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A SYSTEMATIC REVIEW OF THE LITERATURE ON THE APPLICATION OF BLOCKCHAIN IN THE HEALTH SUPPLY CHAIN

UMA REVISÃO SISTEMÁTICA DA LITERATURA SOBRE A APLICAÇÃO DE BLOCKCHAIN NA CADEIA DE SUPRIMENTOS DE SAÚDE

UNA REVISIÓN SISTEMÁTICA DE LA LITERATURA SOBRE LA APLICACIÓN DE BLOCKCHAIN EN LA CADENA DE SUMINISTRO DE SALUD

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Abstract

Objective of the study: This article aims to present a systematic literature review on the application of blockchain in the healthcare supply chain.

Relevance / originality: The relevance and originality consist in the presentation of a systematic literature review that focuses and considers the concepts of blockchain, healthcare and supply chain as equally important, in the studied time frame.

Methodology / approach: The systematic literature review followed a protocol based on Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA), performing the search in eight databases, selecting conference and journal articles based on their content in sequential steps.

Main results: As a result, 122 publications were selected. The number of publications in the field has been found to grow rapidly, and sensors and the Internet of Things (IoT) are two prominent minor topics. Three research challenges were raised.

Theoretical / methodological contributions: Provide understanding to academics and professionals in the field about the state of the art of applying the blockchain in the healthcare supply chain, both in terms of the evolution of the literature, as well as in terms of raising new research.

Social / management contributions: Raising discussions on solutions to healthcare supply chain issues, involving for example data integrity and privacy in electronic medical reports, drug counterfeiting and the use of sensors and the internet of things.

Keywords: Blockchain. Healthcare 4.0. Supply Chain. Systematic Literature Review. Industry 4.0.

Resumo

Objetivo do estudo: Este artigo tem o objetivo de apresentar uma revisão sistemática da literatura sobre a aplicação de blockchain na cadeia de suprimentos de saúde.

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Relevância/originalidade: A relevância e originalidade consiste na apresentação de uma revisão sistemática que lança foco e considera em igual importância os conceitos de blockchain, saúde e cadeia de suprimentos, no recorte temporal estudado.
Metodologia/abordagem: A revisão sistemática da literatura seguiu um protocolo baseado no Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA), realizando a busca em oito base de dados, selecionando os artigos de conferência e periódicos com base em seu conteúdo em etapas sequenciais.
Principais resultados: Como resultados, 122 publicações foram selecionadas. Descobriu-se que o número de publicações na área cresce rapidamente, e sensores e Internet das Coisas (IoT) são dois tópicos secundários proeminentes. Três desafios de pesquisa foram levantados.
Contribuições teóricas/metodológicas: Prover compreensão aos acadêmicos e profissionais da área sobre o estado da arte da aplicação do blockchain na cadeia de suprimentos de saúde, tanto em termos da evolução da literatura, como em termos do levantamento de novos desafios de pesquisa.
Contribuições sociais/para a gestão: Levantar discussões sobre soluções para problemas da cadeia de suprimentos da saúde, envolvendo por exemplo integridade e privacidade de dados em relatórios médicos eletrônicos, falsificação de medicamentos e uso de sensores e internet das coisas.

Palavras-chave: Blockchain. Saúde 4.0. Cadeia de Suprimentos. Revisão Sistemática da Literatura. Industria 4.0.

Resumen
Objetivo del estudio: Presentar una revisión sistemática de la literatura sobre la aplicación de blockchain en la cadena de suministro de atención médica.
Relevancia/originalidad: Consiste en la presentación de una revisión sistemática de la literatura que enfoca y considera los conceptos de blockchain, salud y cadena de suministro como igualmente importantes, en el marco temporal estudiado.
Metodología / enfoque: La revisión sistemática de la literatura siguió un protocolo basado en Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA), realizando la búsqueda en ocho bases de datos, seleccionando artículos de congresos y revistas según su contenido en pasos secuenciales.
Resultados principales: Se seleccionaron 122 publicaciones. Se ha descubierto que la cantidad de publicaciones en el campo crece rápidamente, y los sensores y el Internet de las cosas (IoT) son dos temas menores destacados. Se plantearon tres retos de investigación
Aportes teóricos/metodológicos: Brindar comprensión a académicos y profesionales del área sobre el estado del arte de la aplicación de blockchain en la cadena de suministro de salud, tanto en términos de evolución de la literatura, como en términos de plantear nuevas investigaciones.
Contribuciones sociales / de gestión: generar debates sobre soluciones a los problemas de la cadena de suministro de atención médica, que involucran, por ejemplo, la integridad y privacidad de los datos en informes médicos electrónicos, la falsificación de medicamentos y el uso de sensores e Internet de las cosas.

Palabra clave: Blockchain. Healthcare 4.0. Cadena de suministro. Revisión Sistemática de la Literatura. Industria 4.0.

1 Introduction

Blockchain is a technology and architecture platform, first published by Nakamoto (2008), and launched in 2009. Blockchain works by storing information in recording ledgers among peers bellowed into a distributed infrastructure in a decentralized manner across computing devices that are members of the blockchain infrastructure. This technology has gained widespread importance and acceptance in the last few years, based on (i) its guarantee

of data immutability and integrity (ii) its no need of third trusted parties to perform transactions, and (iii) its capacity of running decentralized and transparent transactions (Abujamra & Randall, 2019; Banerjee et al., 2018; Zhang et al., 2018; Galvez et al., 2018).

The blockchain technology has applicability in various Industry 4.0 applications, according to Bodkhe et al. (2020). Moreover, the blockchain technology could be implemented in several different areas, such as legal, finance, food industries, government, real estate, smart properties, banking, supply chain and healthcare (Badr et al., 2018; Radanović & Likić, 2018; Kumar & Tripathi, 2019; Wang et al., 2019; Min, 2019).

