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Blockchain in healthcare: A systematic literature review, synthesizing framework and future research agenda

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ABSTRACT

This study presents a systematic literature review (SLR) of research on blockchain applications in the healthcare domain. The review incorporated 42 articles presenting state-of-the-art knowledge on current implications and gaps pertaining to the use of blockchain technology for improving healthcare processes. The SLR findings indicate that blockchain is being used to develop novel and advanced interventions to improve the prevalent standards of handling, sharing, and processing of medical data and personal health records. The application of blockchain technology is undergoing a conceptual evolution in the healthcare industry where it has added significant value through improved efficiency, access control, technological advancement, privacy protection, and security of data management processes. The findings also suggest that the extant limitations primarily pertain to model performance, as well as the constraints and costs associated with implementation. An integrated framework is presented to address potential areas wherein future researchers can contribute significant value, including addressing concerns regarding regulatory compliance, system architecture, and data protection. Finally, the SLR suggests that future research can facilitate the widespread deployment of blockchain applications to address critical issues related to medical diagnostics, legal compliance, avoiding fraud, and improving patient care in cases of remote monitoring or emergencies.

1. Introduction

Blockchain was originally introduced as a mechanism to power Bitcoin (Nakamoto, 2008), but has now evolved to the point of being referred to as a foundational technology for multiple decentralized applications (Iansiti & Lakhani, 2017). Blockchain is being touted as a useful technology for managing sensitive data, especially within the sectors of healthcare, medical research and insurance (Meinert et al., 2019). Healthcare may be understood as a system that includes three primary constituents: (a) core providers of medical care services, such as physicians, nurses, hospital administrations, and technicians, (b) critical services that are associated with medical services, such as medical research and health insurance (Campbell et al., 2000), and (c) beneficiaries of medical and health-oriented services, i.e. patients, or the public. In the present study, we consider the healthcare system to be inclusive of contact-based and technology-based remote monitoring services extended by constituent service providers in an effort to promote, maintain or restore the health of beneficiaries (Liao et al., 2012; Devadass et al., 2017). In the field of healthcare, privacy and security breaches are purportedly increasing every year, with over 300 breaches reported in 2017 and 37 million medical records affected between 2010 and 2017 (Talesh, 2017; McCoy & Perlis, 2018). The increasing digitization of healthcare has further led to the acknowledgment of concerns related to secure storage, ownership, sharing of patients' personal health records, and allied medical data (Meinert et al., 2019). Blockchain has been suggested as a way to solve critical challenges faced by healthcare, such as secured sharing of medical records and compliance with data privacy laws (Rupasinghe et al., 2019).

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Yet, prior research has made limited attempts to holistically encapsulate extant knowledge by utilizing systematic literature reviews (SLRs) (e.g. Angraal et al., 2017; Hölbl et al., 2018; Agbo et al., 2019; O'Donoghue et al., 2019; Jaoude & Saade, 2019). For instance, Hölbl et al. (2018) employed bibliometric techniques to present an overview of blockchain elements and research trends pertaining to the application of blockchain in healthcare. Angraal, Krumholz, and Schulz (2017) detailed the various platforms that have been developed to deploy blockchain in healthcare. Agbo et al. (2019) discussed different instances of the adoption of blockchain technology in healthcare, the challenges faced, and possible solutions. O'Donoghue et al. (2019) discussed specific tradeoffs and design choices executed by researchers in various scenarios where blockchain technology was applied. Jaoude and Saade (2019) curated studies pertaining to blockchain applications across multiple industries and broadly discussed the different usage contexts for this technology. Recently, Hasselgren et al. (2020) analyzed 39 studies to present summary statistics on popular platforms and targeted areas wherein blockchain has been applied to improve healthcare.

While these SLRs have contributed to the extant body of knowledge, their focus has primarily been on synthesizing or delineating trends (e.g. Hasselgren et al., 2020) and areas of blockchain application (see Risius & Spohrer, 2017; Hölbl et al. 2018; Agbo et al. 2019; Jaoude & Saade, 2019). However, due to the extent and diversity of prior research on blockchain, researchers would benefit from a focused discussion on the ramifications of its adoption (Risius & Spohrer, 2017), as well as specific challenges and areas for improvement for advancing the field (Agbo et al., 2019). Review-based studies can assist in meeting these needs by assimilating existing knowledge and explicating focal areas that need significant scholarly attention (Agbo et al., 2019; Ozdagoglu et al., 2020).

We address this need by conducting an SLR on the use of blockchain in healthcare (Kitchenham et al., 2009). SLRs can provide a valuable summarization of current knowledge in a field of research (Aznoli & Navimipour, 2017) and allow for the identification of existing knowledge gaps and, consequently, avenues for future research (Gopalakrishnan & Ganeshkumar, 2013). This study contributes to the current literature on blockchain in healthcare by adding to prior SLRs in two ways. First, it provides a thematically organized, state-of-the-art classification of prior studies with respect to their application areas, limitations, and recommendations. Second, based on the findings of the SLR, we propose a synthesizing framework to detail potential themes that require scholarly attention to advance the current body of knowledge. This contribution is made by addressing four research questions: **RQ1**. What is the state-of-the-art research profile for blockchain applications in the healthcare domain? **RQ2.** What are the primary areas of healthcare wherein blockchain has been applied? **RQ3.** What are the emergent limitations and challenges that the literature posits for this research area? **RQ4.** What are the future avenues in healthcare that might benefit from the application of blockchain?

The remainder of the paper is structured as follows. Section 2 provides an overview of blockchain technology. Section 3 explicates the methodology adopted for the current SLR. The findings are presented in the Section 4, followed by a discussion of these findings in Section 5. Section 6 presents a detailed discussion of the implications of the insights derived from the findings of this study, limitations and future scope of research. The last section is dedicated to discussing concluding remarks.

2. Blockchain technology

Blockchain is a distributed public ledger database that is maintained by a network of verified participants or nodes (Jaoude & Saade, 2019) and stores immutable blocks of data that can be shared securely without third-party intervention (Hölbl et al., 2018). Data are preserved and recorded with cryptographic signatures and use of consensus algorithms that are enacted as key enablers of its application (Mendling et al., 2018). This ability for data preservation is a significant reason that has driven the use of blockchain in healthcare (Kuo et al., 2019a), wherein a significant amount of data is subject to extensive exchange and distribution (Meinert et al., 2019).

The evolution of blockchain technology and its application in diverse contexts has occurred in various phases. The first phase of blockchain evolution was related to cryptocurrency and the second pertained to the application of smart contracts in areas such as real estate and finance (Swan, 2015; Agbo et al., 2019). The third generation of evolution was focused on the applications of blockchain in nonfinancial domains such as government, healthcare (Swan, 2015; Miau & Yang, 2018), and culture (Efanov & Roschin, 2018). Additionally, driven by innovative technological features such as data immutability (Yli-Huumo et al., 2016), blockchain is now considered to be in its fourth stage of evolution with the incorporation of artificial intelligence (AI) (Angelis & da Silva, 2019). Blockchain's asserted diversity in its scope of applications may be attributed to its potential for creating decentralized (Silva et al., 2019) and trustless transaction environments (Zhang et al., 2018).

The healthcare industry is a prime candidate for blockchain technology (Kuo et al., 2017; Alla et al., 2018; Cios et al., 2019); as blockchain has the potential to address critical concerns, such as automated claim validation (Angraal et al., 2017) and public health management (Mettler, 2016). This technology may allow patients to own data and choose with whom it is shared (Dimitrov, 2019), thereby addressing extant concerns about data ownership and sharing (Zhang et al. 2018; Ji et al., 2018). Concurrently, it enables data records to be unified, updated, securely exchanged, and accessed in a timely by appropriate authorities with the use of consensus protocols (Alla et al., 2018). This is a major advantage afforded by the application of blockchain technology within the healthcare space because current practices require data to be stored with third parties (Hölbl et al., 2018). Finally, blockchain can potentially bring transparency to data management processes (Ito et al., 2018) while also reducing the chances of data mishandling or misuse because of possible human error (Alla et al., 2018).

Despite the positive connotations of blockchain's effect on societal and business transformation, there seems to be a debate on its prevalent advantages and derived benefits in comparison to previously established expectations. A recent report suggests that although organizations will undertake significant investments in implementing blockchain-based technologies in the future, they will likely adopt a cautiously pragmatic approach because of a prevalent belief that the benefits may be over-hyped. It may be said that this technology is yet to meet its touted expectations (Iansiti & Lakhani, 2017), a fact that may be attributed to certain challenges to the widespread implementation of this technology, especially in terms of regulatory barriers (Pawczuk et al., 2019). Another important challenge in promulgating the deployment of blockchain is the unfamiliarity of the public and individual users, such as patients or doctors, with the way this technology works, its technical features (Alla et al., 2018) or its benefits for data management. Iansiti and Lakhani (2017) suggest that due to social, organizational, and implementation barriers, such as security or governance, significant time may be required for blockchain to generate the expected levels of business transformation. This may be additionally compounded by a general uncertainty about blockchain's usage with respect to legal compliance and government regulations (Swan, 2015; Alla et al., 2018). Current research is focused on aiding the operational evolution of blockchain and accelerating its prevalence by addressing these challenges and barriers.

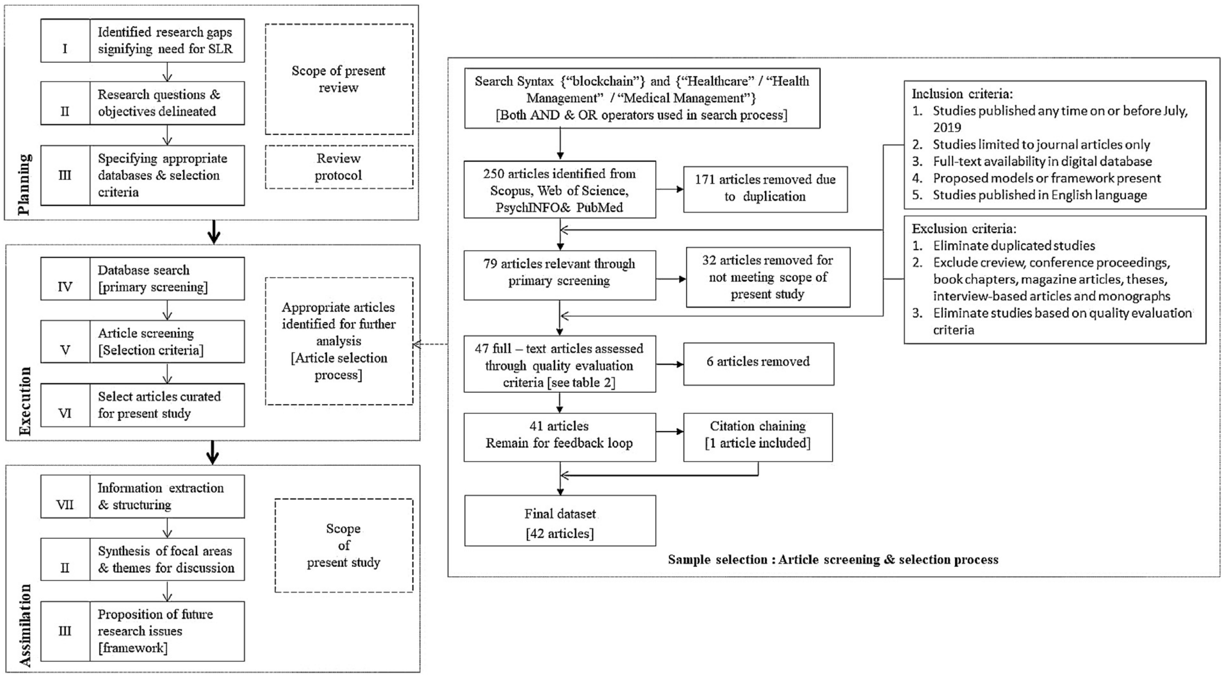

Fig. 1. The protocol for a systematic literature review.

