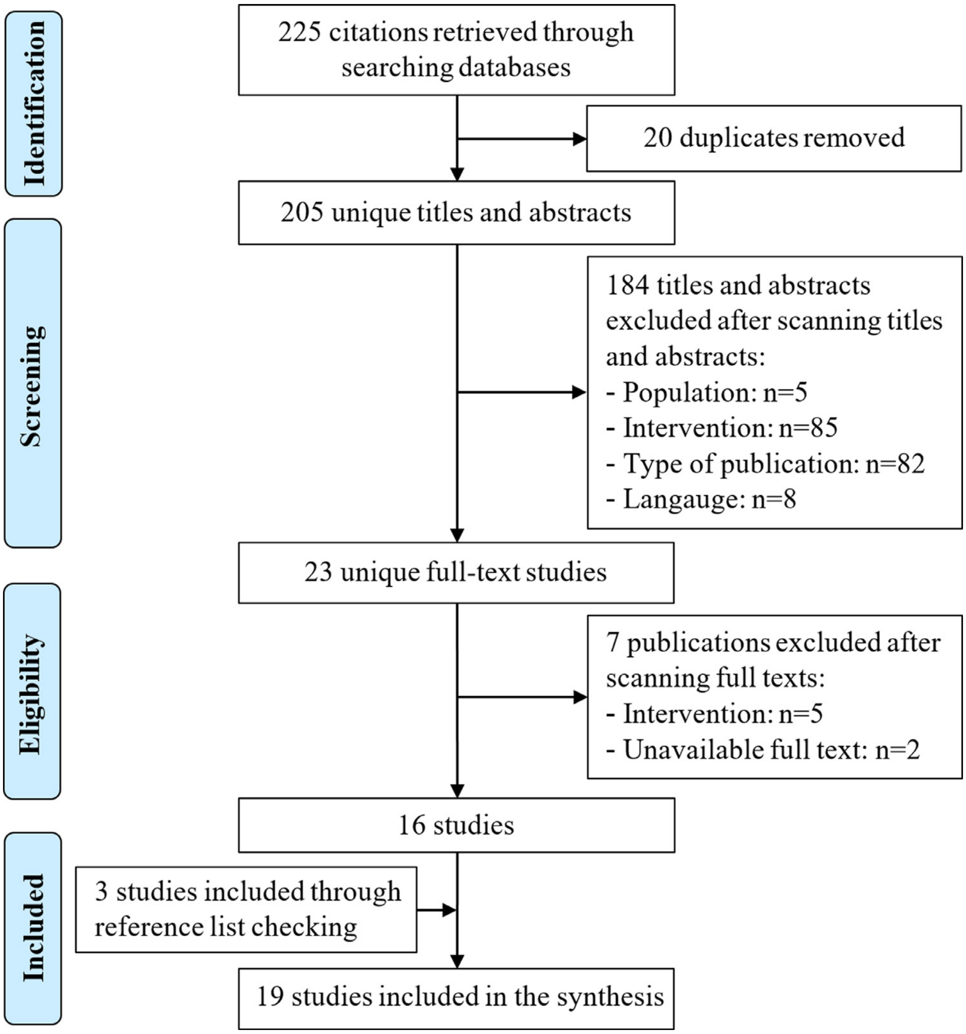

Fig. 1. Flow chart of the study selection process.

Results

Search results

As shown in Fig. 1, the 11 databases retrieved 225 publications. We excluded 20 duplicates of those publications and sifted through the titles and abstracts of the remaining publications ($n = 205$). Screening the titles and abstracts led to removing 184 publications for several reasons reported in Fig. 1. After checking the full text of the 23 remaining publications, we excluded 7 publications due to the irrelevance of the technology or unavailability of the full text. Thus, 16 publications were included from searching the databases. By checking reference lists of the 16 publications, we further identified 3 additional viable publications. In total, we included 19 studies in this review.