Banking and finance have had more research published from the academic community, based on the initial article about bitcoin (Nakamoto, 2009). However, the healthcare supply chain started to receive more attention as a blockchain-enabled application more recently (Yue, et al., 2016). Tanwar et al. (2020) state that blockchain is a key enabler technology of the era of healthcare 4.0, which we have been experiencing from 2016 to the present day. Thus, the blockchain technology has the potential to play a pivotal role in the healthcare supply chain, bringing all its aforementioned benefits.

In this sense, given the novelty of this field of research, the research questions approached by this article emerge. These research questions are: How the literature regarding the application of blockchain in the healthcare supply chain has been performing in recent years? And what are the potential challenges and future research directions regarding the application of blockchain in the healthcare supply chain?

Given the aforementioned research questions, the general objective of this article is to perform a systematic literature review to unravel the state-of-the-art in research on the application of blockchain in the healthcare supply chain. The specific objectives of this article are the ones that follow. First, to show the bibliometric evolution of publications regarding the usage of blockchain in the healthcare supply chain. Second, to indicate the potential challenges and future research directions regarding the application of blockchain in the healthcare supply chain.

The remainder of this article is organized as follows. In Section 2, the background on blockchain and the healthcare supply chain is presented. In Section 3, the research methodology is presented. In Section 4, research results are presented and discussed. Section 5 concludes this work and draws future directions.

2 Theoretical background

This section introduces the basic concepts and background on the main subjects approached by our work. Section 2.1 discusses the blockchain technology, and Section 2.2 discusses the healthcare supply chain.

2.1 Blockchain

Blockchain can be defined as a peer-to-peer network with a distributed database, where each asset transaction is validated by cryptography and rules defined in the smart contract between the participants of blockchain network, before being added to a permanent record ("ledger") and the proof of violations, creating a chronological chain of events (Abujamra & Randall, 2019; Dwivedi et al., 2019; Vazirani et al., 2019; Agbo et al., 2019; Kumar & Tripathi, 2019).

This technology has had great importance and widespread acceptance in recent years, based on two characteristics. The first feature is its immutability guarantee (where all records will be written forever and cannot be changed unless someone who manages to gain more than 51% control of the node at the same time (Niranjanamurthy et al, (2018)), transparency (data's logging by Blockchain system is transparent for each node, each of these nodes can further update the data, which makes it transparent and reliable), integrity (preventing resources to be modified without authorization resources), security (protecting personal data from unauthorized third-party access or malicious attacks and exploitation of data), and trackability (capable to being tracked) for the native data, i.e. the data that is created solely by the customer of an application in the network or its agents and is stored in the blockchain. The second feature is its decentralized (does not have to rely on centralized nodes, the data can be recorded, stored and updated on multiple system) nature, i.e. there is no need of a centralized trusted third party to validate transactions among peers in the network (Abujamra & Randall, 2019; Banerjee, et al., 2018; Zhang, et al., 2018; Galvez, et al., 2018).

Blockchain works as a peer-to-peer distributed and decentralized technology, using the ledger to record all approved digital transactions (Christidis & Devetsikiotis, 2016). In addition, the blockchain ledger offers highly reliable storage capabilities as it is created using consensus algorithm mechanisms, cryptographic signatures, and hash chains. Each transaction runs over smart contract rules, and its approval is based on consensus among blockchain peers. All peers belonging to a blockchain (private, public or consortium) have a copy of the smart contract and the ledger (Tapscott & Tapscott, 2016). Thus, as a peer-to-peer network, there is no centralized trusted third-party authority, and a consensus algorithm authorizes the transaction (Zhang et al., 2018; Zhou et al., 2018).

In the public blockchain, all records are visible to the public and everyone can participate in the consensus process. As the public blockchain is open to the world, it can attract many users and active communities. As for the private blockchain, only nodes that come from a specific organization could

participate in the consensus process. Furthermore, the private blockchain is considered a centralized network as it is fully controlled by an organization. In contrast, only a group of pre-selected nodes among the organizations would participate in the consensus process of a consortium blockchain. The consortium blockchain is built by multiple organizations and is partially decentralized as only a small part of the nodes would be selected to determine consensus. As for consortium blockchain, it can be applied in many business applications.

Each block into the network is responsible for validating the next transaction, due to the use of a hash algorithm to create a hash code used by the last transaction. This sequential dependency creates a chain of blocks. For a transaction to be validated, there is a need for consensus among the peers of the network. If there is an attempt to modify the standards of a previous block, there will be no consensus and the transaction will fail (Badr et al., 2018; Brogan et al., 2018; Boulos et al., 2018; Casino et al., 2019). That consensus process guarantees the immutability, trackability and security of data into the blockchain network.

2.2 Healthcare supply chain

Healthcare is defined by the Cambridge Dictionary (https://dictionary.cambridge.org/, accessed in 31, July, 2021) as "the set of services provided by a country or an organization for treating people who are sick". Thus, it refers to the activity/business of providing medical services. Hospitals, clinics, and medical communities are part of the healthcare system. Such system can be public, private, or nonprofit. A healthcare unit can be considered a facility that provides indirect or direct services to promote or keep personal health condition (Gomes et al., 2016). Healthcare quality is defined as a degree to which health services for individuals and populations increase the likelihood of desired health outcomes and care, consistent with current professional knowledge (Gomes et al., 2016). Supply Chain Management (SCM) is the key business integration process between end users and suppliers, to provide services, products, and valuable information to add value for customers and stakeholders (Lambert & Cooper, 2000).