3. Methodology

SLRs offer readers comprehensive knowledge of the literature in a field through a holistic and organized précis that adheres to standard protocols (Afrooz & Navimipour, 2017; Aznoli & Navimipour, 2017; Ahmad et al., 2018; Mehta & Pandit, 2018). SLRs also assist in explicating existing knowledge gaps and consequent identification of avenues for future research (Gopalakrishnan & Ganeshkumar, 2013). The current study adapted protocols set forth by Behera, Bala and Dhir (2019), which synthesized comprehensive article assessment criteria from previously published SLRs. Our SLR protocol consisted of three main phases, namely planning, execution, and reporting assimilated information (see Fig. 1). To address **RQ1**, the present SLR addressed the obtained descriptive statistics related to the following: (a) number of articles published per year; (b) average citations per year received by a reviewed article; and (c) scholarly contributions in the field regarding publishers, journals, and countries. To address **RQ2, RQ3,** and **RQ4**, four modular queries were created, as suggested by prior literature (see Afrooz & Navimipour, 2017): (a) identifying previously investigated study contexts and primary constructs; (b) identifying current intellectual capital by summarizing findings and limitations; (c) extracting focal implications from practical and theoretical perspectives; and (d) identifying emergent research gaps and potential avenues for future research. These queries allowed for a focused synthesis and analysis of selected studies and derive pertinent insights to answer the RQs.

Four databases—PsycINFO, PubMed, Scopus, and Web of Sciences—were identified by prior studies as popular sources of information for articles related to health informatics (Zhang et al., 2017; Behera et al., 2019). Article selection was based on specific inclusion and exclusion criteria, as recommended by prior research (Zhang et al., 2017). These were adapted from Behera et al. (2019) (see Fig. 1) wherein the adaptations were developed and agreed upon by the authors (see note in Table 2 Three keyword combinations were found to be appropriate for a database search performed in July 2019 —"Health management", "blockchain in healthcare", and "medical management" (see Table 1). These keywords were drawn from a review of prior studies (i.e. SLRs) in this field that used similar keywords, i.e. blockchain, healthcare (or health*), and medical (or medic*) (see Hölbl et al., 2018; Alla et al., 2018; Agbo et al., 2019; Hasselgren et al., 2020). Subsequently, appropriate articles were screened according to specific selection criteria for determining quality, relevance, and robustness (Webster & Watson, 2002). The summary protocol and the review and selection process for all three phases are illustrated in Fig. 1.

The quality of articles selected for the final sample was assessed to ensure that the outcomes of the current SLR presented transparent and unbiased results (Behera et al., 2019; Mehta & Pandit, 2018). Two authors completed this assessment and resolved differences in individual evaluation through discussion to reach consensus on the final inclusion or exclusion of a study. In cases where the two authors could not achieve consensus, a third author was involved in review and discussion. The Fleiss' Kappa value for inter-coder agreement was 0.87, which indicates a strong agreement between the two coders (Landis & Koch, 1977). Quality scores were calculated for all articles per the criteria presented in Table 2. Six articles were removed at this stage for not meeting the predetermined threshold value of 4.5 (50 % of maximum score, see details in Table 3), and 41 studies remained after a quality assessment. Backward and forward citation chaining was conducted to address feedback loops. This resulted in the identification of three articles, of which two were excluded for not meeting the quality evaluation criteria. The final sample comprised 42 articles.

3.1. Research profile

Reviewed articles were profiled to understand the status of research on blockchain applications in healthcare. This review suggests that blockchain has seen a recent integration in the healthcare domain because the earliest article included in the sample was published in 2016. However, a sharp increase in the number of yearly publications (see Fig. 2) and average citations for the selected studies (see Fig. 3) suggests that the academic focus on this field has intensified over the last few years. Cristiano André da Costa (Brazil) and Alex Roehrs (Brazil) emerged as the top authors in the field with two publications each (see Table 3). This suggests that this area of

Table 1
Database search summary.

Database	Keywords	Total hits appeared	Abstracts read*	Full text downloaded[a]
	"Blockchain", "Healthcare"	39	39	31
PsycINFO	"Blockchain", "Health management"	30	30	22
	"Blockchain", "medical management"	37	37	16
	"Blockchain", "Healthcare"	68	68	34
PubMed	"Blockchain", "Health management"	38	38	11
	"Blockchain", "medical management"	37	37	7
	"Blockchain", "Healthcare"	284	284	26
Scopus	"Blockchain", "Health management"	146	146	18
	"Blockchain", "medical management"	121	121	19
	"Blockchain", "Healthcare"	140	140	37
Web of Science	"Blockchain", "health management"	55	55	12
	"Blockchain", "medical management"	51	51	17

Note: Results include articles from multiple disciplines such as medicine, genomics, information science, banking etc. Multiple sources and document types were reflected in the search results including journals, trade magazines, books etc.
Results of the search were sorted for "relevance" before reviewing abstracts.
[a] Individual studies may be duplicated in multiple cells of this column.

Table 2
Quality Evaluation (QE) criteria.

QE#	Criterion
QE1	Explicit discussion of data analysis: "quantitative (+2)", "qualitative (+1.5)" or "no evidence (+0)".
QE2	Discussion of advantages and challenges of the topic of interest: "yes (+2)", "partially (+1.5)" and "no (+0)".
QE3	Are the discussed outcomes aligned with and valid with respect to the utilized methodology and topic of interest: "yes (+2)", "partially (+1.5)" and "no (+0)" Note: partial justification pertains to a limited or unavailable explanation for an employed technique or methodology
QE4	Peer-recognition of the article and source reliability: (+2) sum of citations and H Index is > 100 (+1.5) sum of citations and H Index is > = 50 and < = 99 (+1.0) sum of citations and H Index is > = 1 and < = 49 (+0) sum of citations and H Index is 0
QE5	Comparability of the utilized method(s) with methods popularly used in prior studies: "yes (+1)", and "no (+0)"

[Note: based on Behera, Bala and Dhir (2019 with the following adaptations:
QE1: Quantitative data analysis was considered equivalent to the availability of a detailed algorithm (protocols, architecture, coding script), AND results from experimental or simulation-based performance evaluation; Qualitative analysis was considered equivalent to evidence of (detailed algorithm) OR (limited details on algorithm with limited results of performance evaluation).
QE2: Discussion of advantages has been adapted to current context as: yes (detailed discussion on applicability of results to healthcare context), partially (limited discussion on applicability of results to healthcare context), no (no discussion on applicability of results to healthcare context).
QE5: In terms of comparability of utilized methods, the scoring was adapted to the context of methods used by other studies focused on applying blockchain in healthcare.].

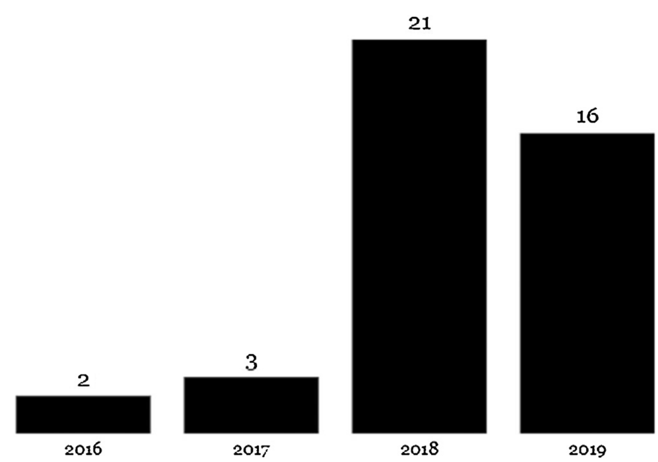

Fig. 2. Yearly distribution of publications.
Note: Publication count for 2019 is inclusive of studies published and available online until July 2019.

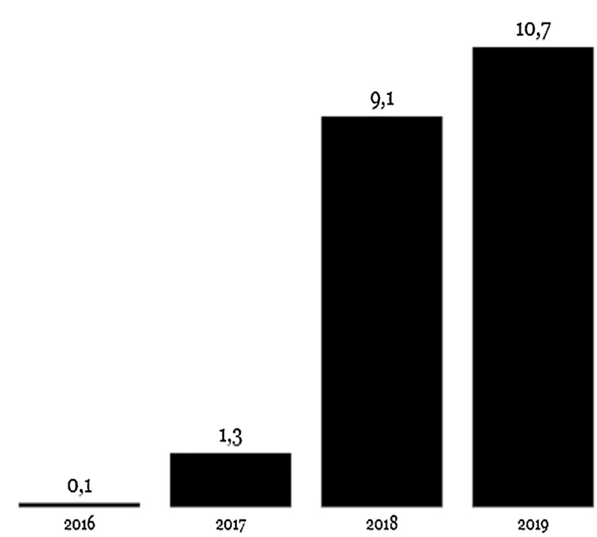

Fig. 3. Average citations per year. Note: Detailed description in Table 3.

research is witnessing conceptual and theoretical development as a way to identify possible avenues for further contribution.

The first authors of the reviewed articles were found to be affiliated with institutes located across 17 countries. Five countries, namely China (n = 12), United States (n = 6), South Korea (n = 4), India (n = 3), and Brazil (n = 3), cumulatively represented 65 % of the sample (see Fig. 4). The inclusion of both developed and developing economies in the sample suggests a global recognition of blockchain's potential application within healthcare. The selected studies were published in multiple journals (see Fig. 5). However, the leading sources were *Journal of Medical Systems* (n = 10), *IEEE Access* (n = 6), and *Applied Sciences* (n = 3), with Springer (n = 12), Elsevier (n = 8), and IEEE (n = 7) emerging as the leading publishers (see Fig. 6).

Furthermore, analysis of author-indicated constructs through word clouds showed that the primary focus of research pertained to "patients," "data," "hospital," "provider," and "devices," which are graphically presented in Fig. 7 (a). Similarly, author-indexed keywords offered by prior studies revealed that "medical," "health," "data," and "sharing" were the most frequently used keywords (see Fig. 7b).

Table 3
Quality assessment results.

