applied sciences

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Review

Blockchain for the Healthcare Supply Chain: A Systematic Literature Review

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Abstract: A supply chain (SC) is a network of interests, information, and materials involved in processes that produce value for customers. The implementation of blockchain technology in SC management in healthcare has had results. This review aims to summarize how blockchain technology has been used to address SC challenges in healthcare, specifically for drugs, medical devices (DMDs), and blood, organs, and tissues (BOTs). A systematic review was conducted by following the PRISMA guidelines and searching the PubMed and Proquest databases. English-language studies were included, while non-primary studies, as well as surveys, were excluded. After full-text assessment, 28 articles met the criteria for inclusion. Of these, 15 (54%) were classified as simulation studies, 12 (43%) were classified as theoretical, and only one was classified as a real case study. Most of the articles (n = 23, 82%) included the adoption of smart contracts. The findings of this systematic review indicated a significant but immature interest in the topic, with diverse ideas and methodologies, but without effective real-life applications.

Keywords: blockchain; distributed ledger; supply chain; healthcare; vaccines; medical device; solution; innovation

Citation: Fiore, M.; Capodici, A.; Rucci, P.; Bianconi, A.; Longo, G.; Ricci, M.; Sanmarchi, F.; Golinelli, D. Blockchain for the Healthcare Supply Chain: A Systematic Literature Review. *Appl. Sci.* **2023**, *13*, 686. https://doi.org/10.3390/app13020686

Academic Editor: Mirco Peron

Received: 25 November 2022
Revised: 30 December 2022
Accepted: 31 December 2022
Published: 4 January 2023

1. Introduction

Supply chain (SC) management refers to the management of information, processes, capacity, service performance, and funds from the earliest supplier to the ultimate customer [1]. An SC is a network of interests, information, and materials involved in processes and activities that produce value in the form of a product, service, or a combination of both for customers. Stakeholders use an SC to deliver value in a market [2]. Therefore, a SC can be viewed as an integration of materials and information flows among suppliers, manufacturers, and customers [3]. Ultimately, the main goal of an SC is to manage the supply and demand cycle.

In healthcare, SCs play a crucial role in ensuring that patients have access to the medical supplies, equipment, and medications that they need to receive proper treatment. The supply chain in healthcare management (SCHM) is complex, involving multiple stakeholders, including manufacturers, distributors, hospitals, pharmacies, and insurance providers [4]. Inefficient SCs can lead to delays in treatment, reduced patient satisfaction, and increased costs. An effective SCHM requires careful coordination and collaboration among all stakeholders to ensure that the right products are delivered to the right place at the right time. This can involve the use of technology, such as inventory management systems and logistics software, to track and manage the flow of goods throughout the SC [5].

In recent years, there has been a growing emphasis on improving SC efficiency in healthcare as a way to reduce costs and improve patient outcomes. This includes efforts to streamline processes, optimize inventory management, and leverage data analytics to better understand and meet the needs of patients and providers. By better understanding and managing their SC, healthcare organizations can improve patient care and drive positive outcomes for both patients and providers [4,5].

An SCHM aims to improve clinical outcomes and ensure patients' and professionals' safety while controlling costs [4,5]. Managing a SCHM implies higher costs for providers and heavier dependence on third parties as compared to other industries [6]. Furthermore, an SCHM presents unique challenges, as it is usually decentralized, lacking in standardized procedures (financial or contractual) among physicians, hospitals, and patients, and subjected to regulatory restraints [7].

Policymakers, drug manufacturers, the pharmaceutical industry, and other institutions and structures, such as hospitals, clinics, and pharmacies, are usually the main stakeholders of SCHMs. On the one hand, an SC ensures the distribution of industry-derived products, such as drugs and medical devices (DMDs), but on the other hand, it must deal with patient-derived products, such as blood, organs, and tissues (BOT) [7]. A summary of an SCHM is represented in Figure 1.