In this work, the study on the logistics and supply chain management will be directed to the healthcare sector. Thus, this study refers to the healthcare supply chain, which is important to describe the importance of manufacturing goods that have been transported across several intermediate healthcare organizations. The importance of ensuring the transportation of a product or service from a supplier to a customer is becoming more complex due to globalization and market expansion. (Azzi et al., 2019). On the other hand, logistics and stock control reduce product cost, increase the operation efficiency, and prevents jeopardizing safety in healthcare segment (Krähenbühl-Melche et al., 2007; Westbrook et al., 2011; Keers et al., 2013). For

instance, Azzi et al. (2019) stated that approximately 6% of patients inside hospitals used to have the experience of adverse drugs during their stay in the period between 1990 and 2003. Therefore, international initiatives and policies to improve patient safety, in terms of safe medication practices, were proposed, and they were supported by logistics (Lotta et al., 2019).

3 Research methodology

To provide a transparent, reproducible, and scientific literature review, the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) protocol was followed in this work (Moher et al., 2009). The first step in the systematic mapping process, was defining the research questions based on the objectives of this work.

Research Question 1 - How the literature regarding the application of blockchain in the healthcare supply chain has been performing in recent years?

Research Question 2 - What are the potential challenges and future research directions regarding the application of blockchain in the healthcare supply chain?

The second step was defining the scientific databases where to perform the search for articles. Table 1 shows the selected databases. The criterion used for selecting these databases was the importance of the digital database to the healthcare and information technology/engineering area, to cover the most relevant scientific literature on blockchain and healthcare.

Table 1

Scientific data sources used in the systematic literature review

Source	URL	Type
Web of Science	https://clarivate.com/products/web-of-science/	Digital Journal library
Emerald Insight	https://www.emeraldinsight.com/	Digital Journal library
Pubmed	https://www.ncbi.nlm.nih.gov/pubmed/	Digital Journal library
Taylor and Francis	https://taylorandfrancis.com/	Digital Journal library
IEEE Xplore	https://ieeexplore.ieee.org/Xplore/home.jsp	Digital Journal library
ScienceDirect	https://www.sciencedirect.com/	Digital Journal library

Source: The authors.

The third step was to define search terms and search string used to perform the search on the selected databases. The final search string used was "((Blockchain OR "Smart Contract" OR Ledger) AND (Healthcare OR Medical OR Hospital) AND (Logistic OR "Supply Chain" OR Dispensation) AND (Security OR Integrity OR Accuracy))". This search string was constructed based on the research domains of this work (blockchain and healthcare supply

chain). This string was adapted for performing the search in each database. The period between January of 2015 and August of 2022 was considered in this research.

Table 2

Summary of screening results

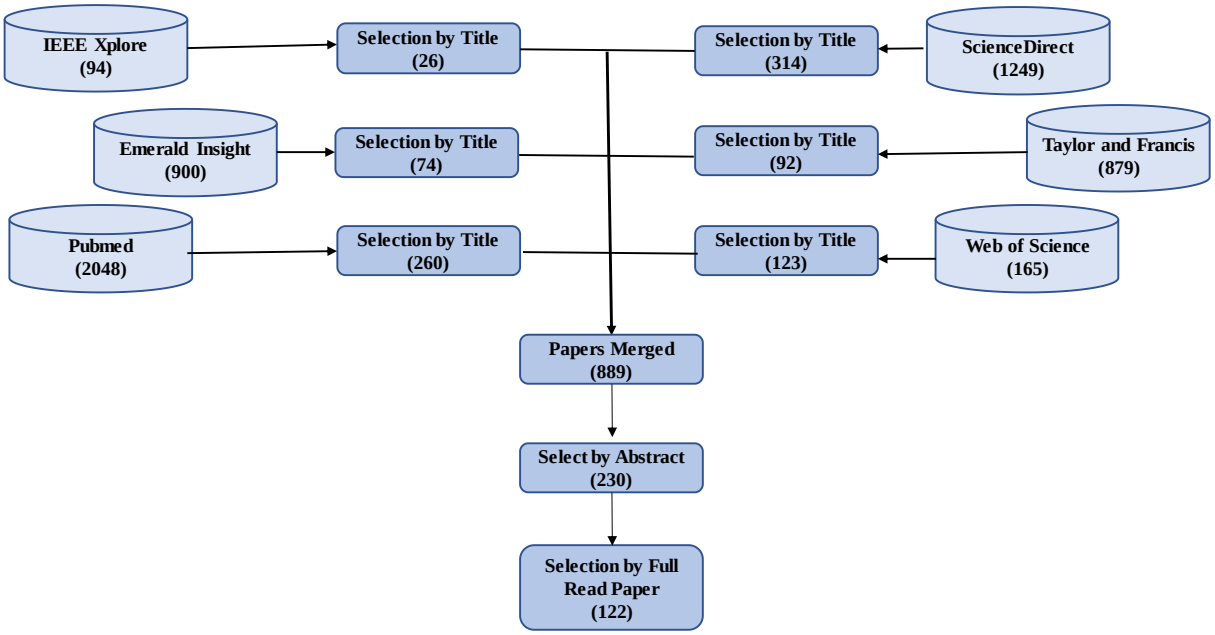
Scientific data source	Raw Results	Results of first selection
Emerald Insight	900	74
IEEE Xplore	94	26
Pubmed	2048	260
ScienceDirect	1249	314
Taylor and Francis	879	92
Web of Science	165	123
Total	5335	889

Source: The authors.