Authors	Quality Evaluation (QE)								Citations per year				Average citations per year
	Total Citations	H-index	QE1	QE2	QE3	QE4	QE5	QSScore	2016	2017	2018	2019	
Badr, Gomaa & Abd-Elrahman (2018)	3	51	2	1.5	1.5	1.5	1	7.5	0	0	1	2	1.5
Brogan, Baskaran & Ramachandran (2018)	12	31	2	2	2	1	1	8	0	0	4	8	6
Casado-Vara & Corchado (2019)	1	8	0	1.5	2	1	0	4.5	0	0	0	1	1
Chattu et al. (2019)	0	0	0	1.5	2	0	0	3.5					
Dagher et al. (2018)	39	36	0	2	2	1.5	1	6.5	0	0	16	23	19.5
Dhagarra et al. (2019)	0	28	0	2	2	1	0	5	0	0	0	0	0
Dimitrov (2019)	1	21	0	1.5	1.5	1	0	4					
Dwivedi et al. (2019)	10	84	0	2	2	1.5	1	6.5	0	0	0	10	10
Fan et al. (2018)	2	50	2	1.5	2	1.5	1	8	0	0	0	2	2
Firdaus et al. (2018)	11	45	0	2	2	1.5	1	6.5	0	0	20	19	19.5
Griggs et al. (2018)	32	45	0	2	1.5	1.5	1	6	0	0	11	21	16
Guo et al. (2018)	46	57	2	1.5	1.5	2	0	7	0	0	22	24	23
Hang et al. (2019)	0	0	1.5	0	1.5	0	1	4					
Hussein et al. (2018)	37	19	2	2	2	1.5	1	8.5	0	0	23	14	18.5
Hyla and Pejaś (2019)	0	18	2	1.5	2	1	1	7.5	0	0	0	0	0
Islam et al. (2019)	0	68	2	1.5	2	1.5	1	8	0	0	0	0	0
Jamil et al. (2019)	0	0	1.5	0	1.5	0	0	3					
Ji et al. (2018)	8	45	2	2	2	1.5	1	8.5	0	0	2	6	4
Kaur et al. (2018)	15	45	0	1.5	1.5	1.5	0	4.5	0	0	2	13	7.5
Kuo, Gabriel & Ohno-Machado (2019)	2	62	2	1.5	2	1.5	1	8	0	0	0	2	2
S.H Lee & Yang (2018)	3	42	2	2	2	1	2	9	0	0	2	1	1.5
S.J. Lee, Cho, Ikeno & Lee (2018)	1	29	2	1.5	1.5	1	1	7	0	0	0	1	0.5
H. H. Li et al. (2018)	18	45	2	1.5	1.5	1.5	1	7.5	0	0	4	14	9
X. Li et al. (2019).	4	57	2	2	1.5	1.5	1	8	0	0	0	4	4
Mamoshina et al. (2018)	45	86	2	2	2	2	1	9	0	2	17	25	22
Nagasubramanian et al. (2018)	0	54	2	2	1.5	1.5	1	8	0	0	0	0	0
Nguyen et al. (2019)	0	57	2	2	2	1.5	1	8.5	0	0	0	0	0
Noh et al.(2017)	1	27	2	2	2	1	1	8	0	0	1	0	0.33
Al Omar et al. (2019)	4	68	2	2	2	1.5	1	8.5	0	0	0	4	4
Patel (2019)	25	21	0	1.5	1.5	1	0	4					
Pourvahab & Ekbatanifard (2019)*	0	89	1.5	0	0	1.5	0	3					
Quaini et al. (2018)	0	0	1.5	1.5	2	0	1	6	0	0	0	0	0
Rahmadika & Rhee (2019)	0	22	2	2	2	1	1	8	0	0	0	0	0
Roehrs et al. (2017)	50	50	2	2	2	1.5	1	8.5	0	1	29	20	16.67
Shen, Guo & Yang (2019)	2	29	2	2	2	1	1	8	0	0	0	2	2
Silva et al. (2019)	0	22	1.5	1.5	1.5	1	1	6.5	0	0	0	0	0
Siyal et al. (2019)*	2	0	0	1.5	1.5	1	0	4					
Tian, He & Ding (2019)	0	45	2	1.5	1.5	1	1	7	0	0	0	0	0
Uddin et al. (2018)	10	57	2	2	2	1.5	1	8.5	0	0	2	8	5
H. Wang & Song (2018)	15	45	2	1.5	1.5	1.5	1	7.5	0	0	1	14	7.5
S. Wang et al. (2018)	9	0	0	1.5	1.5	1	0	4					
Wong, Bhattacharya & Butte (2019)	3	240	1.5	1.5	1.5	2	1	7.5	0	0	0	3	3
Xia et al. (2017)	121	57	2	1.5	1.5	2	1	8	0	3	60	27	30
Yang et al. (2019)	1	29	2	2	1	1	1	7	0	0	0	1	1
Yue et al. (2016)	246	45	0	1.5	1.5	2	0	5	4	36	115	91	61.5
A. Zhang & Lin (2018)	21	45	2	1.5	2	1.5	1	8	0	0	5	16	10.5
P.Zhang, et al. (2018)	41	31	1.5	2	2	1.5	1	8	0	0	10	31	20.5
Zhang, Xue & Huang (2016)*	77	57	2	1.5	2	2	1	8.5	0	11	31	35	19.25
Zheng et al. (2019)	0	82	0	2	1.5	1.5	0	5	0	0	0	0	0
Zhou, Wang & Sun (2018)	14	45	2	1.5	2	1.5	1	8	0	0	4	10	7
Total citations									4	53	383	451	
Avg. citation count									0.09	1.23	8.91	10.49	

Note: Articles marked by * were considered through backward citation chaining search result. No relevant article was found through forward citation search.
Articles marked by a broken underline failed to meet quality criteria and were excluded from further analysis.

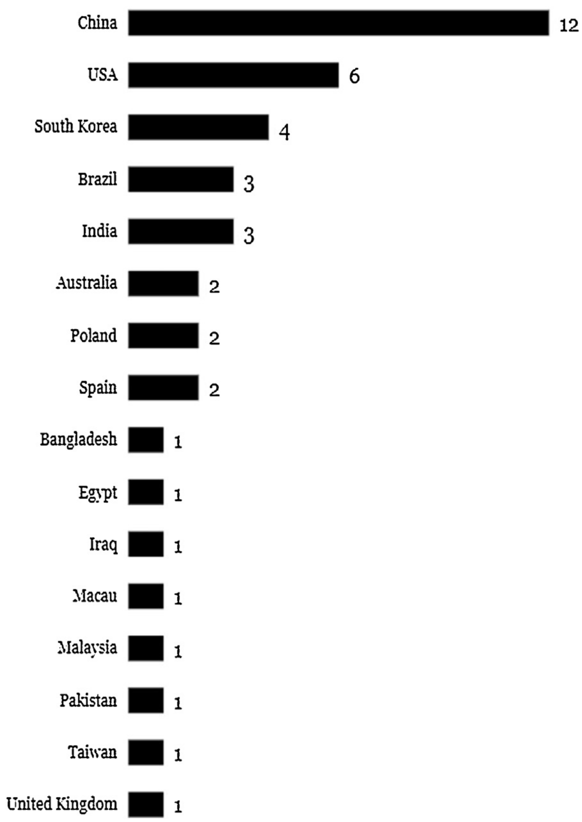

Fig. 4. Publications by country.
Note: Country reflects the location of the institute to which the first author is affiliated.

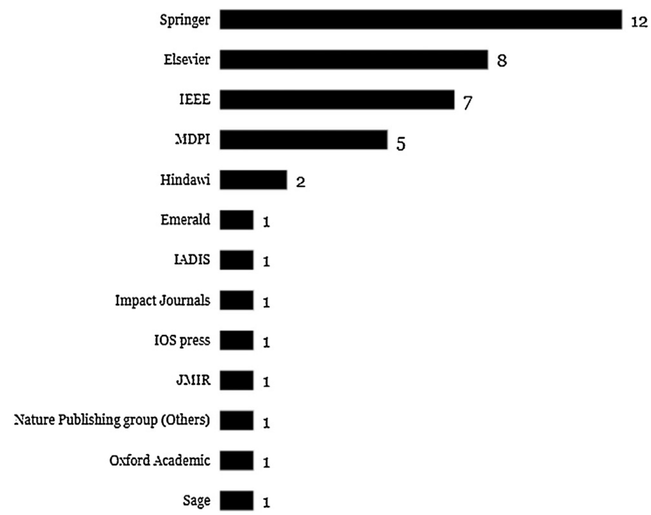

Fig. 6. Articles per publisher.

4. Findings

The current SLR utilized a meta-ethnography-based approach (Noblit & Hare, 1988) to review and synthesize insights from the pool of 42 studies that qualified for inclusion. The process resulted in the development of research themes and identification of research gaps and limitations. Further, extant recommendations from reviewed studies were synthesized, and in conjunction with the explicated gaps in prior research, were used to develop a research framework to advance scholarly work in this domain. These findings are discussed at length in the following sections, and a brief overview is presented in Table 4 and 5.

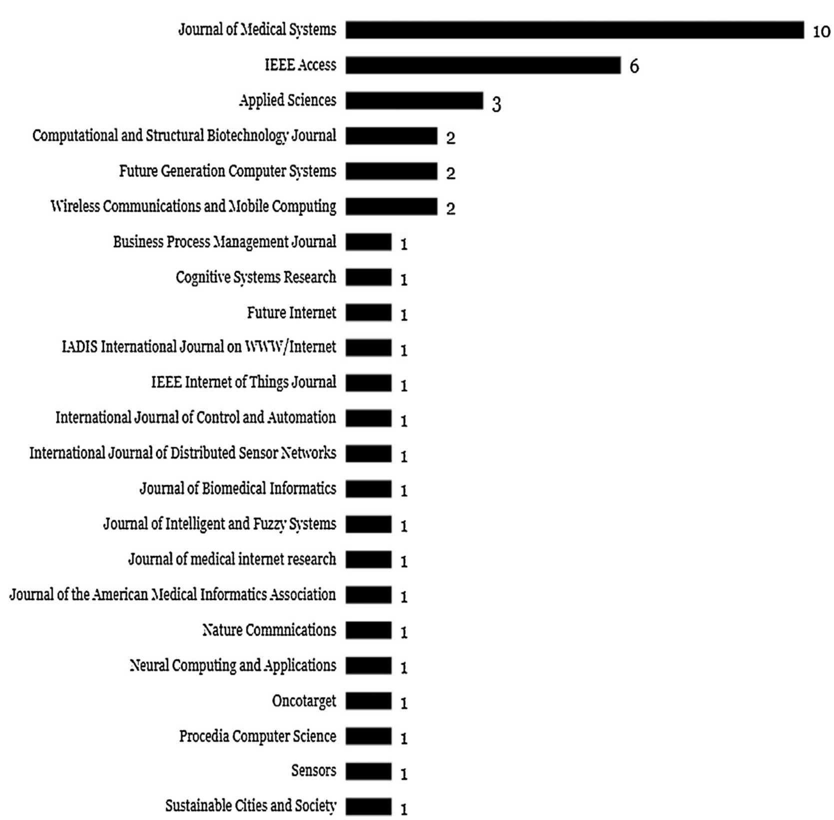

Fig. 5. Number of articles per publication.

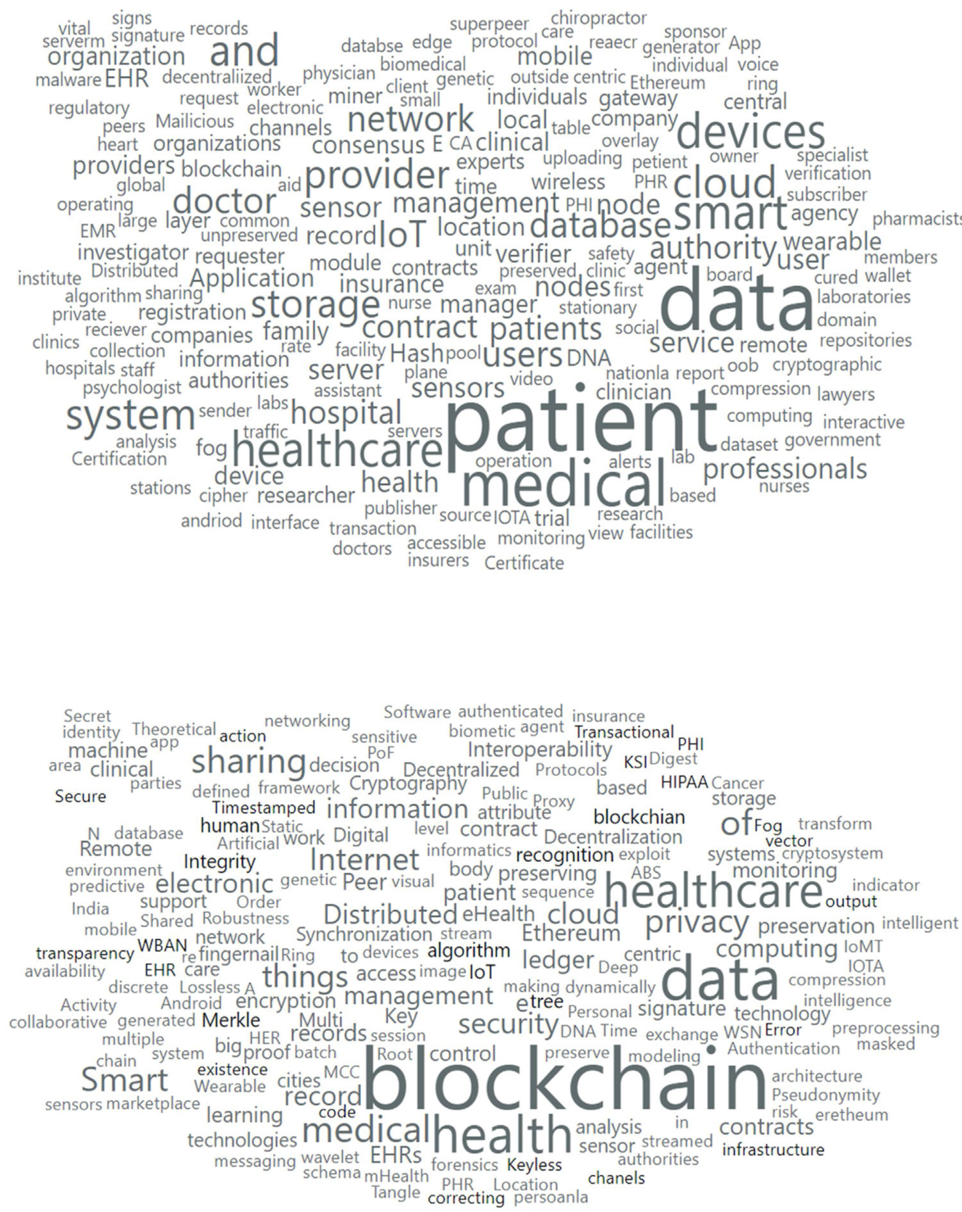

Fig. 7. (a) Key framework constructs (b) Author provided keywords.