Characteristics of included studies

The first article related to blockchain technologies used for COVID-19 was published in March (Table 1). The largest number of the included studies was published in May ($n = 7$) followed by July ($n = 5$). The included studies were conducted in 11 different countries (Table 1). The countries that published the largest number of the included studies were the United Kingdom and China ($n = 3$). The studies consisted of 16 preprints and 3 published articles in peer-reviewed journals. The characteristics of each included study are presented in Appendix C.

Table 1
Characteristics of the included studies.

Characteristics	Number of studies			
Submission month	March: 1	April: 1	May: 7	June: 2
	July: 5	August: 2	September:1	
Country of publication	China: 3	UK: 3	India: 2	Italy: 2
	UAE: 2	US: 2	Turkey: 1	Egypt: 1
	Ireland: 1	Germany: 1	Colombia: 1	
Paper status	Preprint: 16	Published: 3		

Characteristics of blockchain technologies

Table 2 summarises the characteristics of blockchain technologies reported by the included studies for mitigating COVID-19 challenges. Characteristics of blockchain technologies in each included study are presented in Appendix C. These characteristics are elaborated on in the next subsections.

Applications of blockchain technology

The included studies reported 10 used cases or applications of blockchain to mitigate COVID-19 challenges (Table 2). The most prominent use case of blockchain, which was reported in 6 included studies [20–25], was contact tracing; a process wherein individuals who have been in close contact with those who have tested positive for COVID-19 are identified. Another prominent application of blockchain—proposed or developed—in 4 studies was immunity passports [26–29], which

Table 2
Characteristics of blockchain technologies used for COVID-19.

Features	Number of studies		
Application	Contact tracing:6 Social distancing:1 Monitoring isolated:1 Telemedical laboratory:1	Immunity passport:4 Sharing patients' data:1 Identity verification:1	Diagnosing COVID-19:2 Tracking vaccine delivery:1 Tracking COVID-19 status:1
Status	Developed:10	Proposal:9	
Access type	Public:10 Public & Hybrid:1	Private:5	Hybrid: 3
Consensus mechanism	PoA:2 DPoS:1 PrBFT:1	PoW:1 DAG:1 Majority voting:1	PoS:1 PlBFT:1 Not defined: 9
Platform	Ethereum:9	Hyperledger Indy:1	Not defined: 10
Smart contracts	Yes: 13	Not defined: 6	
Programming language	Solidity:6	*C*++:1	Not defined: 7
Abbreviations	**DAG**: Direct Acyclic Graph; **DPoS**: Delegated Proof of Stake; **PlBFT**: Plenum Byzantine Fault Tolerance; **PoA**: Proof of Authority; **PoS**: Proof of Stake; **PoW**: Proof of Work; **PrBFT**: Practical Byzantine Fault Tolerance		

show that an individual is disease risk-free because he has already been infected with COVID-19 or was given a COVID-19 vaccine; therefore, he can travel without restrictions. Two studies employed blockchain for diagnosing COVID-19 based on blood samples [30] or computed tomography (CT) images [31]. The remaining applications of blockchain were used for telemedical laboratory services [32], social distancing [33], securely sharing patients' data [34], monitoring isolated people [35], tracking the COVID-19 status as reported by trusted sources (number of new cases, deaths and recovered cases) [36], tracking and controlling the delivery of a COVID-19 vaccine [37], and identity verification, record attestation, and record sharing [38].

Status and types of blockchain technology

While the blockchain technology was developed in 10 studies [22,23,25,28–32,35,36], its use was proposed in the remaining 9 studies. The type of access rights in using blockchain was public in 10 studies [20,22,24,25,27,29,33,36–38], private in 5 studies [23,26,30, 31, 34], hybrid in 3 studies [21, 28, 35], and both public as well as hybrid in 1 study [32].

Consensus mechanism

About half of the studies ($n = 9$) identified the consensus mechanism of the proposed/developed blockchain, which is the process where entities establish an agreement regarding the validation of each transaction or data block occurring on the network [22, 25, 26, 28, 30, 34–36, 38]. The consensus mechanism used in these studies are Proof of Authority (PoA) [26, 28], Proof of Work (PoW) [34], Proof of Stake (PoS) [36], Proof of Location (DPoS) [22], and Practical Byzantine Fault Tolerance (PrBFT) [35], Plenum Byzantine Fault Tolerance (PlBFT) [38], Majority Voting [30], and Direct Acyclic Graph (DAG) [25].