The fourth step was to perform the search in the databases, obtaining BibTeX and RIS files. The fifth step was to import all the retrieved BibTeX and RIS files that were generated by the databases after each search with the search results into the reference management software Mendeley® (https://www.mendeley.com, accessed in 22 August, 2022), classified by scientific data source. The numbers of papers returned by each scientific data source (raw results) are shown in Table 2.

Figure 1

Research flow datagram



Source: The authors.

The sixth step was to conduct the "first selection" process on the papers of each database, achieving the relevant results also shown in Table 2. The first selection was performed by the following exclusion criteria: a) remove papers written in non-English language; b) remove non-peer-reviewed papers, such as interviews or marketing announces, resulting only in journal and conference papers left; c) remove papers without full text access available. In this first selection, 4446 papers were excluded, and the remaining papers were 889. As shown in Figure 1, the 889 papers were inspected with more detail by reading their titles and abstracts, assessing if the papers met the relevance criterion, i.e. papers which did not focus on the application of blockchain in healthcare supply chain according to their title and abstracts were removed. The remaining result comprised 230 papers. Finally, the 230 papers were downloaded and fully read, using the same relevance criterion. The final list has 122 screened papers, which will be assessed in the following section of this work.

Table 3

Research list of paper, after applied PRISMA statement, selection by year of publication

#	Year	Authors	Publication
1	2022	Abbas, A. F et.al	Strengthening pharmaceutical systems for palliative care services in resource limited settings: Piloting a mHealth application across a rural and urban setting in Uganda
2	2022	Babu, E. S. et. al	Healthcare Data Gateways: Found Healthcare Intelligence on Blockchain with Novel Privacy Risk Control
3	2022	Chen, J. et al.	Blockchain : Securing a New Health Interoperability Experience
4	2022	Hawashin, D. et al.	From blockchain technology to global health equity: Can cryptocurrencies finance universal health coverage
5	2022	Hossain, N. et al.	State of Blockchain Adoption on the Pharmaceutical Supply Chain Industry Study
6	2022	Jadhav, J. & Deshmukh, J.	Blockchain technology for improving clinical research quality
7	2022	Kamenivskyy, Y. et al.	Blockchain distributed ledger technologies for biomedical and health care applications
8	2022	Li, D. et al.	Analysis of Blockchain technology: pros, cons and SWOT
9	2022	Marakala, V. et al.	Blockchain technology for detecting falsified and substandard drugs in distribution: Pharmaceutical supply chain intervention
10	2022	Nurlaela A. et al.	Blockchain-Based Medical Records Secure Storage and Medical Service Framework
11	2022	Torrado, A. & Barbosa-Póvoa, A.	Data resource profile: the National Health Insurance Research Database (NHIRD)
12	2022	Trenfield, S . et al.	Falsification of biotechnology drugs: current dangers and/or future disasters?
13	2022	Zhao, Y.	Future information technology tools for fighting substandard and falsified medicines in low- and middle-income countries
14	2022	Zhao, Y; Du, K.	Geospatial blockchain: promises, challenges, and scenarios in health and healthcare.
15	2022	Zoughalian, K. et al.	Governance on the drug supply chain via gcoin blockchain
16	2021	Ahmad, R. et al.	Hybrid blockchain and internet-of-things network for underground structure health monitoring
17	2021	Alkhader, W. et al.	Information security model of block chain based on intrusion sensing in the IoT environment
18	2021	Alshahrani, W. et al.	MIStore: a Blockchain-Based Medical Insurance Storage System.
19	2021	Alsunbul, A. et al.	Pharma Industry 4.0: Literature review and research opportunities in sustainable pharmaceutical supply chains
20	2021	Baharmand, H. et al.	Potentials and Challenges of the Health Data Cooperative Model
21	2021	Bamakan, S. et al.	Realizing the potential of blockchain technologies in genomics
22	2021	Bischoff, O. & Seuring, S.	Root Exploit Detection and Features Optimization: Mobile Device and Blockchain Based Medical Data Management
23	2021	Dai, H. et al.	Scope for the Application of Blockchain in the Public Healthcare of the Russian Federation
24	2021	Das, A. et al.	Using Blockchain Technology to Manage Clinical Trials Data: A Proof-of-Concept Study
25	2021	Gohil, D. et al.	An automatic RFID reader-to-reader delegation protocol for SCM in cloud computing environment
26	2021	Gupta, P. et al.	On the Way to Close the Loop in Information Logistics: Data from the Patient - Value for the Patient
27	2021	Ismail, L. et al.	Converging blockchain and next-generation artificial intelligence technologies to decentralize and accelerate biomedical research and healthcare
28	2021	Johny, S. & Priyadharsini, C.	A Blockchain Based Framework Secured by ECDSA to Curb Drug Counterfeiting