Table 4
Summarizing past research: Themes, limitations & future research recommendations.

Thematic classification of scope of study	Limitations	Future research recommendations
Conceptual evolution • Concept development • Benefit based application • Promoting decentralization	Performance • Platform • Algorithm features • Node management	Technical advancements • Framework optimization • Replication & extension • Nuanced technology development
Technology Advancement • Developing intelligent healthcare ecosystems • Technical improvements to architecture • Building predictive capabilities	Assumptions • Framework development	Enhanced data & privacy protection Improving medical diagnostics
Efficiency enhancement • Process • System	Constraints • Costs • Data & Analysis • Platform elements • Societal	
Data Management • Data privacy • Data protection • Data handling	Ethics & security	

Table 5
Suggested future research agenda.

Research Gaps (identified based on the SLR)	Directions for future research
Managing medical data obtained from multiple IoT-based sources, e.g. sensors	Holistic purview for adoption
Investigating user-centric and societal barriers for adoption	Blockchain architecture optimization
Strategic perspective of blockchain adoption by an organization	Data management & legal compliance
	Integration with other technologies
Methodological advancements for obtaining real-time data on actual performance and usage	Nuanced application
	Contribution to value chain & supply chain

4.1. Research themes

Content analysis (Krippendorff, 2018) was employed to analyze the reviewed studies and delineate four explicit thematic areas of research that represent focal issues addressed by the reviewed studies (Table 4). These thematic areas are conceptual evolution, technology advancement, efficiency enhancement, and data management. The results of the review indicate that continual scholarly efforts have been directed at refining conceptual and technical knowledge to enhance the efficiency of healthcare, the associated processes, and data management protocols through the application of blockchain.

4.1.1. Conceptual evolution

The results of the review indicate that research in the domain of blockchain in healthcare has been largely directed at promoting the development of concepts that assist scholars in deriving multi-domain (Kaur et al., 2018) and feasible applications for blockchain in healthcare. The feasibility of applications (Quaini et al., 2018) has been developed and tested through research efforts that can be classified into three sub-themes: concept development, benefit-based applications, and building predictive capabilities.

4.1.1.1. Concept development. The results of the review show that significant attention has been paid to developing new proofs and algorithms, e.g. proof of primitiveness of data (H. Li et al., 2018; Z. Li et al., 2018), proof of familiarity (Yang et al., 2019), and simplified workload for proof of work (Lee & Yang, 2018). Studies have also focused on refining frameworks that enable blockchain execution through inclusion, as well as testing of novel constructs and elements in system architectures. Examples include previously utilized attribute-based cryptosystems (Wang & Song, 2018), the Stackelberg game approach (Li et al., 2019), sibling intractable functions (Tian et al., 2019), and homomorphic computations (Zhou et al., 2018) for more efficient frameworks. For instance, Xia et al. (2017) proposed a new blockchain-based data scheme (BBDS) for security and privacy preservation for data transactions. Zhang, Xue and Huang (2016) invoked the idea of the human body as a transmission medium in their attempt to develop a novel protocol for a pervasive social network (PSN) based blockchain network. Islam et al. (2019) utilized fog computing to construct a computationally efficient and accurate model for human activity recognition for promoting remote e-health monitoring. Fan et al. (2018), in turn, focused on incorporating multiple time sources in their framework to avoid a single point of failure. In conclusion, studies classified under this theme have focused on explicating ways to maximize the efficiency of previously developed blockchain-based algorithms and frameworks.

4.1.1.2. Benefit-based applications. Extant studies have incorporated blockchain in healthcare to derive specific benefits by identifying and testing new avenues of application for blockchain technology. This includes studies focusing on enhancing technical benefits derived from blockchain application, e.g. through advanced image processing (Lee & Yang, 2018), efficient activity recognition (Islam et al., 2019), and synchronization of Internet-of-Things (IoT) devices (Fan et al., 2018). Additionally, most studies classified under this theme have focused on blockchain application for developing healthcare-specific benefits, such as collaborative medical decision-making (Yang et al., 2019). For example, blockchain adoption has been posited to have positive connotations in clinical trial management (Wong et al., 2019), DNA data transmission (S.J. Lee et al., 2018), remote patient monitoring (Griggs et al., 2018; Dwivedi et al., 2019) as well as drug discovery, biomarker development, and preventive healthcare (Mamoshina et al., 2018).

4.1.1.3. Promoting decentralization. Extant research has also focused on promulgating the major benefits of blockchain within healthcare ecosystems to promote fairness and effective decentralization (Noh et al., 2017; Zhang et al., 2018; Zheng et al., 2019). For instance Li et al. (2019) developed a framework to promote revenue maximization and decentralized fair trading, whereas Dagher et al. (2018) discuss the necessity of trade-offs for mining incentives. Scholars have also discussed the potential of blockchain for promoting transparency in data transactions (Hyla & Pejaś, 2019), e.g. by incorporating fair client roles (Kuo et al., 2019a,b). Thus, it may be said that prior studies on the evolving adoption of blockchain in healthcare have focused on disseminating the concepts of decentralization and its associated benefits.

4.1.2. Technological advancements

Existing research has made significant inroads in advancing and refining blockchain technology in terms of developing targeted applications in the field of healthcare. Based on our review, we propose that prior studies classified under this theme are oriented towards three key topical issues:

4.1.2.1. Developing intelligent healthcare ecosystems. Some scholars have focused on the incorporation of blockchain platform gateways into healthcare ecosystems (Badr et al., 2018). Such incorporations may enable the creation of intelligent healthcare systems (Yue et al., 2016). For instance, Casado-Vara and Corchado (2019) suggest that blockchain adoption can assist in the creation of an optimized e-health ecosystem. Prior studies have also proposed frameworks to develop blockchain based e-health (Hyla & Pejaś, 2019) and tele-medical information systems (Ji et al., 2018) that may allow healthcare service providers to increase the reach of provision of services in future.

4.1.2.2. Technical improvements to blockchain architecture. Majority of research in this domain has focused on enhancing the performance of developed systems and architectures through technical improvements, such as unknown root exploitation detection (Firdaus et al., 2018), use of smaller data block sizes (Yang et al., 2019), and improvement of transaction propagation delay (Rahmadika & Rhee, 2019). Some attention has also been directed towards addressing issues that have been previously identified as probable problems in the effective deployment of blockchain architectures. Such issues addressed by studies classified under this theme include storage loads (Zhang et al., 2016), memory and CPU requirements (Zhou et al., 2018), temperature (Zhang et al., 2016), and reliable node identification (Uddin et al., 2018). In some cases, the effectiveness of proposed solutions to these issues has also been demonstrated through analyses directed at network and algorithm comparison (Kuo et al., 2019a,b; Yang et al., 2019). However, we posit that this theme may see further advances in the future and call for a concurrent need to focus on comparative analyses that can ascertain optimal effective networks and algorithms.

4.1.2.3. Building predictive capabilities. As blockchain technology moves into its fourth phase of evolution with the increasing incorporation of AI (Angelis & da Silva, 2019), a similar trend can be seen for its use in healthcare. Recent studies have begun to incorporate analogous and peripheral technologies into blockchain-based system architectures that include IoT (Dwivedi et al., 2019), sensors (Casado-Vara & Corchado, 2019), wireless body area networks (Griggs et al., 2018), (Mamoshina et al., 2018), big data (Dhagarra et al., 2019), edge computing (Zheng et al., 2019), and cloud technology (Kaur et al., 2018).

The use of such technologies is assisting researchers in building blockchain-based frameworks with the predictive capabilities to improve medical informatics (Lee et al., 2018) as well as diagnostics (Lee et al., 2018; Zhang & Lin, 2018). Such frameworks have been previously investigated for specific utilitarian functions that are healthcare-oriented, such as prescription fraud avoidance (Casado-Vara & Corchado, 2019), verifiable data generation (Zhou et al., 2018), and automatic claim settlement (Wang & Song, 2018). Additionally, studies have also focused on advancing blockchain technology to assist healthcare service providers in other functions, such as population level data collection (Brogan et al., 2018) and user identity definition (Zhang et al., 2018).

4.1.3. Efficiency enhancement

Multiple studies in the extant literature have focused on understanding how blockchain adoption can effectually enhance the efficiency of healthcare processes. This review indicates that the focus of scholars has been directed towards two aspects of efficiency improvement: processes and systems.

4.1.3.1. Process. Prior research has paid significant attention to enhancing the effectiveness of technical aspects of the processes required for executing a blockchain-based healthcare system. For example, studies have focused on explicating solutions for reducing computational loads (Zhang et al., 2016), communication overload (Uddin et al., 2018), convergence time and overheads (Fan et al., 2018), and reduced energy consumption (Uddin et al., 2018).

Additionally, prior studies have focused on improving processes for timely updates (Wang & Song, 2018) and reporting for adverse events (Wong et al., 2019). Some studies have focused on improving the computational efficiency (Islam et al., 2019) of processes, and accurate testing of proposed architectures (Lee & Yang, 2018) to ensure that the proposed blockchain architectures provide more reliable processing than traditional architectures (Uddin et al., 2018).

Furthermore, studies have made inroads into addressing the purported challenges associated with managing time, managing data, and associated costs by proposing improvements in blockchain frameworks. For instance, some reviewed studies have developed frameworks to lower the cost of execution after the initial set up (Yang et al., 2019), lower storage cost (Nagasubramanian et al., 2018) and facilitate the preservation and storage of files of unlimited size (H. Li et al., 2018; Z. Li et al., 2018). These developed frameworks have purported to provide significant improvements in runtime (Zhang et al., 2016), delivery time (Roehrs et al., 2017), and response time (Nagasubramanian et al., 2018).

4.1.3.2. System. Our review of the existing literature suggests that multiple measures have been adopted for the holistic improvement of the blockchain-based healthcare system. For instance, studies have focused on improving system interoperability (Dhagarra et al., 2019; Silva et al., 2019), and managing inter-institutional access privileges (Quaini et al., 2018; Li et al., 2019) as well as data control (Brogan et al., 2018; Mamoshina et al., 2018; Zhang et al., 2018).

Scholarly attention has also addressed enhancing system scalability (Xia et al., 2017) as well as performance (Nagasubramanian et al., 2018; Lee et al., 2018). Researchers have focused on developing integrated service-oriented architectures (Hyla & Pejaś, 2019) and improving the generalizability as well as flexibility of executed blockchain systems (Kuo et al., 2019a,b; Silva et al., 2019).