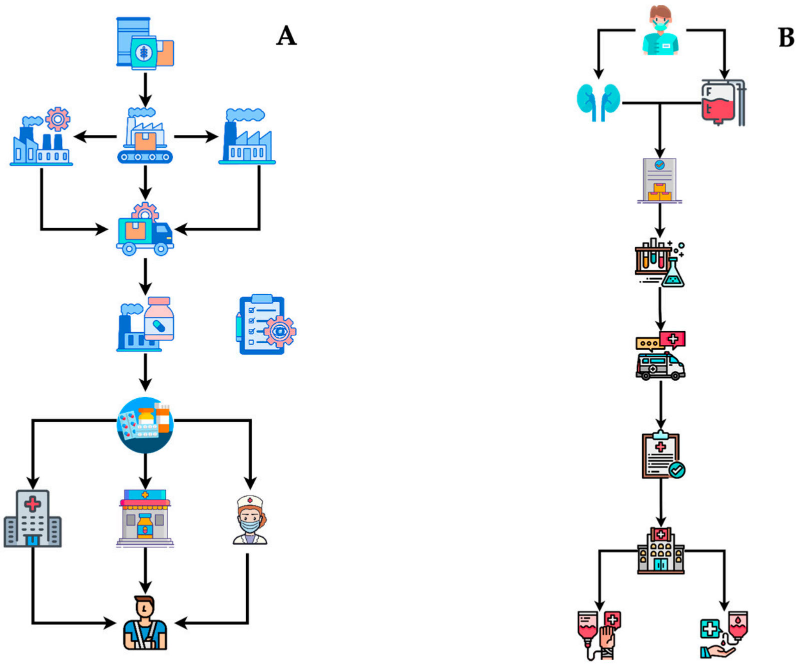

Figure 1. Steps of the supply chain in healthcare, specifically for DMDs (**A**) and BOTs (**B**). (**A**) A pharmaceutical SC's general flow: from the raw material, to the manufactures, to the distribution to the pharmacies and hospitals, and to the patient; (**B**) general flow of BOT: from the donor to storage, transportation, quality check, and utilization for the patient.

Emerging technology needs to be taken into account by clinicians, given that upcoming technologies are looming over their everyday practice. Getting acquainted with technologies will be imperative, as understanding how they work will ensure that patients receive more reliable care and more secure data processing, not to mention the medical–legal implications that will benefit from such applications.

1.1. Supply Chains' Risks in Healthcare

Fraud and misconduct are common in science and in the healthcare industry [8,9]. Substandard or tampered-with medical products hinder progress toward achieving the Sustainable Development Goals (SDGs). As global SCs become more complex, the problem of falsified and substandard medical products is exacerbated by increased demand and subpar distribution systems. [10].

Substandard and/or counterfeit products have an estimated market capitalization of 200 billion/year, which is greater than that of other black markets, such as prostitution

(USD 190 billion/year), cocaine (USD 80 billion/year), and human trafficking (USD 30 billion/year) [11]. The economic and financial externalities of this burden affect employment and the research and development (R&D) capacities of pharmaceutical companies [12].

According to a survey conducted among health service providers and pharmaceutical/life science executives in August–September 2020, 50% of the interviewed pharmaceutical/life science executives considered improving SC transparency to be their priority, while 16% said improving SC security was a priority, and 11% considered understanding and managing third-party risk a priority [13].

Low mutual trust between the subjects involved in SCHMs, such as in security, privacy, and accountability, represents a critical issue. Therefore, new enabling technologies that can be easily scaled are needed to mitigate these risks. Blockchain technology has been identified in the literature as a possible innovative solution for improving SC accountability, integrity, transparency, confidentiality, and reliability [14].

In the following paragraphs, the main features that make blockchain technology a potential game changer for mitigating the risks of SCs in healthcare are described.

1.2. Blockchain Technology in Brief

A blockchain is a distributed ledger that records transactions between different parties in a verifiable and permanent way [15]. Unlike relational databases that are managed by third parties, a blockchain is decentralized, meaning that no single user can control its operations. Its decentralization is paramount because it empowers the system rather than the user, resulting in higher transparency and security [8].

There are five key principles at the core of this technology. First, no one controls the data, but every party can verify its records. Second, communication occurs directly between peers. Third, users can choose to remain anonymous or provide proof of their identity. Fourth, updated transactions cannot be altered. Fifth, each record is linked to the previous one [14]. Data are stored in time-stamped blocks containing an address of the previous block [16]. When a miner adds a new block, it is linked to the entire blockchain network [16]. Based on the participants and rules of the network, blockchains can be classified into four different types: public, private, consortium, and hybrid [17]. Public blockchains, also known as permissionless blockchains, can be joined by anyone. However, accessing data on these blockchains can be time- and resource-intensive [18]. Private blockchains, also called permissioned blockchains, are a specific type of blockchain in which a single party acts as a central authority. Consortium blockchains, also referred to as federated blockchains, are a semi-private network in which a consortium of stakeholders with the same goal forms the authority in the network [17]. Hybrid blockchains, as the name suggests, combine the characteristics of public and private ones [18].