#	Year	Authors	Publication
29	2021	Leal, F. et al.	A decentralized privacy-preserving healthcare blockchain for IoT
30	2021	Leng, Z . et al.	A hybrid framework for multimedia data processing in IoT-healthcare using blockchain technology
31	2021	Masudin, I. et al.	A scoping review of interventions for vaccine stock management in primary health-care facilities
32	2021	Mittal, P . et al.	A Survey of Blockchain Technology Applied to Smart Cities: Research Issues and Challenges
33	2021	Musamih, A . et al.	An attribute-based access control model in RFID systems based on blockchain decentralized applications for healthcare environments
34	2021	Naga N . et al.	Application of Blockchain to Supply Chain: Flexible Blockchain Technology
35	2021	Nair, A. et al.	Blockchain applications - Usage in different domains
36	2021	Palas, Md. J. & Bunduchi, R.	Blockchain Applications in the Biomedical Domain: A Scoping Review
37	2021	Qiu, Z. & Zhu, Y.	Blockchain in internet-of-things: Architecture, applications and research directions
38	2021	Sabbagh, P . et al.	Blockchain recall management in pharmaceutical industry
39	2021	Sadri, S. et al.	Blockchain Technologies: Opportunities for Solving Real-World Problems in Healthcare and Biomedical Sciences.
40	2021	Singh, B. & Gupta, A.	Could Blockchain Technology Empower Patients, Improve Education, and Boost Research in Radiology Departments? An Open Question for Future Applications
41	2021	Sunmola, F. et al.	'Fit-for-purpose?' - Challenges and opportunities for applications of blockchain technology in the future of healthcare
42	2021	Uddin, M.	Implementing blockchains for efficient health care: Systematic review
43	2021	Uddin, M. et al.	Methods and concepts for elaborating a decision aided tool for optimizing healthcare medicines dispatching flows
44	2021	Yang, J. et al.	Prototype of running clinical trials in an untrustworthy environment using blockchain
45	2020	Abu-elezz, I. et al.	Use of Blockchain in Healthcare: A Systematic Literature Review
46	2020	Agbo, C. et al.	When blockchain meets Internet of Things: Characteristics, challenges, and business opportunities
47	2020	Aghamohammadzadeh , E. & Valilai, O.	Traceability of counterfeit medicine supply chain through Blockchain
48	2020	Alharthi, S. et al.	A Cross-Chain Solution to Integrating Multiple Blockchains for IoT Data Management
49	2020	Chenthara, S. et al.	Simulation Model for Blockchain Systems Using Queuing Theory
50	2020	Chiacchio, F. et al.	A novel medical blockchain model for drug supply chain integrity management in a smart hospital
51	2020	De Aguiar, E.J.. et al.	A systematic literature review of blockchain-based applications: Current status, classification and open issues
52	2020	Dutta, P; C. et al.	EHAPAC: A privacy-supported access control model for IP-enabled wireless sensor networks
53	2020	Govindan, K. et al.	A Blockchain based model for Curbing Doctors Shopping and Ensuring Provenance Management
54	2020	Hasselgren, A. et al.	A Blockchain Based Solution for Medication Anti-Counterfeiting and Traceability
55	2020	Indumathi, J.. et al.	A decentralized application for the traceability process in the pharma industry
56	2020	Lam, C. et al.	A decision support system for demand management in healthcare supply chains considering the epidemic outbreaks: A case study of coronavirus disease 2019 (COVID-19)
57	2020	Mackey, T. et al.	A novel cloud manufacturing service composition platform enabled by Blockchain technology
58	2020	Marbouh, D. et al.	A proposed framework model for dairy supply chain traceability
59	2020	Pane, J. et al.	A Survey of Blockchain-Based Strategies for Healthcare

#	Year	Authors	Publication
60	2020	Rahman, M. et al.	Block Chain Based Internet of Medical Things for Uninterrupted, Ubiquitous, User-Friendly, Unflappable, Unblemished, Unlimited Health Care Services (BC IoMT U6HCS)
61	2020	Reda, M. et al.	Blockchain for COVID-19: Review, Opportunities, and a Trusted Tracking System
62	2020	Saindane, P. et al.	Blockchain for IoT Enabled Supply Chain Management - A Systematic Review
63	2020	Sangeetha, A S. et al.	Blockchain in health supply chain management: State of art challenges and opportunities
64	2020	Schniederjans, D. et al.	Blockchain in healthcare and health sciences-A scoping review.
65	2020	Shamsuzzoha, A. et al.	Blockchain in Healthcare Opportunities, Challenges, and Possible Solutions
66	2020	Singh, Rajani; D. et al.	Blockchain in healthcare: A systematic literature review, synthesizing framework and future research agenda
67	2020	Tan, A. & Ngan, P.	Blockchain technology applications to postmarket surveillance of medical devices
68	2020	Tandon, A. et al.	Blockchain technology in supply chain operations: Applications, challenges and research opportunities
69	2020	Wong, L. et al.	Blockchain: A Solution for Improved Traceability with Reduced Counterfeits in Supply Chain of Drugs
70	2020	Zhu, P. et al.	Combating health care fraud and abuse: Conceptualization and prototyping study of a blockchain antifraud framework
71	2019	Abou J. et al.	Data-driven sustainable supply chain through centralized logistics network: Case study in a Finnish pharmaceutical distributor company
72	2019	Ahmad, F. et al.	Developing a Blockchain-Based Supply Chain System for Advanced Therapies: Protocol for a Feasibility Study.
73	2019	Casino, F. et al.	Formalizing Dynamic Behaviors of Smart Contract Workflow in Smart Healthcare Supply Chain
74	2019	Drosatos, G & Kaldoudi, E	Internet of things based blockchain for temperature monitoring and counterfeit pharmaceutical prevention
75	2019	Dwivedi, A.D. et al.	The Impact Of Blockchain Implementation On Pharmaceutical Supply Chain Sustainability: A Conceptual Study
76	2019	Figueroa, S. et al.	Supply chain digitisation trends: An integration of knowledge management
77	2019	Iwu, C. et al.	Unearthing the determinants of Blockchain adoption in supply chain management
78	2019	Jamil, F. et al.	The benefits and threats of blockchain technology in healthcare: A scoping review
79	2019	Jiang, Y. et al.	A Blockchain-Based Approach for Drug Traceability in Healthcare Supply Chain
80	2019	Justinia, T.	A Blockchain-based Contactless Delivery System for Addressing COVID-19 and Other Pandemics
81	2019	Kawaguchi, N.	A Novel Structure of Blockchain Applied in Vaccine Quality Control: Double-Chain Structured Blockchain System for Vaccine Anticounterfeiting and Traceability.
82	2019	Kumar, R. &Tripathi, R.	A Scoping Review of Integrated Blockchain-Cloud (BcC) Architecture for Healthcare: Applications, Challenges and Solutions.
83	2019	Liu, F. et al.	AI and Blockchain-Based Cloud-Assisted Secure Vaccine Distribution and Tracking in IoMT-Enabled COVID-19 Environment
84	2019	Mackey, T. et al.	Antecedents and consequences of supply chain risk management capabilities: an investigation in the post-coronavirus crisis
85	2019	Memon, R. et al.	Application of Hyperledger in the Hospital Information Systems: A Survey
86	2019	Pinheiro, J. et al.	Assessment of Blockchain Technology Application in the Improvement of Pharmaceutical Industry
87	2019	Rathee, G. et al.	Blockchain Application in Healthcare Industry: Attacks and Countermeasures