4.1.4. Data management

Based on our review, we posit that management of medical records and data has received the most substantial amount of scholarly attention in this field. Prior studies have promulgated the use of blockchain as a proficient method of managing medical data (Quaini et al., 2018; Hussein et al., 2018; Silva et al., 2019; Shen et al., 2019; Tian et al., 2019) and electronic personal health information or records (PHRs) (Roehrs et al., 2017; Dagher et al., 2018; Hussein et al., 2018; Guo et al., 2018). Further, blockchain may assist in creating a viable information ecosystem for managing such PHRs (Mamoshina et al., 2018) by incorporating heterogeneous forms of data (Yue et al., 2016; Shen et al., 2019; Silva et al., 2019), including medical big data (Kaur et al., 2018). Based on the SLR, we delineate three focal aspects of extant research in this theme:

4.1.4.1. Data privacy. Preserving data privacy by ensuring authorized access to medical records has been a significant focal area of prior literature on the data management aspects of blockchain technology in healthcare. The review suggests that management of access control (Zheng et al., 2019) has especially seen extensive investigation (Badr et al., 2018; Brogan et al., 2018). This issue is especially critical in healthcare due to the need to preserve the privacy of sensitive medical data through greater accountability, immutability, and access control (Hussein et al., 2018). In response to this critical need, prior studies have developed blockchain-based frameworks to ensure the provision of efficient (Roehrs et al., 2017), user-centric (Noh et al., 2017), and secure/encrypted access to patient PHRs and other medical data (e.g. Guo et al., 2018; Badr et al., 2018; Dwivedi et al., 2019)

4.1.4.2. Data protection. The prevention of unauthorized access and preservation of data security to ensure data protection has been another key issue addressed in the studies on the data management aspects of blockchain in healthcare. The majority of reviewed studies have focused their attention on preventing unauthorized access (Nguyen et al., 2019) and protecting against eavesdropping (Uddin et al., 2018). Multiple means, such as efficient authentication (Nagasubramanian et al., 2018), biometric authentication (Dhagarra et al., 2019), user verification (Hussein et al., 2018), and the use of dual signatures (Li et al., 2019) have been suggested to achieve this objective. However, relatively less attention has been paid to the prevention of external attacks, such as attacks on sensor data (Brogan et al., 2018), escrow, and collusion attacks (Guo et al., 2018).

4.1.4.3. Data handling. Prior research has, to some degree, attended to the need to ensure legally, as well as ethically compliant processing, sharing, and handling of healthcare data. Our review suggests that few studies have acknowledged the need for regulatory compliance (Yue et al., 2016) or even the standards and goals for compliance requirements (Zhang & Lin, 2018; Al Omar et al., 2019; Li et al., 2019).

However, significant attention has been paid to the need to maintain data integrity (Hyla & Pejaś, 2019; Tian et al., 2019; Shen et al., 2019). For instance, prior studies have addressed issues pertaining to authentic data mobilization (Brogan et al., 2018), avoidance of data leakage (Zhang et al., 2016; Zhou et al., 2018) or double spending on storage (Rahmadika & Rhee, 2019), and perpetual data preservation (H. Li et al., 2018). With the increasing inter-institutional adoption of blockchain, scholars have also focused on the issue of storage and preservation of sensitive data (Al Omar et al., 2019) from different sources such as medical devices (Firdaus et al., 2018), and medical insurance (Zhou et al., 2018). A few studies have also directed attention to the facilitation of cross-institutional data sharing (Al Omar et al., 2019), and improvements in efficiency as well as flexibility of data sharing (Shen et al., 2019).

Furthermore, prior studies have also attended to the need for improvements in data processing (e.g. Zhou et al., 2018). The reviewed studies have suggested some measures of inducing these improvements, for instance through the effective integration of heterogeneous data from multiple sources (Quaini et al., 2018), and the integration of smart contracts (Dagher et al., 2018).

These themes suggest that prior research in this field presents an emphasized focus on (a) improvement of technical features, (b) management of medical data, and (c) identification of distinct capacities within the field of healthcare, wherein blockchain can generate significant contributions. Based on these emergent themes, we posit that research in this domain is currently in a transformative state, with contemporaneous aspects of healthcare being continually identified as potential beneficiaries of blockchain's use through technological advancements.

4.2. *Limitations of the current literature*

The limitations acknowledged by prior research indicate technically-oriented challenges (see Table 4). We attribute this to the fact that the reviewed studies have mainly concentrated on developing novel algorithms, frameworks, and proofs of concept for deploying blockchain in healthcare. Based on the review, we categorize the extant limitations into four categories: performance, assumptions, constraints, and ethics and security.

4.2.1. *Performance*

Studies have implied that certain aspects of architectural frameworks developed for adoption of blockchain in healthcare can affect the performance efficiency of the proposed framework (Ji et al., 2018; Mamoshina et al., 2018; Zhang & Lin, 2018). For instance, high compression ratios may affect the inherent stability of a framework, and subsequently, its performance (Lee et al., 2018). The design of the framework and authorizations for data movement may also be contingent on manual approvals by users, which may impact the efficiency of the framework's performance (Shen et al., 2019). Mamoshina et al. (2018) also acknowledge that their proposed framework directed at detecting anomalies may underperform in certain cases where datasets are not labelled. The scalability and performance efficiency of a framework may also be affected by issues such as requirements for continual upgrades by the utilized system (Kaur et al., 2018), the computational load of sensor data (Zhang et al., 2016), keyword set size (A. Zhang & Lin, 2018), the amount of disk space, and the network set-up required by the type of blockchain, e.g. Ethereum, used in the model (Quaini et al., 2018). Similarly, Dagher et al. (2018) suggests that incorporating certain features, such as the use of global smart contracts, in developed frameworks may set-off higher performance-related costs. Further, few studies have indicated that performance-oriented challenges may also be related to the management of nodes in a proposed framework. For example, uncertainties in a framework's performance may also relate to the number of nodes, latency between nodes, and attacks (Hyla & Pejaś, 2019). In the same line of thought, Fan et al. (2018) also suggest that higher numbers of nodes may adversely affect system efficiency.

4.2.2. *Assumptions*

The effectiveness and efficiency of the frameworks proposed in prior literature are limited by the assumptions that they are based on. These assumptions are also likely to impact an accurate assessment of a framework's performance. For example, Uddin et al. (2018) assume that users, i.e. patients, would utilize a smartphone to collect and store required medical data from sensors. However, all data generated may not require storage, and the devices may not have a way to authenticate that a legitimate owner has uploaded the generated data. Similar concerns were raised by Roehrs et al. (2017), who acknowledge that the inability to guarantee the identity or authenticity of persons or devices providing medical records is a significant limitation. In another study, Rahmadika and Rhee (2019 proposed a framework for preserving data privacy in decentralized shared storage on a blockchain network and base their framework on the assumption that the shared storage would have appropriate capacity to support the blockchain system.

4.2.3. *Constraints*

Researchers have acknowledged constraints in prior studies, which may be classified across four dimensions. These identified dimensions imply that such constraints transcend technical boundaries (pertaining to the costs of developing and deploying blockchain-based frameworks, analysis of data for framework evaluation, and the constituent elements of the frameworks) and include some societal aspects as well (e.g. trust in government, technological infrastructure of the country).

4.2.3.1. Costs. This group of constraints primarily relates to the resources, time, and monetary costs associated with executing a blockchain framework. For example, Dwivedi et al. (2019) refer to the resource constraints related to IoT, whereas Zhang et al. (2018) acknowledge the costs associated with deploying a decentralized app for deploying blockchain. Additionally, other costs indicated as constraints and limitations in the extant research include the linear increase in protocol costs contingent upon the characteristics and attributes of the involved entities, such as patients (Guo et al., 2018), increased operational overhead (for the patient) and access latency (for the requester) (Shen et al., 2019), and the transaction and execution costs based on variable inputs of string length & size (Al Omar et al., 2019).

Time-related issues have also been discussed as a constraint, including the time spent searching for the global smart contracts (Dagher et al., 2018), increased time consumption (Islam et al., 2019), transmission timing (Griggs et al., 2018), time required for seeking the required data in shared storage by the data recipient (Rahmadika & Rhee, 2019), and higher total execution time (Kuo et al., 2019a,b).

4.2.3.2. Data and analysis. Some studies reported limitations for data, such as non-representativeness of sample data (Quaini et al., 2018; Firdaus et al. 2018), the limited availability of training data for running simulations or tests (Lee & Yang, 2018), and the possibility of data duplication (Roehrs et al., 2017). Other reported constraints pertain to lack of testing using actual inter-institutional medical data (Quaini et al., 2018), and the lack of time for dynamic analysis (Firdaus et al. 2018). Such constraints may affect the completion or initiation of protocol tests associated with communication and authentication between entities (Xia et al., 2017), and affect the performance evaluation for the developed framework. For example, H. Li et al. (2018) reported that the performance of their framework could be affected by having a small structure/ amount of data that would not only waste space, but also affect multimedia image content recognition.

4.2.3.3. Platform and framework elements. Certain elements of the blockchain platform and developed framework may also serve as constraints for its deployment. Some previously reported constraints include the necessity of a gateway layer for Tangle to establish direct communication with sensors (Zheng et al. 2019), the limited storage provided by a fog layer (Silva et al., 2019), as well as semantic interoperability and incompatibility with legacy systems (Zhang et al., 2018). Complications may also arise as a result of failing to prioritize inherently associated entities, leading to conflicts–especially in the case of decision-making during emergencies (Yang et al., 2019). Further, there is a need to ensure rewards and incentives for miners (Quaini et al., 2019), which may be adversely affected by users' unwillingness to share data (Li et al., 2019). A few studies have reported constraints specific to their developed algorithms, such as a lack of a mature scheme for PSN-based blockchains for healthcare (Zhang et al., 2016), and a lack of an optimized masked authenticated messaging (MAM) module library (Brogan et al., 2018).

4.2.3.4. Societal environment. Comparatively, fewer studies have discussed constraints related to the societal environment within which blockchain-based frameworks may be used. For example, there may be a possibility of collusion for fabricating data (Wong et al., 2019) or a healthcare system may be constrained by an inability to control clinical malpractice (Zhang et al., 2018) Dhagarra et al. (2019) acknowledge that the performance of their proposed architecture would be contingent on users' country-wide access to Internet connectivity. Similarly, Islam et al. (2019) also admit that Internet bandwidth is a constraint. Dhagarra et al. (2019) further posit the inaccessibility of certain groups, such as refugees, to a country's healthcare system and the existence of a central identification database for patients, as additional constraints.

4.2.4. Ethics and security

Our review also suggests that users' concerns related to the ethical and secure use of data may be a significant limitation that may affect the adoption of blockchain by healthcare organizations. These concerns are mainly related to the technical limitations of blockchain technology, such as the security of individual nodes (Griggs et al., 2018), the level of security enabled by the cryptographic elements incorporated in framework (Tian et al., 2019), and the maintenance of data privacy while requesters complete their computations (Yue et al., 2016).

However, certain studies have also pointed to more socially-oriented concerns about public data sharing (Wong et al., 2019) and users' trust in governments (Dhagarra et al., 2019). Such concerns may also be related to maintaining the security of the proposed frameworks from the users' perspectives, for example, the users' management or mismanagement of their authorized private keys (Brogan et al., 2018).

4.3. Future research: recommendations of the reviewed studies

Based on the review, we now discuss avenues in this field that would benefit from additional attention from scholars. Prior literature has suggested various recommendations for future research, including extending (e.g. Zhou et al., 2018) or replicating current frameworks (e.g. Quaini et al., 2018), and developing targeted treatment solutions (e.g. Mamoshina et al., 2018), to name a few. We group these proposed recommendations into three categories (see Table 4); the first category addresses potential technical advancements, the second is specifically directed at the improvement of medical services and the last relates to the need for enhanced data protection.

4.3.1. Technical advancements

The extant research revealed the need to focus on optimizing previously developed frameworks by concentrating on addressing technical issues that may optimize framework performance during their actual usage in a healthcare ecosystem. Therefore, scholars may direct their attention to issues such as the strategic management of nodes (Yang et al., 2019), automatic generation or uploading of data (Shen et al., 2019), and improvement of process and system efficiency (Lee & Yang, 2018; Fan et al., 2018).

