Review

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Implementing Blockchains for Efficient Healthcare: A Systematic Review

ABSTRACT

Background: The scattered nature of sensitive health information can bring about situations where timely information is unavailable, worsening health outcomes. Furthermore, as patient involvement in healthcare increases, there is a growing need for patients to access and control their data. Blockchain is a secure decentralised online ledger that could be used to manage electronic health records efficiently, and so improve health outcomes by enabling interoperability.
Objective: To perform a systematic review to assess the feasibility of blockchain as a method of managing healthcare records efficiently.
Methods: Reviewers identified studies via systematic searches of databases including Pubmed, Medline, Scopus, Embase, Proquest and Cochrane Library. Suitability for inclusion of each was assessed independently.
Results: Of 71 included studies, the majority discuss potential benefits and limitations without evaluation of their effectiveness, although some systems were tested on live data.
Conclusions: Blockchain can efficiently manage access to electronic health records stored on the cloud. Using a blockchain can increase interoperability without compromising privacy and security of data. It contains inherent integrity, and conforms to strict legal regulations. Increased interoperability would be beneficial for health outcomes. While this technology is currently unfamiliar to most, investments into creating a sufficiently user-friendly interface and educating users on how best to take advantage of it would also improve health outcomes.

Trial registration

International Prospective Register for Systematic Reviews (PROSPERO) number CRD42018096947.

Keywords

Blockchain, Electronic Health Records, Efficiency, Interoperability, Health

INTRODUCTION

Medical records in Britain comprise legacy paper records and numerous disconnected electronic systems. Despite the advancement of other fields in using technology, there remains a lack of interoperability in healthcare systems arising from the non-uniform record storage methods, that restricts doctors in their capacity to provide appropriate care.[1] Furthermore, the lack of (correct) information has been considered the primary cause of problems in healthcare, leading to medical errors and adverse events.[2] Patients must recount their history multiple times, which may be done incompletely. They too appreciate that interoperability would be beneficial in alleviating these adverse events. [3, 4] The NHS planned to mend the situation by computerising all records by 2018, however this target was delayed first to 2020, and again to 2023.[5] In the United States, almost 90% of physicians already use a computerised system,[6] although these are not all interoperable. Blockchain could solve the problem of interoperability by allowing doctors to gather information about a patient from multiple independent systems.[7]

A blockchain is a decentralised online ledger (database), first implemented to store an ever-increasing record of all transactions using the cryptocurrency Bitcoin.[8] It works by replacing trusted third party signatories of a transaction (in a financial context, typically a 'middle-man' payment provider such as VISA) with computational (cryptographic) proof in order to validate transactions. This validation is carried out by a network of users ('full nodes') who collectively adhere to previously agreed rules, which are implemented by the software. This method saves both the cost of mediation, as a blockchain involves no mediator, and the cost associated with reversing transactions when disputes arise, as blockchain transactions are essentially irreversible. The transaction records are grouped into blocks, each of which is locked to the next with a cryptographic hash. Once recorded, data in any given block cannot be modified without altering all subsequent blocks (as each block's hash depends on the last), nor without the agreement of a majority of the members of the network.

The system is also flexible enough to allow the addition of arbitrary logic to process, validate and access the data. This is implemented via components of business logic known as smart contracts, which reside on the blockchain and are synchronised across all nodes. A smart contract is a string of computer code that executes whenever certain conditions are met, ensuring security and authorised access.[9] The ability to create smart contracts makes blockchain suitable for healthcare, where strict regulations govern how sensitive data can be used.[10, 11] Information exchange using smart contracts is transparent and conflict-free, and eliminates the need for a middleman as the blockchain executes the data sharing based on the conditions of the contract.[29, 43]

Ownership and privacy of data are important issues that blockchain could solve. It is currently unclear whether the healthcare provider or the patient owns healthcare data relating to a patient, although patients have a definite right to access the data.[12] In addition to ownership issues, with the introduction of GDPR, it is important for patients to know how their personal information is being handled.[10, 13] Smart contracts implemented by a blockchain would simplify the consent process for data access by doctors. The current consent process is not standardised or personalised, which makes it difficult for a patient to express his/her access control policy, which may for example involve allowing selected access to particular specialists.