1.3. The Blockchain Technology for Healthcare Supply Chains

In the healthcare sector, blockchain can potentially play a vital role in improving data security, interoperability, and the traceability of data and information.

One major challenge facing the healthcare industry is the lack of secure and reliable methods for storing and accessing data. Blockchain technology offers a solution by allowing data to be securely stored and shared in a decentralized database, making it difficult for unauthorized individuals to access or alter the data.

Additionally, blockchain can facilitate interoperability among different healthcare systems and organizations, allowing for more seamless communication and data exchange. Currently, many healthcare systems are siloed and use incompatible technologies, making it difficult for different providers to access and share data. By using a shared, decentralized database, healthcare providers can more easily access and share relevant information, leading to better care coordination and outcomes.

Another potential benefit of blockchain in healthcare is the ability to trace the history and authenticity of medical products, such as prescription drugs and medical devices. By using blockchain to track the SCs of these products, it becomes easier to identify counterfeits and ensure that patients are receiving genuine, safe, and effective treatments.

Therefore, blockchain has been widely implemented in healthcare [19–21], and it could also help solve SC challenges [22]. A fundamental advantage of these distributed systems is that they resolve problems of disclosure and accountability among individuals and institutions whose interests might not be aligned [23]. Therefore, blockchain technology could be effective for SCs' accountability, integrity, transparency, confidentiality, and reliability.

Product tracing using blockchain technology enables manufacturers, distributors, and dispensers to store traceability information in a distributed ledger that automatically verifies key data. This creates a system for verifying products and, if necessary, can be used to detect and report counterfeit or unapproved drugs through notifications from both public and private actors [23].

1.4. Aim of the Study

This systematic literature review aims to evaluate the state of the art of the development and applications of blockchain technology to support SCs in the healthcare industry.

2. Materials and Methods

2.1. Search Strategy and Selection Criteria

This systematic review sought articles in two electronic databases, i.e., PubMed and Proquest, with terms deemed appropriate by the authors to find relevant articles on the development of blockchain technology to support the SCHMs. The strings used can be found in the supplementary material (Table S1).

Reference lists in the review articles identified during this search and the final included articles were checked to identify additional potentially eligible studies.

The inclusion criteria were: experimental or observational studies, primary/original studies, and peer-reviewed articles published in English between January 2000 and June 2022. The exclusion criteria were: non-primary studies (meta-analyses, reviews, systematic reviews, opinion papers), surveys, and articles published in languages other than English.

2.2. Data Analysis

Three pairs of reviewers (MF and AC, GL and AB, and FS and MR) screened the articles independently—first by the title and abstract, and then by the full text—to determine the eligibility for final inclusion. Any discrepancy in the reviewers' decisions was discussed by the authors in each pair. A consensus decision for eligibility and inclusion was made for all articles. Whenever a consensus could not be reached between authors, a third independent author (DG) acted as tiebreaker. The pairs of reviewers performed data extraction on the same set of articles by using an extraction table. Disagreements about the extracted data were discussed with an independent arbiter (DG). The variables selected for the data extraction are listed in Supplementary Table S2. This review was registered with PROSPERO (CRD42022345200) on 19 July 2022 [24]. The PRISMA reporting guidelines were followed [25].

2.3. Quality Assessment

For quality appraisal, the quality checklist by Kitchenham et al. [26] and Kitchenham et al. [27] based on the Centre for Reviews and Dissemination (CRD) Guidelines was used [28,29]. The quality assessment scale focused on: (a) study design (answering the question: Is there a clear statement of the aims of the research?), (b) conduct (does the paper provide relevant data related to blockchain assessment?), (c) analysis (how adequately are the research results documented?), and (d) conclusions (does the study allow the research questions to be answered?). The selected papers were assessed by means of this set of questions. The possible scores for each of the aspects were: Yes = 1, Partially = 0.5, and No = 0 points. Accordingly, the maximum score for a primary study was 4.