#	Year	Authors	Publication
88	2019	Sahoo, M. et al.	Blockchain for drug traceability: Architectures and open challenges
89	2019	Vazirani, A.A . et al.	Blockchain Medledger: Hyperledger fabric enabled drug traceability system for counterfeit drugs in pharmaceutical industry.
90	2019	Verde, F. et al.	Blockchain Technology for Hospital Management: A Visualisation and Review of Research Trends
91	2019	Viriyasitavat, W. et al.	Blockchain Traceability in Healthcare: Blood Donation Supply Chain
92	2019	Wong, D. et al.	Blockchain-Based Decentralized Digital Manufacturing and Supply for COVID-19 Medical Devices and Supplies
93	2019	Wu, X. & Lin, Y.	Blockchain-Based Forward Supply Chain and Waste Management for COVID-19 Medical Equipment and Supplies
94	2019	Xie, J. et al.	Blockchain-Empowered Edge Intelligence for Internet of Medical Things Against COVID-19
95	2019	Yagoob, S. et al.	Blockchain-enabled pharmaceutical cold chain: Applications, key challenges, and future trends
96	2018	Anandhi, S.. et al.	Blockchain-integrated technologies for solving supply chain challenges
97	2018	Chen, Y. et al.	Building Blocks for Blockchain Adoption in Digital Transformation of Sustainable Supply Chains
98	2018	Ding, B.	Effectiveness of blockchain to solve the interoperability challenges in healthcare
99	2018	Firdaus, A. et al.	Evaluation and Classification Risks of Implementing Blockchain in the Drug Supply Chain with a New Hybrid Sorting Method
100	2018	Hackl, W. & Hoerbst, A.	Exploring interpretations of blockchain's value in healthcare: a multi-stakeholder approach
101	2018	Janvier, S. et al.	Exploring the application of blockchain to humanitarian supply chains: insights from Humanitarian Supply Blockchain pilot project
102	2018	Jo, B . et al.	FAIR: A Blockchain-based Vaccine Distribution Scheme for Pandemics
103	2018	Kamel B. et al.	Global Level Smart Vaccination Tracking System using Blockchain and IoT
104	2018	Koshechkin, K A. et al.	Investigations on the Implementation of Blockchain Technology in Supplychain Network
105	2018	Li, D. et al.	Opportunities and limitations of public blockchain-based supply chain traceability
106	2018	Lin, L. et al.	Smart Pharmaceutical Manufacturing: Ensuring End-to-End Traceability and Data Integrity in Medicine Production
107	2018	Mamoshina, P. et al.	The impact of the traceability of the information systems on humanitarian logistics performance: Case study of Indonesian relief logistics services
108	2018	Maslove, D. et al.	A Blockchain Secured Pharmaceutical Distribution System to Fight Counterfeiting.
109	2018	Niranjanamurthy, M. et al.	A Blockchain-Based Solution for COVID-19 Vaccine Distribution
110	2018	Ozercan, H. et al.	A Blockchain-Based Solution for Mitigating Overproduction and Underconsumption of Medical Supplies
111	2018	Rasheed, H. et al.	A Matching Scheme from Supply and Demand Sides of Electronic Health Records Based on Blockchain
112	2018	Sylim, P. et al.	A review study of the blockchain-based healthcare supply chain
113	2018	Tseng, J. et al.	A Traceable Blockchain-Based Vaccination Record Storage and Sharing System
114	2018	Van R. et al.	Advancing pharmacy and healthcare with virtual digital technologies.
115	2018	Zhou, L. et al.	An Exploratory Study on the Design and Management Model of Traditional Chinese Medicine Quality Safety Traceability System Based on Blockchain Technology
116	2017	Benchoufi, M. & Ravaud, P.	Design of Optimal Scheduling Model for Emergency Medical Supplies by Blockchain Technology
117	2017	IEEE-SA	Incorporation of Block Chain Technology for Better Operational Management within Medical Industry
118	2017	Kuo, T. et al.	Pharma 4.0: analysis on core competence and digital levelling implementation in pharmaceutical industry in Indonesia

#	Year	Authors	Publication
119	2017	Till, B. et al.	Role of systems engineering attributes in enhancing supply chain resilience: Healthcare in context of COVID-19 pandemic
120	2016	Brodersen; K. et al.	Secure and transparent pharmaceutical supply chain using permissioned blockchain network
121	2016	Namisango, E. et al.	The Blockchain Technologies in Healthcare: Prospects, Obstacles, and Future Recommendations; Lessons Learned from Digitalization
122	2016	Yue, X. et al.	Towards an Optimized and Sustainable Blood Supply Chain Network under Uncertainty: A Literature Review

Source: The authors.