Further, in order to improve the scalability (Zhang et al., 2016) and functionality (Wong et al., 2019) of previously proposed frameworks, researchers have called for the need to extend the current technical boundaries of framework development, e.g. by consideration of novel blockchain platforms (Rahmadika & Rhee, 2019). Additionally, scholars have proposed the need for a more nuanced development of existing technology and existing algorithms for enabling more effective blockchain-based healthcare ecosystems. To this end, future researchers may address issues such as eliminating the need for global smart contracts (Dagher et al., 2018), utilizing conjunctive keyword searches (Zhang & Lin, 2018), and improved data transference (Hussein et al., 2018), among others.

4.3.2. Improving medical diagnostics

Although algorithms exist for the deployment of blockchain that are geared towards improving healthcare processes, few studies have proposed the need for scholars to focus on the nuances of improving medical diagnostics (Mamoshina et al., 2018) and extending their application to other areas of healthcare, such as rehabilitation (Zheng et al., 2019). This may be achieved through development of improved diagnostic tools (Mamoshina et al., 2018), remedial interventions for specific diseases (Dhagarra et al., 2019), and determining the priority of service providers' access to patient records in emergencies (Brogan et al., 2018).

4.3.3. Enhanced data and privacy protection

Existing studies present the need to enhance current standards of data protection for ethically and legally compliant use of medical data. Scholars need to focus on two topical issues. First, future studies need to improve compliance with security and regulatory measures by addressing issues such as guarantees for work security (Dwivedi et al., 2019), and addressing system vulnerabilities (Badr et al., 2018) to improve robustness (Firdaus et al., 2018). Second, there is a need to improve data privacy and authentication by addressing issues pertaining to shared storage (Rahmadika & Rhee, 2019) and key distribution (Al Omar et al., 2019).

4.4. Gaps in the extant literature

Based on the SLR, we explicate four gaps in the current body of knowledge that exclude the limitations already acknowledged by prior researchers. An agenda for future research that comprises these gaps together with our recommendations for future research directions is presented in Table 5. First, comparatively few studies have focused on managing medical records and data sourced from IoT sensors. Furthermore, we also elucidate a significant gap in terms of research that examines the potential integration of data from multiple sources of medical records into a singular framework.

Second, we explicate a critical gap in studies that explicitly examine the barriers to the adoption of blockchain by users, including beneficiaries (patients), as well as service providers, such as doctors or hospital administrators (Jaoude & Saade, 2019). Understanding the perspectives of these users may assist in generating insights for more effective and efficient management of blockchain-based healthcare ecosystems. Similar suggestions regarding the inclusion of users and society were made by Risius and Spohrer

(2017), but their study extended to the general adoption of blockchain across different industries and organizations.

Third, there is a distinct lack of studies that adopt a strategic perspective in the implementation of blockchain in an organization focusing on aspects such as prevention of external attacks (Guo et al., 2018; Fan et al., 2018), value creation or governance (Risius & Spohrer, 2017). Finally, we posit a gap in the presentation of real-time results based on case studies. Addressing this methodological approach gap could provide pertinent information on the true costs and benefits of using blockchain.

4.5. Directions for future research

Based on the SLR, we advance a brief summarization of the thematic issues (Table 5) that would demand attention from future scholars:

4.5.1. Adoption of a holistic overview

While it is imperative to find solutions for performance and security-related issues, such as interoperability (Al Omar et al., 2019) and access-control (Rahmadika & Rhee, 2019), we argue that scholars need to adopt a holistic purview of blockchain adoption. This is imperatively needed in order to develop holistic, as well as legally and ethically compliant (Kuo et al., 2019a,b), e-health ecosystems with robust data management and authentication protocols (Ji et al., 2018). Further, Pawczuk, Massey and Holdowsky (2019) suggest that contextual factors such as people and culture can be critical success factors for an innovative technology. Subsequently, we suggest the need for testing blockchain-based e-health ecosystems in cross-national and cross-institutional contexts to create context-based customized healthcare solutions by collaboration with organizations within the healthcare ecosystem, e.g. medical research centers (Lee & Yang, 2018).

4.5.2. Architecture optimization

Researchers may focus on ensuring improvements in performance and efficiency of proposed/ tested architectures to account for the increased volumes of transactions (Xia et al., 2017) that can be expected with a higher integration of blockchain with healthcare processes in the future. This may be done by addressing issues such as network latency (Shen et al., 2019), throughput (Zheng et al., 2019), scalability (Quaini et al., 2019), and bandwidth (Swan, 2015).

4.5.3. Data protection and legal compliance

A significant area for future research will pertain to addressing data as well as user privacy and legal issues (Griggs et al., 2018; Kuo et al., 2019a,b). These may be specifically addressed by creating blockchain protocols for managing medical data that are enforceable through smart contracts (Pawczuk et al., 2019) and compliant with data and privacy protection regulations, such as HIPAA (Griggs et al., 2018; Alla et al., 2018; Pawczuk et al., 2019).

4.5.4. Integration with other technologies

Blockchain's application in healthcare may benefit from exploring a deeper integration of the technology with business processes for improved functionality (Pawczuk et al., 2019). For instance, scholars may focus on the further integration of edge computing, artificial intelligence (AI) and machine learning (ML) with blockchain-based healthcare ecosystems to create enhanced predictive analytics models for personalized patient care and diagnostics (e.g. Mamoshina et al. 2018; Firdaus et al., 2018; Li et al., 2019). Further, research may target service enhancement by increased integration of IoT-based sensors to improve service and data accessibility, remote monitoring, and emergency services.

In addition, we propose two more potential directions that may be considered by future scholars in order to broaden the current scope of intellectual boundaries in this field. First, we suggest the need to study the connotations of blockchain deployment in healthcare in more niche, yet allied, areas such as users' digital rights management (Jaoude & Saade, 2019), drug prescription management (Hölbl et al., 2018), and avoidance of prescription fraud (Casado-Vara & Corchado, 2019), among others.

Second, research could be aimed at examining the ramifications of blockchain use in the entire healthcare value chain and supply chain. This could assist researchers in understanding user-related interoperability issues and perhaps even allow them to develop standardized protocols for using blockchain-based systems.

4.6. Synthesizing framework

This review and analysis aided us in the development of a research framework that has been synthesized from research gaps explicated from the extant literature and recommendations proposed by prior scholars. This framework has five components that exhibit a degree of interconnectedness and would assist in creating a blockchain-based healthcare ecosystem that can be examined in future research (see Fig. 8).

a) **Data sources**. Medical and personal health records are now generated and managed at multiple levels through patients via smart devices (Casado-Vara & Corchado, 2019), healthcare service providers, and allied industries, such as pharmaceutics, insurance, and research (Cios et al., 2019; Tian et al., 2019). These act as building blocks of the blockchain system's architecture and need to be managed in accordance with legal and regulatory guidelines. Blockchain can assist in developing authenticated databases to be accessed by interinstitutional authorities with the appropriate permissions to support the patient's treatment and medical decision-making (Kuo et al., 2019a,b). With the integration of newer technologies, for example smart devices for patient monitoring (Griggs et al., 2018), future research needs to focus on managing such data sources to improve the comprehensiveness of medical record databases.
b) **System architecture**. As blockchain technology evolves, its architecture will continue to witness significant changes and improvements of elements incorporated into the blockchain system. For example, utilization of permissioned consortium blockchain (Zhang et al., 2018) or platforms other than Ethereum (Zhou et al., 2018; Rahmadika & Rhee, 2018) may improve current architectures being used to deploy blockchain in healthcare ecosystem. Furthermore, future research needs to focus on developing strategies for managing developed system architectures, especially in the context of issues that can affect performance and efficiency, such as node management (Yang et al., 2019) and key distribution techniques (Al Omar et al. 2019).
c) **Strategic implementation of blockchain technology**. With the increasing assimilation of ICT and blockchain across healthcare ecosystems, scholars need to focus their attention on the factors that can hinder or facilitate the prevalent adoption of this technology. Based on the review, we posit the need for organizations to consider how, and whether, blockchain can be a potential source of value creation or value enhancement by addressing the specific issues identified through this review. These include strategic issues, such as resource constraints (Dwivedi et al., 2019) and technical issues, such as performance uncertainty (Hyla and Pejaś, 2019) and system requirements (Quaini et al., 2018). Addressing such issues may aid researchers in developing blockchain system architectures that provide more functional utility and effective performance with regards to the manage-

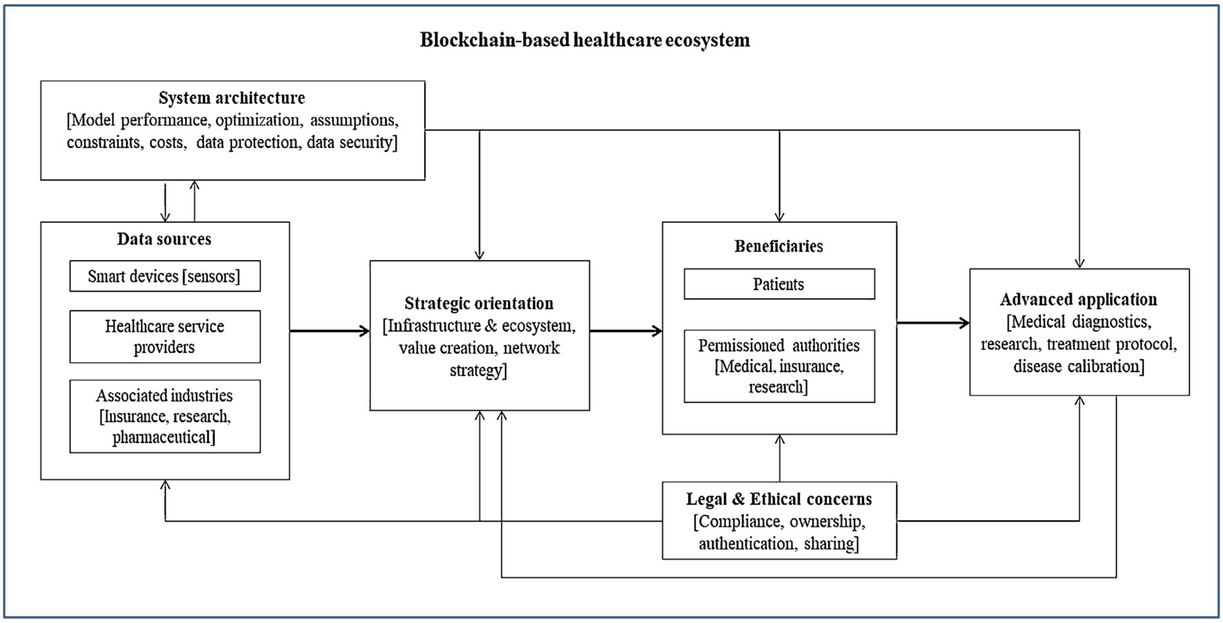

Fig. 8. Research framework.

ment of resources and outputs. This could also assist healthcare administrators and managers in adopting a strategic and holistic perspective towards the potential inclusion of blockchain as a critical part of an organizational value chain.

d) **Beneficiaries**. Blockchain-based databases are capable of providing reliable information for specific beneficiaries in the healthcare sector, including patients who retain ownership of their personal data. Beneficiaries also include authorities, such as doctors, medical researchers, pharmacists, and insurance agencies. They may be authorized by patients to access and use medical data for varied purposes, such as collaborative medical decision-making (Li et al., 2019), medical diagnostics and informatics (S.J. Lee et al., 2018), and avoiding fraud (Casado-Vara & Corchado, 2019). The blurring boundaries between the healthcare, mobile technology, and wellness sectors make it imperative for researchers to identify such beneficiaries to ensure that data is accessed by the appropriate authorities. It is also critical to ensure that data integrity is preserved in accordance with legal and ethical guidelines. Thus, researchers should focus on understanding users' perspectives on the perceived advantages and costs of being involved in a blockchain-based system. This could help in identifying and neutralizing critical barriers that may affect the widespread deployment and actual usage of this technology.

e) **Legal and ethical considerations**. Interoperability, authentication, and secure sharing of medical data are critical issues being addressed by blockchain applications (Dhagarra et al., 2019; Dimitrov, 2019). Despite the increased focus on blockchain, the prevalence of such concerns may be considered a significant hindrance in its widespread adoption. There is a need to direct more attention to regulatory compliance (Yue et al., 2016) and ethical guidelines for issues such as patients' ownership of their data and access control (Quaini et al., 2018). We suggest that future scholars may adopt a multi-disciplinary approach to identifying avenues for resolving legal and ethical compliance related issues for blockchain's adoption in cross-institutional or multi-national contexts. We further posit the need to positively influence the public and appease regulatory bodies by deliberating on and emphasizing the critical benefits gained by using blockchain technology.