3. Results

3.1. Included Studies

The search identified 2368 articles (MEDLINE n = 132, ProQuest n = 2236). After the initial search, 2368 articles were screened, with 2231 being excluded at the title/abstract screening stage, as they were not eligible. This left 137 full-text articles that were assessed for eligibility, 28 of which met the criteria for final inclusion (Figure 2) [30–57]. Most of the articles (n = 24, 86%) were published between 2020 and 2022. Among the articles selected for data extraction, the majority were published by authors from organizations based in Asia (n = 24; 86%). The remaining articles were published by authors from Europe (n = 3; 11%) and North America (n = 1; 3%). A summary of the included studies is presented in Table 1.

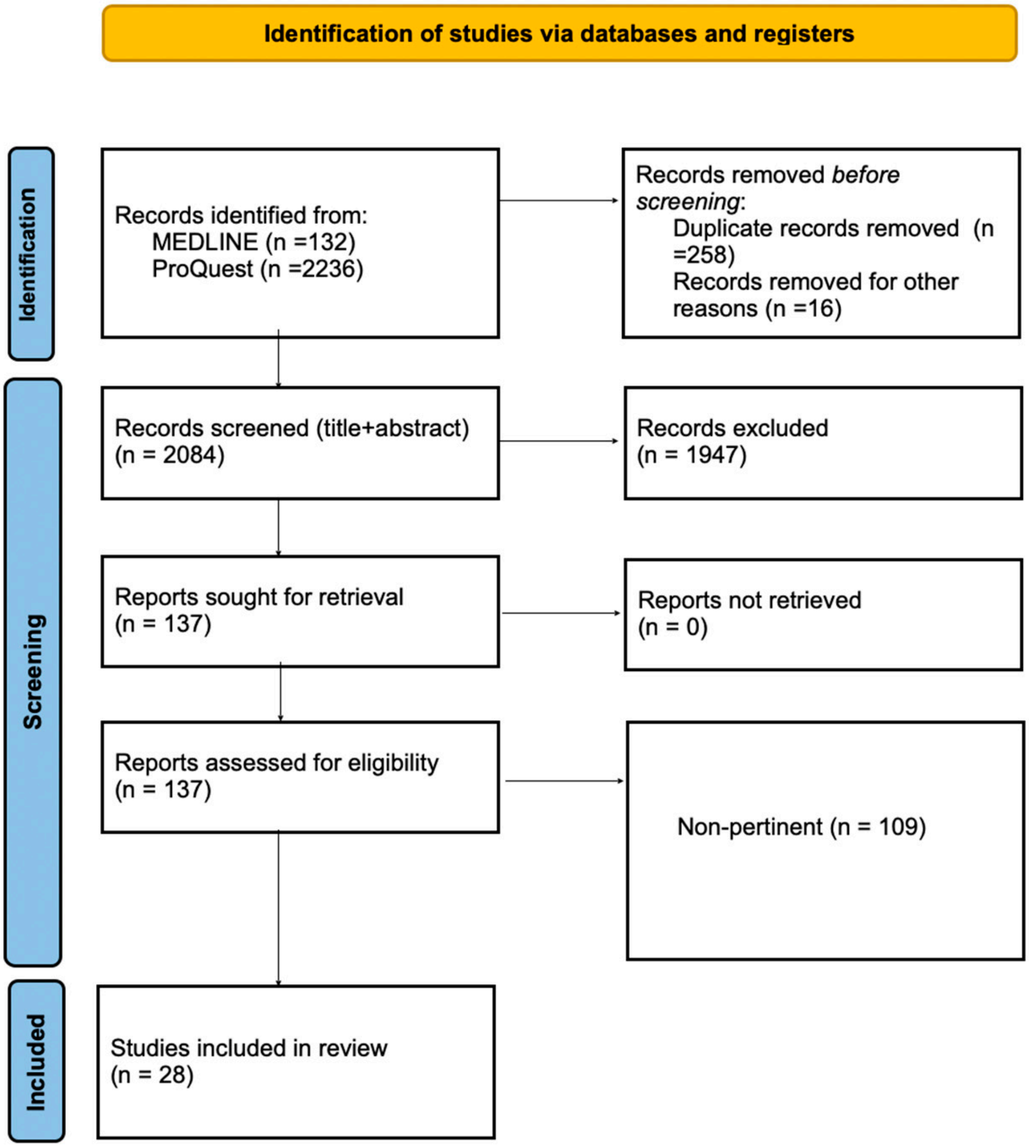

Figure 2. PRISMA flowchart.