Platform, smart contracts, and programming language

The platforms that run the blockchain were identified in 10 studies. Specifically, the platform Ethereum was used in 9 studies [23, 25, 28, 29, 32, 34–37], and Hyperledger Indy was used in the remaining study [38]. While smart contracts were integrated to about 68% of blockchain technologies proposed/developed in the included studies [20–23, 27, 29, 30, 32–36, 38], the remaining studies did not identify whether smart contracts were integrated to their blockchain technologies or not. The programming language used in developing the blockchain technology was determined in 7 studies. While Solidity was used in 6 studies [23, 32-36], the remaining study used *C*++ [22].

Transaction costs

Of all the included studies, only four studies reported the transaction costs [23, 29, 32, 36]. In the first study [23], the average cost of each transaction was USD 10^{-10}. The cost of a transaction in the second study ranged from USD 0.0245-USD 0.0306 [29]. In the third study [32], the average cost of each transaction was 0.0002 Ether (cryptocoin concurrency used in Ethereum). The average transaction fee incurred for deploying the contract and executing the main transactions was less than USD 5 in the fourth study [36].

Expected latency and scalability

None of the included studies had identifiable expected latency (i.e., the time that blockchain technology takes to complete one transaction) or expected scalability of the proposed/developed blockchain technology (i.e., the maximum number of transactions that blockchain technology can process in a given time).

Discussion

Principal findings

As we make progress in developing vaccines, blockchain has quickly become a trusted ally of medical and healthcare institutions across the globe. In this paper, we identified 19 papers from 11 different countries that detail their proposed and developed uses of blockchain technology to collect, manage, and utilize data integral to monitoring and eradicating the spread of COVID-19. To combat the pandemic, the studies have described their country's utilization of blockchain distributed ledger technology to enhance interoperability and the sharing of information across entities in a secure manner. Blockchain transactions between entities provide the following key features: (a) Immutability as health data stored in the blockchain ledger cannot be modified as this will be detected with the new hash values, (b) Decentralization as transactions can be validated by the majority of nodes in a distributed fashion, and (c) Traceability as the source of the health data can be traced with analysis of the ledger transactions. Moreover, smart contracts technology built on top of the blockchain can allow automated execution of business login (i.e., contractual agreements) based on some pre-defined conditions. The applications of blockchain in contact tracing, immunity passport, and COVID-19 diagnosis, and other health scenarios to combat the pandemic utilize the mentioned technical features. This section discusses the prominent findings while providing some context.

(1) **Applications:** Of 10 use cases reported in the included studies, contact tracing had the most prominent application of blockchain technology. This may be attributed to the fact that tracing COVID-19 potential cases in the community was one of the most pressing needs to help authorities contain the virus outbreaks. By tracking individuals who had been in close contact with people who had tested positive for COVID-19, public health strategists can quickly identify

"hotspot" areas and more effectively divert their efforts to eradicate where the risk of contact with the virus is greatest. The early-developed technology was not privacy-preserving with a centralized design giving governments the ability to potentially do mass surveillance. To ameliorate the privacy concerns, blockchain is used to have a purely decentralized system without a trusted third party. Immunity passports and COVID-19 diagnoses utilize the blockchain to store and share patient information while ensuring the data is only accessible to authorized entities. Smart contracts add an extra layer of automation to organize access to sensitive data. It is noteworthy that immunity passports may not currently be effective for two reasons: (1) at the time of this study, vaccines for COVID-19 have not been developed yet, (2) an individual who has already been infected with COVID-19 is still at risk of being re-infected with the disease [39-41]. Other applications such as remote monitoring, tracking status, and identity verification are general blockchain health applications predating the current pandemic outbreak so the existing systems will be utilized for COVID-19. All blockchain applications proposed/developed by the included studies were suggested in other relevant reviews [18, 42-44]. However, these reviews suggested other blockchain applications that were not found in the included studies; such as disaster relief insurance [18], contactless delivery (e.g., robots and unmanned aerial vehicle) [18], online education [18], manufacturing management (e.g., sanitizers, personal protective equipment, test swabs, medications, and vaccinations) [18], e-government (e.g., visa processing, salary payment, and marriage and divorce services) [18], agriculture [18], food distribution [18], donation tracking [18, 42, 43], and smart hospitals (e.g., real-time monitoring of environmental hygiene, air quality, and temperature in the hospitals) [44].