4 Results of the systematic literature review

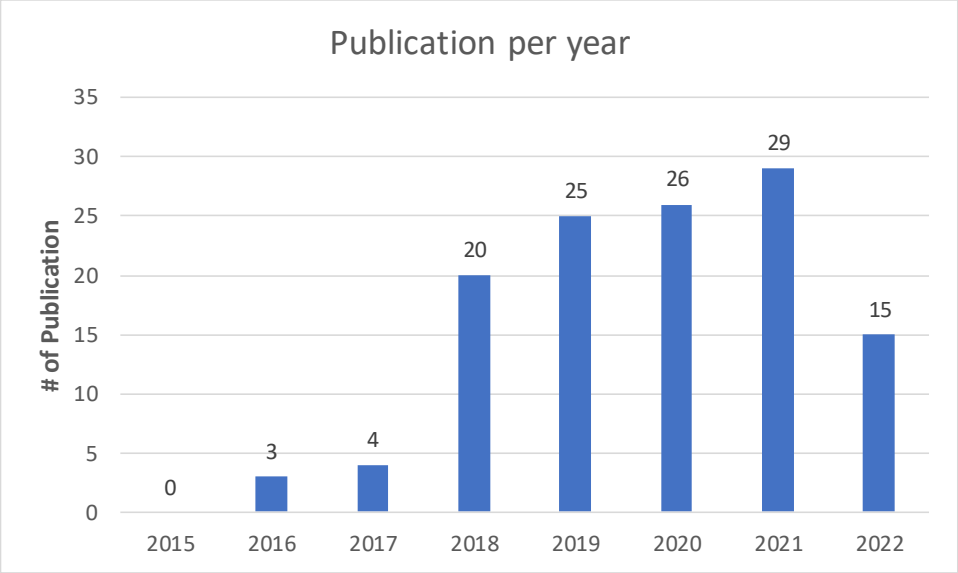
This section shows the results of this research regarding the 122 final papers screened. Sections below discuss the results regarding, respectively, research questions 1 and 2, and provide answers to such questions.

4.1 Performance of literature on blockchain in healthcare supply chain

Even though the search period started in 2015, there are no publications regarding blockchain and the healthcare supply chain topics together in that year. Figure 2 shows the distribution of papers along the years. The papers started to be published in 2016 and few others published in 2017. The number of published papers increased a lot (500%) starting in 2018 and still rising until 2021. Although the search period ends in August, 2022, the number of publications is 15 represent 51,72% of year before (2021). This result shows that the research on blockchain applied to healthcare supply chain is a new topic and the number of published papers in this topic is growing fast.

Figure 2

Number of papers published (# of Publication) by year of publication



Source: The authors.

This research considers some different subject areas (Engineering, Computer Science, Decision Science, Medical, Health, Biology, Physics), represented by the scientific data sources selected. Most of the selected papers were published in Computer Science (22,13%), Engineering (20,08%) and Medicine (14,34%) respectively. This suggests that academics from technology behind the blockchain are the main support for healthcare supply chain. Meanwhile, Business, Management and accounting (6,97%) and Decision Sciences (6,97) should represent the Supply subject area. This suggests that specialists in blockchain are interested in this new application of healthcare supply chain.

4.2 Challenges and future research directions on blockchain in healthcare supply chain

Publication in this area started from 2016 (Yue, et al., 2016) regarding Electronic Medical Record (EMR) controls and implementation. Although EMR takes care of patient's journey, the related information has significant importance to track and trace trust device to individual patients, can control stock of medication (including source, quantity, batch number, date of expiry), advise of hospital's logistic room availability (Namisango, et al., 2016). Several researchers have highlighted the potential of using blockchain technology to address existing challenges in healthcare applications (Abujamra & Randall, 2019; Banerjee et al., 2018;

Benchoufi & Ravaud, 2017; Chen et al., 2018; Gordon & Catalini, 2018; Kuo et al., 2017; Hölbl et al., 2018; Agbo et al., 2019; Tseng et al., 2018).

Blockchain can be applied within healthcare management applications in public or private areas, monitoring and automatizing health claims adjudication and online patient information, achievement of healthcare records, sharing patients' medical data information, pharmaceutical and drug medicine counterfeiting, medical clinical trial, and precision medicine. (Casino et al., 2019; Boulos et al., 2018; Badr et al., 2018; Benchoufi & Ravaud, 2017; Gordon & Catalini, 2018; Vazirani et al., 2019). Combining blockchain technology and the healthcare supply chain allows solving problems of scientific credibility of losing information (data missing or dredging, endpoint switching and selective publication) in clinical trials as well as issues of patients' informed consent (Benchoufi & Ravaud, 2017).

The adoption of blockchain technology at supply chain hospital operations tends to increase the efficiency, reflecting on costs reduction, because virtually all transactions with blockchain are safer, more transparent, traceable and efficient (Kshetri, 2018). Furthermore, the blockchain adoption can enhance customers' trust, which will allow them to check the entire journey of goods across the supply chain in full confidence. In this regard, the traceability mechanisms of the blockchain will support products fraud prevention and fake across the supply chains (Chen et al., 2018). As a result, hospital supply chains will gain efficiency and cost reduction.

There is some literature on blockchain that reported benefits and advantages of this technology that could directly impact the healthcare logistic and supply chain management (L/SCM). Such impacts can be about transparency and accountability (Kshetri, 2018; Zhou et al., 2018), traceability and fraud prevention (Chen et al., 2018), cybersecurity and protection (Kshetri, 2018), for instance.

The healthcare system has become complex years after years for over the last three decades (Plsek & Greenhalgh, 2001; Reibling et al., 2019) due to differences regarding how countries fund, provide, and organize their health system. The new digital technologies, part of industry 4.0, such as blockchain, along with Radio frequency identification (RFID), Internet of Things (IoT), and Cloud of Sensors (CoS) are helping to control, to define, to monitor healthcare applications (Dhanvijay & Patil, 2019; Santos et al., 2018).