Another concern with medical records is the cost currently associated with transferring records between locations.[14] Repeated imaging studies carried out because of unavailability of prior results can be dangerous in terms of delayed treatment as well as financially costly. Sending data via email is considered a security risk,[15, 16] and there is clear inefficiency inherent in transcribing a digital asset onto optical media which is commonly read only once at the receiving site.[11, 17] A system integrating patient consent as well as access to authorised individuals would save on these costs.

Medical information is no longer limited to written reports, imaging studies and blood tests. Genomic data and that collected by wearable devices, such as bracelets and watches embedded with sensors, are increasingly accumulated. These may lead to improved treatment options and outcomes, and may also be examined by health insurance companies offering discounts for ‘healthy’ behaviour. Further benefits arise in the realm of artificial intelligence. This can infer trends from the data that are then used to generate population-level insight, and so achieve population health as a whole. These new data formats require careful integration, to allow appropriate analysis while maintaining patient privacy and security from hackers.

While digitisation of health records has been in place in the GP sector for over thirty years (albeit lacking essential data sharing and exchanging capabilities), secondary care has not yet successfully achieved this de facto standard. Distributed ledger technology, initiated and exemplified by the Bitcoin blockchain, is having a growing impact on information technology environments in which conformation to legislative regulations and maintenance of public trust are increasingly paramount,[18] and it may be used in realising NHS Digital's target. The aim of this review is to summarise the evidence relating to the implementation of blockchains to manage electronic health records, and to discuss whether this would improve efficiency of record management.

METHODS

The protocol[19] was used with the following modifications:

- The research question was modified to focus on efficiency, as the issues of privacy and scalability would broaden the review excessively.

- Five additional search databases were included to account for the potential lack of published research on the topic.

- The population was extended to include anyone whose data is stored in a healthcare blockchain. It was also noted that much of the literature would consist of unimplemented frameworks, so would have no population.

Research question and definitions

What strategies have been proposed or trialled to implement a blockchain or blockchains for the management of electronic medical records, and how do they improve efficiency compared to currently employed medical record management methods?

Medical record: [any] record consisting of information about the physical or mental health or condition of an identifiable individual made by or on behalf of a health professional in connection with the care of that individual.[20]

Efficiency: Either improved administrative capabilities or cost-effectiveness, or improved health outcomes as a result of these.

Current methods: These may consist of traditional paper-based methods or more advanced technology adopted to provide more coordinated healthcare.

Search strategy and study selection

We searched Pubmed, Scopus, Embase, Medline, Proquest, CINAHL, AMED, Global Health, Books@Ovid and Cochrane Library for all relevant literature including articles, theses and conference abstracts that have been published electronically. We also searched for other systematic reviews on the topic using PROSPERO.[21] The search strategy was based on keywords and search term combinations derived from the MeSH database [22], describing the intervention (blockchain for electronic health records) and outcome (efficiency, as defined above) (Supplementary Table 1). As blockchains applied to the healthcare sector remains a novel approach, we did not place restrictions on the study type. Nor were restrictions placed on dates of publication or geographic locations. However, only studies in English were included.

Results of the search strings (Supplementary Table 2) were imported into EndNote X8.0.1 (Clarivate Analytics), which was used to remove duplicate articles. Remaining duplicates were deleted manually. Potentially eligible articles were identified using an iterative approach of full text screening followed by title and abstract searches (Supplementary Table 3). These were exported into Microsoft Excel, and the title and abstract of each was independently screened by two reviewers, based on the following inclusion criteria:

- Articles must discuss the use of blockchain to manage medical records in some manner

AND

- Articles must describe the benefits and/or disadvantages of using this technology [and compare this to currently used methods of managing medical data]

Where the second point may not be determined from the abstract alone, the study should be taken to full text screening. Studies may not identify a comparator, and these may be included provided the remaining inclusion criteria are met.

Reviewers resolved discrepancies through discussion (Supplementary Table 4), and no adjudication from a third reviewer was required. The full texts of the remaining articles were subsequently assessed for their eligibility, based on the same eligibility criteria. This selection process is demonstrated using the PRISMA flow diagram (Supplementary Figure A).

Data extraction

A template was designed to collect information required to address the research question. Basic information was collected automatically by Endnote, and the remaining data items (Supplementary Table 5) were gathered after reading the papers in full.