(2) **Status and Access type:** Almost 50% of the included studies are in the proposal stage. This may be attributed to the steep learning curve of adopting blockchain technology and limited skills to develop blockchain systems, especially in the health domain. Health applications in particular have a difficult choice between the public blockchains that are widely adopted and provide stronger security guarantees that can also raise privacy concerns, and the private blockchains with controlled access but higher requirements to configure and manage. Most studies utilize public blockchains (i.e., Ethereum and Bitcoin), which may be attributed to the availability of skills, ease of adoption, and stronger security guarantees. In contrast, a scoping review of blockchain applications in healthcare, health sciences, and health education before COVID-19 found that hybrid blockchain was the most common type (38%) utilized in the 39 included studies followed by public blockchain (10%) [45].

(3) **Consensus mechanism:** Blockchain performance depends to a large extent on the consensus algorithm. Most public blockchains deployments use the Proof of Work algorithm, which requires nodes in the blockchain network to solve a mathematical puzzle to confirm transaction blocks. This process is computationally expensive and can exhaust the energy of a resource-constrained device. Different COVID-19 applications are experimenting with different consensus algorithms to enhance performance (i.e., reduce latency and energy consumption, and increase throughput/scalability) and make blockchains more feasible in critical time-sensitive applications using limited devices. Private or hybrid blockchains (e.g., Hyperledger) and some public Blockchains (e.g., Ethereum) allow the use of different consensus algorithms leading to better performance. This variety of consensus mechanisms found in the current review was also reported in another relevant review of blockchain applications in healthcare before the COVID-19 pandemic [45].

(4) **Platform:** Most studies use Ethereum as the blockchain platform since smart contracts are a critical building block in most health applications. In these applications, smart contracts automatically execute the business logic after being triggered by specific conditions found within the app. Ethereum can be used in the public or private mode, making it an ideal candidate for experimentation. Bitcoin is also easy to use but it does not natively support smart contracts and works mainly as a public blockchain. The prominent use of Ethereum found in this review was also reported by another review of blockchain applications in healthcare, health sciences, and health education. Specifically, Ethereum was the most common platform (28%) used in the studies included in that review [45].

(5) **Smart contracts**: Most included studies integrated smart contacts to their blockchain technologies whereas the remaining studies did not report information about smart contacts integration. This finding was inconsistent with a previous review of blockchain applications in healthcare before the COVID-19 pandemic, where smart contacts were used in 38% of blockchain technologies proposed/developed in the included studies [45].

(6) **Programming language:** Most standard programming languages such as C++, Python, JavaScript, Go or Java are used to program blockchain applications. Solidity is a new statically-typed programming language customized for developing smart contracts on different blockchain platforms, notably Ethereum. Solidity is becoming the de facto language for smart contract development as more blockchain platforms adopt it. ECMAScript's syntax of Solidity makes it easier for web developers to learn. For studies that did not report the blockchain platform and the language used, we found they either have developed a new blockchain platform in their study or their work was proposed with an initial design or analytical model without implementation in a specific platform. Finally, some studies used standard languages, but this was not reported as they were focused on the scientific outcomes, not the practical implications.

(7) **Transaction costs:** Services using public blockchains need to pay transaction fees. Few studies reported the costs because it changes across systems based on the complexity of the application utilization of the blockchain (i.e., the number and frequency of transactions) and the blockchain instantaneous prices, which vary significantly over time. Therefore, it is hard to compare costs across different studies. For private blockchains, there is no transaction cost but the platform owner has a running cost of managing the platform. Some studies report costs to show the feasibility of using public blockchains or for comparison purposes.

