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).

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 or public) 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).

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
SpringerLink	https://link.springer.com/	Digital Journal library
IEEE Xplore	https://ieeexplore.ieee.org/Xplore/home.jsp	Digital Journal library
MEDLINE Complete	https://health.ebsco.com/products/medline-complete	Digital Journal library
ScienceDirect	https://www.sciencedirect.com/	Digital Journal library

Note: 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 July of 2019 was considered in this research.

Table 2
Summary of screening results

Scientific data source	Raw Results	Results of first selection
Emerald Insight	70	18
IEEE Xplore	8	8
MEDLINE Complete	5	5
Pubmed	95	54
ScienceDirect	210	85
SpringerLink	307	24
Taylor and Francis	94	3
Web of Science	10	10
Total	799	207

Note: Source: the authors

The fourth step was to perform the search in the databases, obtaining BibTeX files. The fifth step was to import all the retrieved BibTeX 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 31, July, 2021), classified by scientific data source. The numbers of papers returned by each scientific data source (raw results) are shown in Table 2.

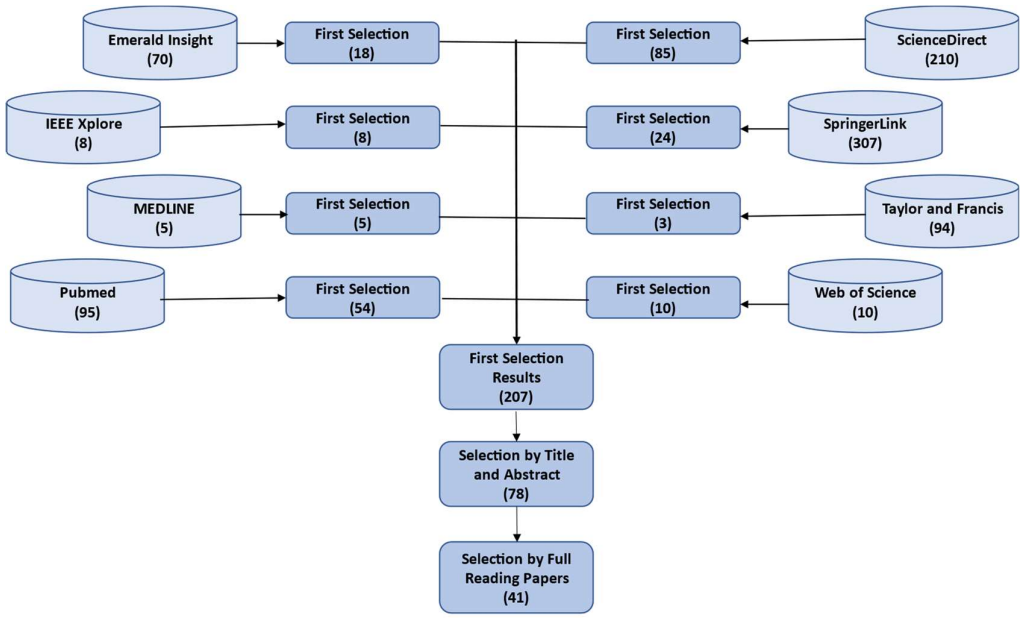

Figure 1. Research flow datagram
Source: the authors

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, 592 papers were excluded, and the remaining papers were 207. As shown in Figure 1, the 207 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 78 papers. Finally, the 78 papers were downloaded and fully read, using the same relevance criterion. The final list has 41 screened papers, which will be assessed in the following section of this work.

4 Results of the systematic literature review

This section shows the results of this research regarding the 41 final papers screened. Sections 4.1 and 4.2 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 majority of published papers is from 2018 (20 papers, i.e. 48,78% of publications). Although the search period ends in July, 2019, the number of publications in 2019 is already 70% of total publications of 2018. 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.

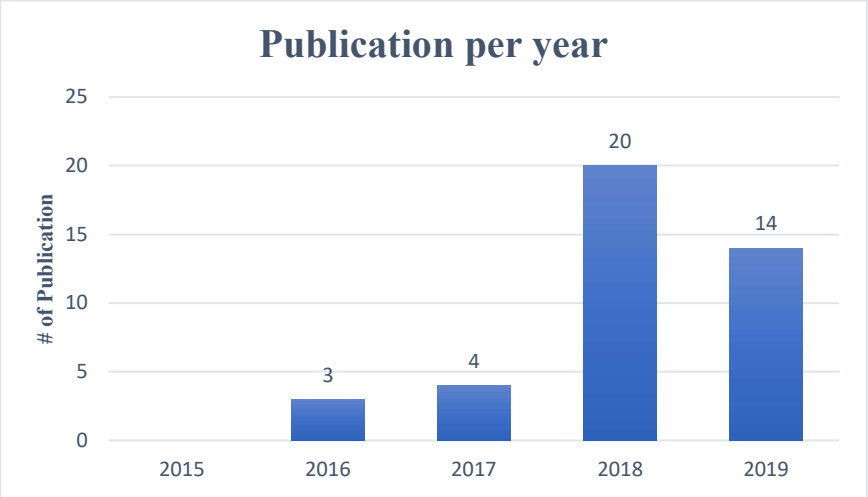

Figure 2: Number of papers published (# of Publication) by year of publication
Source: the authors

This research considers some different scientific areas (Electronic, Computer Science, Logistics, Medical, Health, Biology, Network), represented by the scientific data sources selected. Most of the selected papers (25, i.e. 60,98% of the 41 papers screened) were published in Medical, Health, or Biology areas. This suggests that academics from the healthcare supply chain are interested in the application of blockchain. Meanwhile, 39,02% of papers were published in Electronic or Computer Science areas. This suggests that specialists in blockchain are interested in this new application of healthcare supply chain.

Table 4:
Number of papers published per area

# of Publication	Publisher area	%
25	Medical, Biology, or Health	60,98
16	Eletronic or Computer Science	39,02

Note. Source: the authors

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. 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 41 papers screened, IoT technologies and sensors seem to be a representative new scenario within the application of blockchain in healthcare supply chain. Among those papers we can reference 7 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. 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.

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. 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. Thus, the IoT can be part of such framework. 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. 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. 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.

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 few publications (41) with blockchain and healthcare supply chain directly involved between 2015 and 2019. 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. Sensors and IoT technologies 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.

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