Table 1. Summary of the included studies.

Title	First Author	Year	Sector	Type of Blockchain	Data A.	Data I.	Data T.	Data C.	Data R.	Smart Contracts	Study Type	Scalability
Blockchain-based Supply Chain Traceability for COVID-19 personal protective equipment.	Omar, IA. [30]	2022	Tools	Public	1	1	1	1	1	Yes	S.	No
Protecting Vaccine Safety: An Improved, Blockchain-Based, Storage-Efficient Scheme.	Cui, L. [31]	2022	Vaccine	Consortium	1	1	1	0	1	Yes	S.	Not explored
A Blockchain Secured Pharmaceutical Distribution System to Fight Counterfeiting.	Zoughalian, K. [32]	2022	Drugs	Private	0	1	1	1	1	Yes	S.	Not explored
Blockchain-Based Distributed Information Hiding Framework for Data Privacy Preserving in Medical Supply Chain Systems.	El Azzaoui, A. [33]	2022	DTV	Private	0	1	1	1	0	Yes	S.	Not explored
Blockchain Medledger: Hyperledger fabric enabled drug traceability system for counterfeit drugs in pharmaceutical industry.	Uddin, M. [34]	2021	Drugs	Consortium	1	1	1	1	1	Yes	T.	Not explored
Blockchain for drug traceability: Architectures and open challenges.	Uddin, M. [35]	2021	Drugs	Private	0	1	1	1	0	Yes	T.	Not explored
Governance on the Drug Supply Chain via Gcoin Blockchain.	Tseng, JH. [36]	2018	Drugs	Consortium	1	1	1	1	0	Yes	T.	Not explored
Blockchain Technology for Detecting Falsified and Substandard Drugs in Distribution: Pharmaceutical Supply Chain Intervention.	Sylim, P. [37]	2018	Drugs	Consortium	1	1	1	1	1	Yes	S.	Not explored
Internet of Things Based Blockchain for Temperature Monitoring and Counterfeit Pharmaceutical Prevention.	Singh, R. [38]	2020	Drugs	Hybrid	0	1	1	1	1	Yes	S.	Yes
Blockchain-Based Forward Supply Chain and Waste Management for COVID-19 Medical Equipment and Supplies.	Ahmad, RW. [39]	2021	Tools	Private	0	1	1	1	0	Yes	S.	Not explored
A robust drug recall supply chain management system using hyperledger blockchain ecosystem.	Agrawal, D. [40]	2022	Drugs	Hybrid	0	0	1	0	0	No	S.	Yes
Blockchain-Based Decentralized Digital Manufacturing and Supply for COVID-19 Medical Devices and Supplies.	Alkhader, W. [41]	2021	Tools	Hybrid	1	1	1	0	1	Yes	T.	Yes
HerBChain, a blockchain-based informative platform for quality assurance and quality control of herbal products.	Yik, Mavis Hong-Yu [42]	2021	Drugs	Consortium	0	0	1	0	1	No	R.C.S.	Not explored
Implementation of a Blood Cold Chain System Using Blockchain Technology	Kim, Seungeun [43]	2020	Blood	Private	0	0	1	0	1	No	T.	Not explored