(8) **Expected latency and scalability**: Most public and private blockchain implementations are not optimized for all scenarios so none of the included studies reported the latency and scalability/throughput numbers. For example, Bitcoin was reported to have a 10-minute delay to confirm a transaction and a maximum throughput of 7 transactions per second [46]. Some private blockchains (such as Hyperledger) allow for more customization of different parameters to enhance the blockchain performance in different applications [47].

Strengths and limitations

Strengths

This is the first review that explores blockchain technologies proposed or developed to mitigate the COVID-19 challenges. This helps readers, policymakers, health system leaders, and informaticians considering using blockchain technology to their armoury to fight COVID-19. To ensure conducting a high-quality and transparent review, we followed the PRISMA-ScR guidelines [19]. This review can be deemed comprehensive given that we searched the most common databases in health and information technology fields to retrieve as many relevant studies as was possible, and we did not impose any restrictions on the country of publication, study design, and measured outcomes. The risk of publication bias in this review is minimal as we searched via Google Scholar and carried out backward and forward reference list checking to retrieve grey literature as much as possible. Selection bias was minimal in this review because two reviewers independently selected the study, extracted its data, and achieved high agreement in their decisions.

Limitations

This review focused on blockchain technologies reported in the literature. Thus, the review missed several blockchain technologies that were developed but not described in the existing literature such as VeChain (a platform for tracking the development of COVID-19 vaccines) [48], Hyperchain (a platform for tracking donations) [49], Hashlog (a platform for monitoring COVID-19 development) [50], and Civitas (a mobile application for social isolation) [51]. We likely missed some studies published in non-English languages as we restricted the search to English studies, owing to practical constraints. While some characteristics of blockchain technologies for COVID-19 were reported in a few studies (e.g., consensus mechanism, platform, and transaction cost), other characteristics were not described at all (e.g., expected latency and expected scalability). Accordingly, we could not adequately describe and discuss several characteristics of blockchain technologies used for COVID-19. Most included studies in this review are preprints, which have not been peer-reviewed and are more likely to have inaccurate information. Thus, the accuracy of our findings may be influenced by the accuracy of the information reported in the included studies.

Practical and research implications

Practical implications

There are several practical implications that can be appreciated when considering using blockchain technology. Although the included studies in this review reported 10 applications of blockchain for the COVID-19 pandemic, blockchain can be employed for other applications such as disaster relief insurance, contactless delivery, online education, manufacturing management, e-government, agriculture, food distribution, donation tracking, and smart hospitals.

We noticed that most applications of blockchain reported by the included studies were not proactive to prevent the spread of COVID-19 such as developing drugs and vaccines, prediction of COVID-19 spread, prediction of the need for resources in certain times or places, smart hospitals, contactless delivery (e.g., (e.g., robots and unmanned aerial vehicle), and prediction of any future epidemic. Artificial intelligence can be used for analyzing data collected from the blockchain network to provide the above-mentioned proactive applications. Thus, we expect new specialized blockchain systems to combat the pandemic in a wider set of proactive applications as we face the second wave.

About half of the studies in this review discussed proposals of blockchain technology. Thus, we encourage governments, health authorities, policymakers, healthcare workers, medical laboratories, health informaticians, airline agents, border control authorities, airport authorities, and those interested in utilizing blockchain to consider these proposals and to put these ideas into practice to mitigate COVID-19 challenges.

As the reviewed systems get more deployment experience, more interactions with health practitioners and policymakers are expected, leading to more refined designs. To have a constructive deployment of blockchain-empowered health applications, it would be ideal for clinical staff and policymakers in major health organizations (hospitals, primary care centers, government, and insurance companies) to become more aware of the technical features and the limitations of blockchain technology to reap its benefits. Common misconceptions stemming from blockchain association with bitcoin and illegal activities (e.g., purchasing drugs) need to be corrected.