5. Discussion

The present study performed a systematic review of the literature on blockchain applications in healthcare to understand its present status and prospective potential. For this purpose, four broadly framed research questions were identified. **RQ1** explored the current profile of research on blockchain applications in healthcare and was addressed by summarizing the top contributors, publication sources, publishers, and publication trends in this domain. The alphabetic reporting of reviewed articles in the sample is detailed in Table 6. **RQ2** was aimed at understanding the application contexts for blockchain and was answered by delineating specific themes and sub-themes that represented focal areas of blockchain's applications in healthcare. **RQ3** addressed the limitations and challenges faced by prior researchers. The summarization of the primary research themes and extant limitations allowed us to identify gaps in current knowledge in response to this research question. **RQ4** focused on the potential areas wherein future research could offer significant insight. This question was addressed by integrating insights derived from the emergent gaps, limitations, and previously posited recommendations into a single, synthesized framework. This framework may further the current level of knowledge in this domain by addressing the issues (detailed in Tables 4,5) that may be critical for the further development of the field.

6. Implications

The findings of this SLR present significant implications for both academics and practitioners involved in the development and implementation of blockchain-based technical models for the field of healthcare. We propose five theoretical and practical implications based on the present review.

6.1. Implications for research

Our first contribution is a detailed review of the recent literature on the application of blockchain in healthcare. This includes an encapsulated version of the top contributors, publishers, and publication outlets. Additionally, the main areas wherein blockchain has

Table 6
Reviewed studies.

Authors	Journal	Classification	Method mentioned in article	Description of method	Platform	System architecture proposed/ implemented (evaluated)	Key system design components
Badr, Gomaa & Abd-Elrahman (2018)	Procedia Computer Science	Concept implementation	Public blockchain methodologies	Algorithm details given	Public, multi-tier	Implemented	Pseudonym based encryption with different authorities (PBEDA), elliptic curve diffie-Hellman (ECDH) key agreement protocol, Menezes-Vanstone protocol and elliptic curve digital signature algorithm (ECDSA), implemented through MIRACL
Brogan, Baskaran & Ramachandran (2018)	Computational and Structural Biotechnology Journal	Concept implementation	Masked Authenticated Messaging (MAM) for broadcasting real time activity through wearables	Algorithm details given	IOTA	Implemented	MAM for Tangle, Merkle signature scheme, Merkle hash technique, One time signature, data structured through FHIR and coded with LOINC.
Casado-Vara & Corchado (2019)	Journal of Intelligent and Fuzzy Systems	Concept implementation	Edge computing	One simulation for data searches done but limited information provided on its results and efficiency	Ethereum	Proposed (one simulation)	Wireless sensor network (WSN) and WSN controller v.2, Edge computing, Raspberry Pi, Open Thread IPv6 protocol
Dagher et al. (2018)	Sustainable Cities and Society	Concept implementation	N.A.	Performance analysis for cost done with MedRec but no algorithm or data shared	Ethereum	Proposed (Ancile), comparative performance analysis (computational costs) against MedRec	QuorumChain algorithm, smart contracts (consensus, ownership, classification, service history, re-encryption), proxy re-encryption, Ethereum Go-client, cipher manager, database manager
Dhagarra et al. (2019)	Business Process Management Journal	Conceptual analysis	Unique identification number (UID) system	Algorithm details not given	Ethereum	Proposed	Unique identification number (UID) system, Big Data analytics, registration & history contract
Dwivedi et al. (2019)	Sensors	Conceptual analysis/ mathematical	N.A.	Algorithm details given with security margins evaluated for specified criteria	Bitcoin	Proposed (security margins considered in model for attacks)	Internet of Things (IoT), Merkle tree, ARX crypto cipher (SPECK), digital ring signature with Diffie–Hellman key exchange

Fan et al. (2018)s	IEEE Internet of Things Journal	Concept implementation + laboratory experiment	N.A.	Algorithm details given	Consortium	Implemented (simulated comparison with STETS and TPSN	Practical Byzantine fault tolerance consensus mechanism, precision time protocol (time synchronization)
Firdaus et al. (2018)	Journal of Medical Systems	Data Analysis	Practical swarm optimization (PSO)	Detailed result of static analysis for performance according to detailed evaluation criteria	Not available	Implemented (training, testing and cross validation)	Android debug bridge (ADB), boosting for machine learning (ML) (adaboost, realadaboost, logitboost, and multiboost), root exploit detection system, malware analysis (static analysis), reverse engineering, feature extraction & selection, ML classification
Griggs et al. (2018)	Journal of Medical Systems	Conceptual analysis	N.A.	Algorithm details not given, no experiments or simulations	Consortium blockchain	Proposed (implemented proof of concept via Solidity, security analysis through comparison of proposed and traditional system)	IoT sensors (wireless body area networks (WBANs)), smart device (oracle)
Guo et al. (2018)	IEEE Access	Conceptual analysis/ mathematical	Proposed Attribute-based signature (MA-ABS) scheme	Detailed computational and mathematical notations provided for implementation of scheme as well as security and performance evaluation	Not available	Implemented (security analysis and performance evaluation through random oracle model)	MA-ABS scheme, computational bilinear Diffie-Hellman
Hussein et al. (2018)	Cognitive Systems Research	Concept implementation + Simulation + Data analysis	Proposed blockchain-based access control method (discrete wavelet transform) supported by genetic algorithm	Detailed results for simulation in terms of input and output strings, time processing and block generation given	Not available	Implemented (simulation scheme)	Genetic algorithm, discrete wavelet transform, cryptographic hash key, MD5 strings
Hyla and Pejaś (2019)	Future Internet	Concept implementation	Design-science methodology for proposed Blockchain-based eHealth Integrity Model	Details for algorithm and results test of integrity-verification algorithm shared	Permissioned blockchain	Implemented (verification speed test)	Practical Byzantine Fault Tolerant consensus algorithm

Table 6 (*Continued*)

Authors	Journal	Classification	Method mentioned in article	Description of method	Platform	System architecture proposed/ implemented (evaluated)	Key system design components
Islam et al. (2019)	Future Generation Computer Systems	Concept implementation + laboratory experiment + Data analysis	uni model based human activity recognition methods (HAR)	Some mathematical notations and detailed results for experiments for performance revaluation on three datasets shared	Not available	Implemented (comparative performance evaluation)	Error-correction-output-codes (ECOC) framework for HAR, support vector machine (SVM), Fog computing, multi-class cooperative categorization procedure
Ji et al. (2018)	Journal of Medical Systems	Conceptual analysis/ mathematical + laboratory experiment	N.A.	detailed mathematical and algorithmic notations provided along with results of experiments for performance evaluation	Not available	Implemented (performance evaluation)	Order-preserving encryption and merkle tree
Kaur et al. (2018)	Journal of Medical Systems	Conceptual analysis	N.A.	Concept based discussion on applicability of blockchain in healthcare	Not available	Proposed	Blockchain based environment
Kuo, Gabriel & Ohno-Machado (2019)	Journal of the American Medical Informatics Association	Concept implementation + Data Analysis	Newton-Raphson method	Details on algorithms as well as results for consensus iterations and execution time shared.	Permissioned blockchain	Implemented (experiments)	Batch model learning, blockchain data/network, consensus learning algorithm, concurrent use of server and “client” roles, Proof of equity algorithm
Lee & Yang (2018)	International Journal of Distributed Sensor Networks	Concept implementation + Data Analysis	Image preprocessing	details shared for experimental results and classification training as well as testing results	Bitcoin	Implemented (experiments)	Histogram of oriented gradients (HOG), local binary pattern (LBP), support vector machine, random forest tree, deep neural network
Lee et al. (2018)	Applied Sciences	Concept implementation	Compression ratio method, Pearson’s correlation	Results shared for compression ratio and stability performance testing	not available	Implemented (performance evaluation)	Blockchain applied FASTQ and FASTA lossless compression (BAQALC) proposed, next generation sequencing (NGS), LZW modification, NCBI sequence read archive (SRA)
H. Li et al. (2018)	Journal of Medical Systems	Conceptual analysis/ mathematical	Authentication methods (acquisition of preservation content, verify consistency)	Details shared for algorithm and performance evaluation in terms of operational cost	Ethereum	Implemented (security analysis through theorems, performance evaluation for operational cost)	Proof of primitiveness of data introduced, preservation Submission, primitiveness verification
Li et al. (2019).	IEEE Access	Data Analysis	Primal-dual Varangian method	Results for performance evaluation of scheme shared for reaching Stackelberg equilibrium	Not available	Implemented (performance evaluation of Stackelberg game)	Hierarchical architecture (three layer), edge computing

Mamoshina et al. (2018)	Oncotarget	Conceptual analysis	Machine learning	Proposed architecture illustrated with workflow examples instead of simulation or experiment based evaluation	Exonum	Proposed	Coefficient of inbreeding, deep neural network predictor, time value of data, utility crypto token (LifePound)
Nagasubramanian et al. (2018)	Neural Computing and Applications	Concept implementation + Data Analysis	N.A.	Limited algorithmic notations but detailed results for performance evaluation using Apache Jmeter provided	Not available	Implemented (performance evaluation)	Keyless signature infrastructure, timestamped algorithm, Merkle tree
Nguyen et al. (2019)	IEEE Access	Concept implementation	N.A.	Details shared for code script, access control protocols along with performance evaluation results for access control and network overheads.	Ethereum	Implemented (performance evaluation through & security analysis)	Decentralized storage interplanetary le system (IPFS), mobile cloud, attribute-based encryption (ABE)
Noh et al. (2017)	International Journal of Control and Automation	Conceptual analysis	N.A.	Limited preliminary notations for computations shared without results of experiments or simulations	Permissioned blockchain	Proposed (security analysis considered theoretically)	Proxy re-encryption (PRE) scheme,
Al Omar et al. (2019)	Future Generation Computer Systems	Concept implementation + laboratory experiment	N.A.	Details of algorithmic notations shared with results for performance evaluation on multiple parameters	Permissioned blockchain	Implemented (experiment)	Elliptic curve cryptography (ECC), MediBChain protocol
Quaini et al. (2018)	IADIS International Journal on WWW/Internet	Qualitative	Case study	Primarily conceptual. Case study method used to provide test case scenario results for response time and memory consumption	Ethereum	Implemented (test scenario execution)	Interplanetary file system (IPFS),
Rahmadika & Rhee (2019)	Wireless Communications and Mobile Computing	Concept implementation + Simulation	N.A.	limited algorithmic notations but detailed results for simulation provided for performance parameters (block propagation & block size)	Not available	Implemented (simulation)	Ring signature algorithm, Cryptonote protocol, one time transaction and stealth address
Roehrs et al. (2017)	Journal of Biomedical Informatics	Conceptual analysis/ mathematical + Data analysis	Modeling and profiling methodology	Limited discussion on algorithm, with extensive discussion on results of mathematical model testing of multiple performance parameters	Bitcoin	Implemented (performance evaluation, mathematical systems analysis)	OpenEHR data standard, Chord algorithm, routing overlay incorporated to develop OmniPHR architecture
Shen, Guo & Yang (2019)	Applied Sciences	Conceptual analysis/ mathematical + laboratory experiment	N.A.	Limited algorithmic notations with discussion of results from theoretical (mathematical) and experiment based results for multiple parameters	Permissioned blockchain	Implemented (security analysis, theoretical efficiency analysis, performance evaluation through experiment)	Elliptic curve cryptography, BFT smart consensus protocol, modified digest generation algorithm, MedChain (prior methodology advanced)