Blockchain is considered a disruptive technology, the potential uses of blockchains transcended the initial idea of the financial industry (Nofer et al., 2017). Because blockchains allow the secure exchange of data in a distributed manner, the technology could affect the

structure and governance of healthcare supply chains as well as relationship configurations and information sharing between supply chain actors. If integrated with field-sensing technologies such as the Internet of Things (IoTs), blockchains could create permanent, shareable, and actionable records of products' digital footprints throughout the entire supply chain. Such improved visibility would provide product traceability, authenticity, and legitimacy – all of which are crucial to the medical, pharmaceutical, and healthcare supply chains (Nofer et al., 2017).

Based on the 122 papers screened, IoT technologies and sensors seem to be a representative new scenario within the application of blockchain in healthcare supply chain (Kumar & Tripathi, 2019; Singh, et at.,2020; Sahoo, et al., 2019). Among those papers we can reference 28 papers discussing about topics related to sensors/RFID/IoT. In this scenario, there is a possible solution to implement a sensor network system to control and to grant data security and trackability of medical information.

Therefore, a first challenge that emerges on the application of blockchain in the healthcare supply chain is how to use blockchain and IoT, to track medicine/drugs/medical equipment into the healthcare supply chain to avoid loss of information and medical dispensation, as well as counterfeited drugs (Kumar & Tripathi, 2019; Qiu, & Zhu, 2021). It is necessary to understand the internal logistic process among diverse internal areas of a hospital/clinic and elaborate a process to use electronical devices (sensors and IoT technologies) to collect data on medicine transactions among those areas. This allows controlling and managing medicine stock to avoid dispensation. It is necessary to identify the logistic technology process behind the healthcare areas, map the medicine or drug flow into the hospital and analyze the usage of electronical equipment, such as scanners, to collect the information to be processed (Sahoo, et al., 2019)

A second challenge that emerges on the application of blockchain in the healthcare supply chain regards the EMRs. It refers to how to build a framework based on blockchain to meet accuracy and integrity requirements of EMRs (Jamil, et al., 2019). It is also possible to use sensors and the IoT technology to help improving the accuracy of data collected, to maintain the integrity of EMR information and provide insights to adjust the hospital internal logistics with invoicing procedures, to associate patients with medical device and prescription use, control medicine/ vaccine dispensed (Jamil, et al.,2019). There is a broad area to be explored in challenge, regarding the specification of topology models and information technology architectures to attend the EMR requirements.

A third challenge that emerges on the application of blockchain in the healthcare supply chain regards the development of new devices and protocols to use for collecting data in healthcare supply chain applications (Casino et al., 2019; Abu-elezz, et al., 2020; Vazirani, et al.,2019) . The benefits of using technologies such as sensor networks and clouds of sensors (CoS) with blockchain and healthcare may comprise, besides ensuring the accuracy of data collected and maintaining the integrity of exchanged information, the processing of large amounts of data, along with the reduction in the response time of applications (Mamoshina, et al., 2017). However, further implementations and evaluations in real scenarios are still necessary. Moreover, the usage of RFID to control healthcare supply chain applications is the current standard nowadays and have more competitive prices than more recent technologies (Sylim, et al., 2018).

5 Conclusion

This paper presented a systematic literature review on the application of blockchain in the healthcare supply chain. The systematic literature review followed a protocol based on PRISMA. The first research question referred to investigating the bibliometric evolution of publications regarding the usage of blockchain in the healthcare supply chain. The second research question referred to indicating the potential challenges and future research directions regarding the application of blockchain in the healthcare supply chain. As results, there are 122 publications with blockchain and healthcare supply chain directly involved between 2015 and August, 2022. The topic is relatively new. The results show that research in this field is growing rapidly as the number of publications have increased in the most recent years, and there is much interest from specialists from the areas of healthcare and computer science. In addition, the potential benefits of blockchain to several applications in the healthcare supply chain were raised.

Blockchains have the potential to revolutionize the way healthcare data is efficiently stored, manipulated, and exchanged between healthcare entities while maintaining those entities' incentives. For example, after a patient receives a lab result, the data – rather than being stored centrally on the lab's servers – can be stored encrypted on the blockchain network. The data itself can be tagged with the creator of the data (ie., the lab) so that all parties accessing the data in the future can see who generated it. This allows for the preservation of commercial incentives for the laboratory, as they will still be able to bill insurers and receive funding based on their work. However, control of the data is now given to the patient, who can actively decide

to share it with a new family doctor or send it to a university for research purposes. This reduces concerns about lost or corrupted data, slow data exchange, and unknown resale of data.

There are also new technologies like sensors and IoT are closely related to the topic of this research. Three challenges were raised regarding (i) the tracking of medicine/drugs/medical equipment, (ii) a framework to monitor EMRs, and (iii) the development of novel IoT/CoS technologies. As a future research direction of this work, it is suggested the research of solutions for each of these challenges. Another research direction refers to performing another systematic review for assessing the joint use of IoT/CoS technologies and blockchain in the healthcare supply chain.

Authors' contributions

Contribution	Araujo, A. R. C.	Santos, I. L.	Reis, A. C.
Contextualization	X	X	X
Methodology	X	X	X
Software	X	------	----
Validation	X	X	----
Formal analysis	X	X	----
Investigation	X	----	----
Resources	X	----	----
Data curation	X	----	----
Original	X	X	----
Revision and editing	X	X	----
Viewing	X	X	X
Supervision	X	X	X
Project management	X	-------	----
Obtaining funding	X	----	----

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