The cost, performance, and security guarantees vary between public and private blockchains leading to different choices by application designers. The cost of the public blockchain fluctuates drastically; health services need to manage their transactions and budget carefully. The prices need to be reasonable considering the expected number of transactions. Blockchain can be complemented by various security, artificial intelligence, sensing, communication, and cloud computing technologies to build effective health systems combating COVID-19. For example, recent studies have utilized reinforcement learning to adapt the rate of transactions based on the blockchain costs in IoT monitoring applications [52].

Using blockchain technology for contact tracing is an excellent example of information that needs to be quickly transmitted, privately held, and publicly accessed. Individuals can both look up "hotspots" that must be approached with caution as well as safely provide their information about themselves or individuals in their social group. Moreover, healthcare outreach workers can specifically target these areas to provide necessary treatment, education, and resources. This data must be rapidly accessible and quick to update, as occurrences of COVID-19 "hotspots" can easily fluctuate.

Usually, blockchain technology is largely considered to be a platform that is secure and consistently monitored to reassure its users of their privacy and safety. However, a scoping review uncovered that blockchain-related to healthcare and medical systems had inherent security weaknesses [9]. Blockchain software can be compromised by data threats or other adversaries that can take and maintain control of medical transactions or patient information modifications. Therefore, it is integral to blockchains' success for policymakers and government safety and privacy regulators to consider laws that detail appropriate risk management to put in place while still allowing the tool to work as intended.

Research implications

While blockchain technology is being quickly implemented in practical ways, there is enormous potential for future research based on what blockchain technology has so far captured and will, ideally, begin to collect and manage in the future. Given the lack of information reported in the included studies related to latency, scalability, transaction costs, consensus mechanisms, and platforms of proposed/developed blockchain technologies, future studies should report such details to facilitate developing or replicating the proposed blockchain technologies and to compare them.

None of the included studies assessed the effectiveness or impact of blockchain technologies on mitigating COVID-19 challenges; as such, benefits of such technologies will be theoretical unless they are proven. Accordingly, there is a pressing need to empirically assess how effective blockchain technologies are in the fight against this pandemic. Further, we encourage researchers to examine the performance of blockchain technology in terms of transaction cost, scalability, and/or latency when using different consensus algorithms, platforms, and access types.

As discussed, many blockchain technologies have been used in the fight against the COVID-19 pandemic (e.g., VeChain, Hyperchain, Civitas, and Hashlog), but they were not described in the existing literature. Therefore, we recommend researchers to review of such blockchain technologies to build a comprehensive view of their role and potentials.

As blockchain-based applications assist in government agency's ability to monitor current patients as well as potential new cases, doctors can give real-time analyses of patients' symptoms and monitor diagnostics data. As such, researchers can track how symptoms can manifest in numerous patients in real-time. As such, they can capture not only a day-to-day perspective of patients but analyse symptoms in numerous cases to better investigate a specific and greatly detailed general timeline of how the virus affects patients nationwide.

Conclusion

Blockchain technologies are expected to help people return to their normal lives previously unaffected by the pandemic and reduce the spread of COVID-19 until a vaccine is developed. Although many possible applications of blockchain were found in this review, most of them are not mature enough to show their expected impact in the fight against COVID-19. We expect new specialized blockchain systems to combat the pandemic in a wide set of applications as we face the second wave. We encourage governments, health authorities, and policymakers to consider all blockchain technologies proposed by our included studies and other reviews, and to put them into practice to combat the challenges of COVID-19 and similar major public health emergencies. Further studies are required to empirically assess the effectiveness of blockchain technologies in mitigating COVID-19 challenges. We also encourage researchers to examine the performance of COVID-19 blockchain technologies in terms of transaction cost, scalability, and/or latency when using different consensus algorithms, platforms, and access types.

Authors' contributions

Alaa Abd-alrazaq and Zubair Shah developed the protocol and ran the search with guidance from and under the supervision of Mowafa Househ. Study selection and data extraction were carried out independently by Mohannad Alajlani & Alaa Abd-alrazaq. The manuscript was drafted and revised critically for important intellectual content by all authors. All authors approved the manuscript for publication and agree to be accountable for all aspects of the work.

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Statement on conflicts of interest
The authors have no competing interests to declare.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.cmpbup.2020.100001.

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