Table 1. *Cont.*

Title	First Author	Year	Sector	Type of Blockchain	Data A.	Data I.	Data T.	Data C.	Data R.	Smart Contracts	Study Type	Scalability
Securing E-health Networks from Counterfeit Medicine Penetration Using Blockchain	Pandey Prateek [44]	2021	Drugs	Consortium	0	1	1	1	0	Yes	T.	Not explored
BloodChain: A Blood Donation Network Managed by Blockchain Technologies	Le, Hai Trieu [45]	2020	Blood	Private	1	1	0	1	1	No	S.	Not explored
An Exploratory Study on the Design and Management Model of Traditional Chinese Medicine Quality Safety Traceability System Based on Blockchain Technology	Li, Dacan [46]	2022	DTV	Hybrid	0	1	1	1	1	Yes	S.	Not explored
Go-Win: COVID-19 Vaccine Supply Chain Smart Management System using BlockChain, IoT and Cloud Technologies	Saranya, S [47]	2021	Vaccine	Private	0	1	0	1	0	No	T.	Not explored
A Non-Fungible Token Solution for the Track and Trace of Pharmaceutical Supply Chain	Chiacchio, Ferdinando [48]	2022	Drugs	Hybrid	0	1	1	1	1	Yes	S.	Not explored
Blockchain Application Design and Algorithms for Traceability in Pharmaceutical Supply Chain	Bali, Vikram [49]	2021	Drugs	Private	0	1	1	1	0	Yes	T.	Yes
Securing Drug Distribution Systems from Tampering Using Blockchain	Mamoona Humayun [50]	2022	Drugs	Public	1	1	1	0	1	Yes	T.	Not explored
A Novel Medical Blockchain Model for Drug Supply Chain Integrity Management in a Smart Hospital	Jamil, Faisal [51]	2019	Drugs	Private	1	1	1	1	1	Yes	S.	Yes
A Blockchain and Machine Learning-Based Drug Supply Chain Management and Recommendation System for Smart Pharmaceutical Industry	Abbas, Khizar [52]	2020	Drugs	Private	1	1	1	0	1	Yes	S.	Not explored
Blockchain-Based Solution for the Administration of Controlled Medication	Musamih, Ahmad [53]	2021	Drugs	Private	1	1	0	1	0	Yes	S.	Yes
A Blockchain-Based Approach for Drug Traceability in Healthcare Supply Chain	Musamih, Ahmad [54]	2021	Drugs	Public	1	1	1	1	1	Yes	T.	Not explored
Research on Medical Waste Supervision Model and Implementation Method Based on Blockchain	Wang, Hui [55]	2022	DTV	Private	1	1	1	1	1	Yes	T.	Not explored
Blockchain Enabled Transparent and Anti-Counterfeiting Supply of COVID-19 Vaccine Vials	Chauhan, Harsha [56]	2021	Vaccine	Public	0	1	1	1	1	Yes	S.	Not explored
Improving Opportunities in Healthcare Supply Chain Processes via the Internet of Things and Blockchain Technology	Jayaraman, Raja [57]	2019	Drugs	Public	0	1	1	1	0	Yes	T.	Not explored

Table Acronyms: Data A. = Data Accountability. Data I. = Data Integrity/Security. Data T. = Data Transparency/Traceability. Data C. = Data Confidentiality/Privacy. Data R. = Data Reliability. S. = Simulated. T. = Theoretic. R.C.S. = Real Case Study.

3.2. Study Type, Domain, and Technology

Of the 28 articles included in this systematic review, 15 (54%) were classified as "simulated" studies and 12 (43%) were classified as "theoretical". Only one was classified as a "real case study".

Among the different domains of application, the application of blockchain technology for drug SCs was the most frequently investigated (n = 17, 61%). Three (11%) studies investigated the use of blockchain technology in medical devices' SCs, three (11%) were in vaccines, and two (7%) were in blood management. Three (11%) studies simultaneously investigated the use of general applications for drugs, vaccines, and tools.

The types of blockchains implemented by the included studies were classified as "private blockchain" (n = 12, 43%), "consortium blockchain" (n = 6, 21%), "hybrid" (n = 5, 18%), and "public" (n = 5, 18%).

The most frequently adopted blockchain platforms were Ethereum (n = 8, 32%) and Hyper-ledger Fabric (n = 6, 21%). In two studies, ETH was used alongside FileCoin. IBM Hyperledger Fabric was adopted in two studies, and Open-Source Blockchain was implemented in two cases. Only one study developed an "in-house" blockchain technology. In the remaining articles (n = 9, 32%), it was not possible to identify the adopted technology.

Most of the articles included the adoption of smart contracts (n = 23, 82%).

Among the 28 included studies, only seven investigated the system's scalability—six of which declared that the investigated solution was scalable, while the remaining one declared that their system was not. The majority of the articles (n = 21, 75%) did not explore the scalability of the proposed system.

3.3. Blockchain Principles

All of the articles included in the systematic review addressed at least one of the five founding principles of blockchain technology (i.e., accountability, integrity/security, transparency, confidentiality/privacy, and reliability).

Twenty-five studies deemed their systems suitable for effectively addressing the data integrity/security issue. The same number of studies declared that their systems ensured data transparency. Data confidentiality/privacy was mentioned by 21 studies, data reliability was mentioned by 18, and data accountability was mentioned by 13.

3.4. Quality Assessment

The average score was 2.53 ($\pm$0.78) on a four-point scale, where four was the highest quality level. Detailed quality assessment results are presented in Supplementary Table S3.