Table 6 (*Continued*)

Authors	Journal	Classification	Method mentioned in article	Description of method	Platform	System architecture proposed/ implemented (evaluated)	Key system design components
Silva et al. (2019)	Wireless Communications and Mobile Computing	Qualitative	Case study	Limited discussion on tests conducted with Apache Jmeter for access time and application amount for Fog, Cloud & blockchain environments	Ethereum	Implemented (performance evaluation)	Fog computing paradigm
Tian, He & Ding (2019)	Journal of Medical Systems	Simulation	N.A.	Limited algorithmic notations with discussion of results for simulated security analysis and performance evaluation.	Hyper ledger	Implemented (security analysis, performance evaluation)	Sibling intractable function families (SIFF)
Uddin et al. (2018)	IEEE Access	Simulation + Data analysis	Sessional symmetric key generation	Extensive discussion of simulated performance &security analysis	Customized (bitcoin & Ethereum)	Implemented (simulation & performance analysis)	Proximity user authentication (PUA), HMAC (keyed-hash message authentication code), mutual authentication protocol, Trei tree
Wang & Song (2018)	Journal of Medical Systems	Conceptual analysis/ mathematics	N.A.	algorithmic notations and syntax explained with defined security analysis but no simulation or experimental test results	Consortium blockchain	Implemented (security analysis through theorems)	Attribute-based encryption (ABE) and identity-based encryption (IBE), identity based signature, proposed combined attribute-based/identity-based encryption and signature (C-AB/IB-ES)
Wong, Bhattacharya & Butte (2019)	Nature Communications	Conceptual analysis	N.A.	Limited discussion on results of simulated blockchain based clinical trial. Algorithm or syntax not explained	Not available	Implemented (simulation)	Parallel healthcare system, artificial healthcare, parallel execution, interactive voice response system (IVRS)
Xia et al. (2017)	IEEE Access	Conceptual analysis	N.A.	Results discussed for test examples based on assumed vendor transactions per unit time (calculated) but no experiments or actual simulation. No algorithm or syntax	Permissioned blockchain	Implemented (simulation based on calculated assumptions)	Cryptographic keys, user-issuer protocol and user-verifier protocol
Yang et al. (2019)	Applied Sciences	Concept implementation	N.A.	Limited discussion on algorithm and results from prototype implementation primarily theoretical.	Consortium blockchain	Proposed (prototype implemented with qualitative comparison)	Application programming interface, proof of familiarity proposed

Yue et al. (2016)	Journal of Medical Systems	Conceptual analysis	N.A.	Limited illustration of computing code transformation and indicator schema. No experiments or simulations reported	Not available	Proposed	Indicator-centric schema (ICS), MPC (secure multi-party computing), proposed app (healthcare data gateway (HGD))
Zhang & Lin (2018)	Journal of Medical Systems	Concept implementation	Secure and privacy-preserving PHI sharing (BSPP) protocol proposed	Extensive detailing of algorithm notations, system architecture along with results from protocol implementation and performance evaluation	Consortium, private	Implemented (performance evaluation, comparison of security properties)	Consensus mechanism, Bilinear maps
Zhang et al. (2018)	Computational and Structural Biotechnology Journal	Qualitative	Case study	Detailed description of proposed architecture and workflow through case study. No experiments and discussion on algorithm or syntax	Ethereum	Proposed	Public key cryptography - sign then encrypt mechanism, Oauth, fast healthcare interoperability resources (FHIR), Solidity smart contract
Zhang, Xue & Huang(2016)	IEEE Access	Concept implementation + laboratory experiment	N.A.	Detailed discussion on algorithm. Details also provided for security and performance evaluation through theorems and experiments	Not available	Implemented (security analysis through theorem proofs, experiments, performance evaluation)	Elliptical curve digital signature algorithm, secure hash algorithm, IEEE 802.15.6 display authenticated association protocol, display-based out of band (OOB) channels, pervasive social network (PSN)-based healthcare
Zheng et al. (2019)	Journal of Medical Internet Research	Concept implementation + laboratory experiment	N.A.	Limited discussion on algorithm but significant details provided for experiment conducted to test system feasibility	IOTA Tangle	Implemented (experiment)	Masked authenticated messaging (MAM), IoT integration, GPS
Zhou, Wang & Sun (2018)	Journal of Medical Systems	Conceptual analysis/ mathematical + laboratory experiment	N.A.	Discussion provided for algorithm construction, and performance evaluation for processing time and verifying transactions	Ethereum	Implemented (experiment, performance evaluation)	Practical Byzantine fault-tolerance (PBFT), MIStore

added value to healthcare have been identified through investigating the constructs used, research findings, and limitations faced by researchers. These structured insights will assist researchers in understanding the focal areas of the research and identifying future research directions.

Our second contribution was the development of a synthesizing research framework. In doing so, our study adds to prior SLRs in the area. In particular, our synthesizing framework summarizes key contributions made by the extant research and classifies them under themes. Moreover, our framework marks a novel theoretical contribution by presenting a contemporary delineation of pertinent avenues to aid future researchers. This, in turn, helps to expand the scope for future research. For example, our framework explicates the collaborative role of blockchain technology in helping data interchanges between stakeholders, such as service providers from allied industries, patients, and permissioned medical authorities.

Third, our review has shown that attempts have been made to increase the benefits of applying blockchain technology in healthcare through other technologies such as artificial intelligence (AI) and machine learning (e.g. Mamoshina et al., 2018; Kuo et al., 2019a,b; Zheng et al., 2019). Future attempts may also promote research grounded in semantics and natural language processing. This would allow researchers to deploy advanced data management solutions, such as augmented normalization in the processing of diseases and clinical and biomedical texts (H. Li et al., 2018).

Fourth, based on the gaps explicated from the review, implications arise for the need to broader disciplinary and particularly methodological coverage of the research to advance the current understanding of the field. For example, research based on survey methodology or interviews can enhance the understanding of e.g. the challenges and barriers inhibiting user adoption.

Fifth and finally, there is a need for more holistic approaches to examine the adoption and utilization of blockchain in the healthcare domain. This in turn requires a better understanding of the interoperability of frameworks such as Ancile (Dagher et al., 2018), and GloreChain (Lee & Yang, 2018) that have been developed and proposed by extant research to facilitate the adoption of blockchain in healthcare. This may be achieved by examining the utility of such frameworks for users based across multiple institutions, such as hospitals, pharmacies, and medical research institutes.

6.2. Implications for practice

The study's findings can be utilized by multiple stakeholders, including healthcare providers, managers, and policy makers. First, we imply the need to adopt a strategic perspective towards the implementation of blockchain within an organizational framework through a careful assessment of the potential benefits and costs of implementing and running blockchain-based systems. For example, organizations should carefully evaluate the operating costs of blockchain considering the fact that blockchains can consume very large amounts of energy (Truby, 2018; Uddin et al. 2018).

Second, our study can inform management of healthcare to make decisions pertaining to technology deployment and resource allocation. In particular, our results can help identify areas for potential blockchain implementations and new applications for further efficiency enhancement (e.g. Fan et al., 2018), predictive analytics (e.g. Kuo et al., 2019a,b; Brogan et al., 2018), and improved diagnostics (e.g. Mamoshina et al., 2018; Lee et al., 2018). This in turn will require that organizations focus on how blockchain could add value to their specific business models and the contribution this technology could make towards organizational value creation process. Managers would then be empowered to inculcate positive attitudes towards the use of blockchain and increase the technology's perceived ease of use and utility.

Third, it is possible that the increased adoption of blockchain technology will lead to disruptive changes in the current structure of the healthcare system. The insights from this study can help the management of healthcare service providers as well as governmental authorities and decision-makers to evaluate the potential disruptiveness of blockchain technology (Mäntymäki et al., 2020) in the healthcare domain.

Fourth, our results can inform policy makers, and legal officers associated with healthcare, who may acquire ideas for creating sustainable policies for data sharing, storage, and the privacy protection of all stakeholders. This is especially important for blockchain-based systems for international use that may be subject to cross-national regulation or laws (e.g. HIPAA) for data protection and preservation of the sanctity of medical records (cf. Dhagarra et al., 2019). Such policies are currently critical because of rising incidences of security breaches involving medical data for reasons such as hacking (61 %), accidental exposure of data (44 %), and challenges in securing legacy infrastructures (Accenture, 2018). These policies may also be extended to incorporate international data sharing to facilitate the discourse among the international healthcare community, thus providing valuable insights for patient care, diagnostics, and treatment.

Fifth, due to the highly sensitive and personal nature of the information stored, processed, and exchanged in the healthcare system, issues related to social responsibility are of paramount importance. As in the case of artificial intelligence, our findings suggest a need to develop governance mechanisms for the use of blockchain in healthcare (Arrieta et al., 2020). In particular, reducing the opacity associated with blockchain can be important in maintaining stakeholders' trust in the underlying technology but also in the healthcare system as a whole.

6.3. Limitations and future research directions

The findings of the current study should be considered in light of its limitations. First, the review focused solely on articles appearing in peer-reviewed journals available in selected scholarly databases. Thus, other forms of publications, such as conference reviews and book chapters, were excluded. Similarly, despite the employment of citation chaining, it is possible that articles appearing solely in the ACM and IEEE databases were not captured. Second, the review considered blockchain as an umbrella keyword and did not consider vernacularly interchangeable terms, such as smart contracts or distributed ledgers, as keywords. These limitations may be addressed in future research by considering additional keywords such as smart contracts, and databases such as ACM and IEEE to expand the scope of the assimilated information.

Beyond the previously discussed four future research directions derived from the reviewed studies, we highlight three specific areas where future research could inform research and practice in the domain of blockchain and healthcare. First, future research could focus on the potential adoption and infusion of smart contracts in healthcare (Pawczuk et al., 2019). This might improve customer service through more efficient information exchange between stakeholders of the healthcare ecosystem. Secondly, since privacy and information security play a pivotal role in healthcare, we advocate policy and service development-oriented research to further safeguard users' privacy and the information stored in blockchain-based systems. In particular, future research could focus on designing protocols for managing private cryptographic keys for network nodes. This could ensure authenticated use of private keys and avoid data breaches due to mismanagement of keys. Third, there is a need to advance the conceptual knowledge of blockchain applications for specific issues, such as diagnostics, biometric authentication, and continual monitoring of senior patients.

7. Conclusions

The present study aimed to understand the scope of the application of blockchain in the healthcare domain. To address this objective, an SLR was performed on four well-regarded digital databases following specific protocols to identify appropriate articles to be reviewed. The findings were used to summarize existing knowledge on blockchain's application in the specific sector of healthcare and encapsulate past as well as current thematic trends of academic research in this area. Future avenues of research have been presented through a synthesized framework that was developed by amalgamating insights from extant limitations, recommendations, and emergent gaps in current knowledge identified during this review.

Authors' contributions

Author AT was responsible for the study conduction and assimilating the literature to select the final sample; Authors AT, AD, NI and MM reviewed the sample selection protocol and assessed the quality of the included studies; AT synthesised the literature according to the described methodology and wrote a first draft of the manuscript; AD, NI and MM contributed to the final version and provided several suggestions to improve the quality of the systematic literature review. All authors have read and agreed to the paper being submitted in the present form.

Declaration of Competing Interest

The authors of this manuscript declare no conflicts of interest.

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