Outcomes

The primary outcome measures were interoperability and cost-effectiveness (our definition of primary efficiency). The secondary outcome measure was improved health outcomes, although it was noted that it might be difficult to determine a quantitative measure of this with respect to blockchains.

Strength of evidence and data synthesis

Studies of interventions involving randomised and non-randomised methods were assessed for risk of bias using the Cochrane Collaboration Risk of Bias Tool and the Risk of Bias in Non-Randomised Studies - of Interventions (ROBINS-I) tools respectively.

The extracted data were subsequently summarised qualitatively. No meta-analysis was performed, because application of blockchains in healthcare remains a novel method and articles with sufficient numerical data were not found. In addition, the heterogeneity of studies prevented a meta-analysis.

RESULTS

Description and characteristics of included studies

After the initial literature search, removal of duplicates, eligibility and full-text screening, 61 articles were included in the paper. An additional ten papers were added via snowballing of the full texts screened (Table 1).

Table 1 - Quantitative analysis of included articles

Article type	Number of articles
Implementation of system	4 [23, 24, 25, 26]
Proposal of framework	18 [10, 11, 18, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41]
Discussion of benefits and drawbacks	10 [4, 15, 42, 43, 44, 45, 46, 47, 48, 49]
Description of company in the field	20 (Table 2)
Newspaper, magazine, columns	19 in searched databases, many more online

Only very few articles described the implemention of a blockchain system to real world medical data, highlighting the novelty of this technique. One of these[23] used smart contracts to manage access to medical data that was stored on the cloud, while the others stored medical data directly on the blockchain. Of the largest group of articles, which proposed a framework (without implementing it), the majority advocated cloud-based data storage and blockchain-based access control. In addition to the primary outcome of interoperability, issues considered in these papers included those of privacy and data security, scalability and administrative affairs. There were also number of companies identified which are currently implementing blockchains in healthcare (Supplementary Table 7), many of which have not published any academic literature.

The majority of the information comparing blockchain's potential versus current methods of managing records was found in opinion articles, which were set more broadly in the context of developments in healthcare technology. Many described the disarray of current health record management. Some used the successes of blockchain in other fields than healthcare and finance to demonstrate its versatility.

Outcome measures

Interoperability was seen as feasible using a blockchain approach, if the blockchain is used for access control (as opposed to sensitive data storage). The approach was cost effective compared to administrative costs of transporting records. Administrative difficulties and costs may arise in collating legacy data, although these would be accounted for in savings from improved health outcomes in the long term.

DISCUSSION

Summary of evidence

A blockchain can allow improved interoperability as data across multiple systems can be accessed simultaneously and immediately. The interfacing of different systems would also save costs.[33] These factors reduce administrative delays, as does the use of smart contracts to execute patients' consent preferences immediately. An off blockchain data repository ('data lake') is scalable and can store a variety of data types, as well as being a tool for research. It is interactive and supports high throughput data analysis and machine learning, while being encrypted and digitally signed to ensure data privacy and authenticity.[39] The collaboration between patients, doctors, and researchers arising from a blockchain-based system allows for a greater degree of exchange and comparison, leading to specific and personalised care pathways.[18, 33] The ONC has described several features critical to the development of an interoperable health system,[[50]] such as establishing a directory of resource locations that can be easily referenced to locate information, and establishing an economic environment in which interoperability is a sound business decision, which are addressed by blockchain.[11]

Interoperability

Health data is dynamic and expansive, so it would not be practical in terms of speed, storage capacity or sustainability to replicate all health records on every computer in the blockchain network.[44] The majority of authors instead proposed blockchain to manage access-control (and for smart contract management), by storing an index of all users' health records and related metadata. Each time data is added by a doctor or by the patient from a mobile application or wearable sensor, a pointer to this is added to the blockchain, and the data is stored securely on the cloud.[39] The fact that Blockchain is based on open source software also has potential benefits, as health IT systems could use the Open API to integrate data as they wish, giving them timely access to accurate information. The strive for interoperability is a key feature of the HITECH Act, which has meant that since 2011, American healthcare providers have been given financial inventives to demonstrate meaningful use of EHRs.[[51]]