4. Discussion

4.1. Technical Overview

In our study sample, private (a blockchain in which access is restricted to a specific group of individuals or organizations) and consortium-based (a blockchain that is owned and operated by a group of organizations) blockchains were the most commonly used types, while hybrid (a blockchain that combines features of both public and private blockchains) and public (a blockchain that is open and accessible to anyone) blockchains were less prevalent.

Non-public blockchains, also known as permissioned blockchains, offer several advantages over public blockchains, including increased control, higher data confidentiality [58], lower energy consumption, and lower costs [59]. These advantages may have led researchers to choose this technology over a fully decentralized solution for efficiency purposes. A possible disadvantage of a public blockchain is the scalability issue, as reported by Ilhaam and colleagues [30], who deemed their public-blockchain-based solution as not fully scalable. Blockchain needs to be scalable if the technology is intended to be used on a large scale [60]. As the data flow provided by users increases, performance must remain viable. For this reason, an energy-consuming solution, such as a public blockchain, may not be the best choice when dealing with SCHMs. Our analysis shows that the scalability issue is not a prerogative of public blockchain alone, given that even studies investigating private, consortium, or hybrid blockchains did not explore scalability [31–37,39,42–48,50,52,54–57] and, in one case, failed to achieve it [30]. In the article published by Singh et al. [38], scalability issues were solved thanks to the Raft consensus. A. Musamih et al. [53] dealt with scalability issues by proposing a proof of authority (PoA) instead of a proof of work (PoW). The results emerging from this review suggest that further studies are needed to assess the scalability of blockchain technologies before real-world implementation might be commenced.

Many articles in this review chose ETH as the pre-blockchain platform of choice [30,37,39,41,53,54,56,57], likely due to its open-source nature and cross-industry focus, which allows for decentralized applications [61].

Another notable feature of blockchain technology is the use of smart contracts, which offer an automated and transparent way to exchange data and contracts without the need for a third-party intermediary [62]. While the use of smart contracts was widely theorized and simulated in these articles, the technological readiness level of the proposed solutions appears to be too low to determine their effectiveness in real-world settings.

4.2. Drugs and Vaccines

The traceability of drugs and vaccines is critical in healthcare, as counterfeited products pose unacceptable health hazards for patients [10]. This review found that the topic of the traceability of drugs and vaccines was the most widely explored in the selected articles, comprising 61% of the studies. However, only one real-world application was found in this review [41], which demonstrated the potential of blockchain technology to lower the risk of purchasing fraudulent herbal materials from upstream stakeholders and to improve data sharing and collaboration within the manufacturing and SC of healthcare products.

Blockchain technology holds promise for providing transparency, privacy, and accountability in the SCs of healthcare products, particularly in low- and middle-income countries, where the failure rate of drugs is estimated to be 10% [10]. This is a pressing issue, as the use of substandard and falsified antibiotics has been linked to excess pneumonia deaths in these countries [63,64].

These data highlight the urgent need to address this problem, since these deaths are avoidable. The solution by Zoughalian et al. [32] provides, thanks to a decentralized system, a transparent flow of medicine between entities within an SC. Entities such as hospitals, pharmacies, and government institutions can trace healthcare products back to ensure integrity and avoid counterfeit drugs.

It must be noticed that the COVID-19 pandemic and its vaccine rush strongly influenced the discourse on blockchain applications in SCHMs regarding vaccines, as confirmed by the fact that the entire set of articles focused on vaccines was published between 2021 and 2022. Cui and colleagues [31], alongside Saranya [47] and Chauhan and colleagues [56], cited the pandemic as a stressor for SCHMs and proposed a blockchain-based solution for digital SCs for a healthcare monitoring system. This technological solution could contribute to effective vaccine distribution and management. Specifically, Cui et al. [31] listed the several potential fragilities of a vaccine SC that could be mitigated by using blockchain technology. Among those fragilities, manufacturers could produce unqualified vaccines, intermediate suppliers could collude to sell and use fake vaccines, and vaccine transportation could fail to comply with strict cold-chain requirements [31]. Currently, traditional SCHMs rely on centralized systems to manage vaccine supervision [31]. Given the fact that these systems do not allow for secure and immutable transactions among keyholders, it is not easy to unconditionally trust an entire SC. Since a central characteristic of blockchain is decentralization—meaning that no single user can control it [8]—this technology can be used to build trustworthy environments with high transparency and security. Unfortunately, no articles tested this approach in real case studies, but all three of them [31,47,56] endorsed the implementation of blockchain technology to ensure data integrity and security.

While promising, the adoption of blockchain for vaccine SCs requires a significant change in organizational structure and policies, as well as the implementation of a large-scale Internet of Things infrastructure and technical expertise [65–67].

4.3. Medical Tools, Blood, Organs, and Tissues

As in the previously cited articles, the discourse on the use of blockchain in the SCs of medical tools, such as COVID-19 medical equipment and personal protective equipment, has been influenced by the COVID-19 pandemic [30,39,41]. However, these studies were purely theoretical and did not assess scalability [30,39,41]. The effectiveness of data reliability is the common feature proposed.

The SC of blood transfusions is a suitable candidate for blockchain implementation due to the potential for adverse events and the associated high risk of death or serious complications related to this procedure [68].

The secure information visibility, transparency, and reliability [65,69] of blockchain technology can improve the efficient management of blood transfusions by providing real-time recordings of donated blood, preventing forgery and information tampering, and reducing blood supply time. However, there is insufficient verification of the proposed systems for blood transfusion SC management by using blockchain technology. [43,45].

4.4. Summary of Evidence

In summary, the currently available knowledge on the application of blockchain in SCHMs is still theoretical. The bottom line is that much more must be done to actually harvest these technologies' full potential. The lack of concrete use cases and case studies might be related to the novelty of blockchain technology and to its complexity. Moreover, many barriers need to be overcome to pave the way for the adoption of blockchain technologies in the healthcare industry: financial issues, security issues, lack of expertise and knowledge, and uncertain government policies [70].

As blockchain promises efficiency and reliability, the necessity of advocating for its implementation grows stronger among both scholars for further theoretical studies and in industry for real-world applications. Given that SCs are interdependent webs of different stakeholders' interests and actions, it is crucial to have them aligned with this common innovation and committed to sharing the same objectives and guidelines.

4.5. Limitations

There are a few limitations to be noted in this review. First, it was limited to English-language studies, which may have limited the number of assessed papers. However, as English is still the language of choice for the internationally peer-reviewed literature, this limitation has a modest impact. Secondly, the initial search for this review was conducted before 15 September 2022. On that date, the Ethereum (ETH) network transitioned from proof of work (PoW) to proof of stake (PoS) in a process known as "the merge" [71]. As a result, all simulations in the ETH network before that date may be considered obsolete. However, while the node validation method changed, the technology itself did not. Therefore, theoretical studies may still be considered valid, while real-world applications will need to be updated. Additionally, as improvements and impairments in node validation primarily affect data-flow efficiency, scalability is the main characteristic that needs to be reassessed. Fortunately, the assessed studies seldom took scalability into consideration, and findings of this review are largely unaffected by "the merge". However, new studies exploring the performance and scalability of the ETH network after "the merge" are necessary.

5. Conclusions

This systematic literature review on the use of blockchain technology to support SCs in healthcare showed the current efforts of researchers worldwide to leverage this innovative technology, particularly for industry-derived products, such as drugs and medical devices, as well as patient-derived products, such as blood, organs, and tissues.

Despite its limitations, the findings of this systematic review highlight a significant but nascent interest in this topic within the available literature, with heterogeneous ideas and methodologies and a lack of effective real-life applications. Smart contracts have emerged as a useful strategy for automating transactions among peers when predefined conditions are met in blockchain networks. The adoption of blockchain in healthcare has the potential to improve patient outcomes and the overall healthcare system. However, further research with real-life applications is needed to provide a clearer conclusion on the uses and performances of blockchain in healthcare SCs.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/app13020686/s1, Table S1: Literature search; Table S2: Description of the extracted variables; Table S3: Quality assessment. References [18,62,72–80] are cited in the supplementary materials.

Author Contributions: Conceptualization, M.F., D.G. and A.C.; methodology, A.B. and F.S.; validation D.G. and P.R.; formal analysis, M.F., G.L. and M.R.; investigation, M.F., G.L., M.R. and A.B.; data curation, M.F.; writing—original draft preparation, M.F. and A.C.; writing—review and editing, D.G. and F.S.; supervision, P.R., F.S. and D.G.; project administration, M.F. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author, P.R., upon reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

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