Health

The capability of personalised medicine would be improved as a single access point for all real time health data is created for each patient.[51] Data gathered from wearable sensors and mobile applications would contribute information on the risks and benefits of treatments, and on patient reported outcome measures. The availability of more frequent data would allow physicians to create specialised treatment plans based on outcomes and treatment efficacy. It is also thought that daily health data would engage a patient more in their own health care, and improve patient compliance.[39]

Integrity

The immutability of a blockchain that stems from linking the hashes of subsequent blocks, carries with it inherent integrity, as blocks cannot be rewritten without collaboration of a majority of nodes. This property was exemplified by RadBit at last year's Yale Healthcare Hackathon.[34] Potential ways to improve the integrity are to use blind signatures, which reinforce protection from tampering as well as confirming the sender's and viewer's identities,[42] or to use signatures from multiple authorities.[30] Temporary keys ('tokens') can be created by users and passed onto those such as healthcare providers and insurance companies, providing them temporary access. The token is independent of the data, containing only authorisation commands, and is verified and validated (by recording them on the chain) before the required reports are dispatched.[31, 42] Integrity may also be maintained by the use of external auditors, who may verify the accuracy of the system in real time and retrospectively.[10]

ONC Blockchain Challenge

In 2016, the ONC organised the "Use of Blockchain in Health IT and Health-Related Research" challenge, seeking ideas to address the difficulties of managing health records.[9, [52], 63] Winning papers described innovative ways to securely empower patients through interoperability.[47, [53]] MedRec, one of the winning entries, is now being implemented in Boston. This proposal from MIT's Media Lab involves associating a medical record with viewing permissions and data retrieval instructions for execution on external databases, thus using the blockchain to record patient provider interactions via smart contracts. Once a doctor creates a record, it is verified, and its viewing permissions are authorised by the patient. The party receiving new information receives an automated notification,[1] and a hashed pointer to the new medical record and its permissions are stored on the chain. This system allows patients to be empowered through access and control of their data, options which have until now not been available.[47] So far their system has been successful with medications, blood tests, vaccination histories and other therapeutic interventions.[[54]]

Real world implementation

Blockchain has been adopted on a large scale by the Estonian government, in collaboration with Guardtime, where it secures millions of records. Other companies involved in introducing blockchain to everyday healthcare include Medicalchain, which allows users to sign up and use the interface to interact with their GP, Patientory, that connects doctors, health providers and consumers, and others listed in Supplementary Table 7.

CHALLENGES AND LIMITATIONS

Data Ownership and Privacy

Achieving interoperability depends on patients taking control of their data and deciding on how it is to be used. Shifting data ownership from the government and companies to patients would require extesive reengineering of legacy systems, but would incentivise patients to become active agents in their own care by contributing data in order to get the best possible treatment.[4, [55], [56]] It would also give them the sole power to authorise data access to various providers at their discretion,[28] eliminating delays associated with the current bureaucracy,[40, 50, [57]] and ensuring patient privacy.[10] Patients could also selectively share data with researchers, either for the greater scientific good or to enable studies on their unique condition.[[58]] The system would guarantee their consent. A recent example, 23andMe, 80% of whose users chose to make their genomic data available to researchers, demonstrates that patients will be happy to share data for research should they stand to benefit. Enabling direct patient involvement in controlling the use of their records in this open and secure manner will enhance the uptake of such platforms and potentially lead to improved health outcomes.[18] In addition to sharing data, which may be accomplished with a trusted system, there is the idea of 'rewarding' patients for healthy behaviour, such as with lower insurance premiums.[10, 46]

Legal

Under GDPR (Article 17), the OECD privacy guideline, the HIPAA Privacy Rule and others,[48] individuals may request for their data to be erased. However, a record of the data's existence would still be maintained within the chain, even if the data itself were to be deleted from the cloud. The legal question arising from this relates to whether metadata of personal data classifies as personal data.[44] Were a private or consortium-led blockchain to be used, these privacy concerns would be addressed (as well as those of security and scalability). However they may not be vendor neutral or have open standards,[38, 39] issues which would have to be dealt with by the respective governing authority. These sorts of regulatory constraints are necessary to ensure appropriate use of information, however they may slow development in the field. HIPAA, for example, requires that an institutional review board approve the use of data.[10]

Security

Sensitive data must be kept safe from eavesdroppers and intruders.[28, [59]] Breaches have a negative impact on the public perception of the healthcare field, and threaten to hinder future research through more stringent regulatory restrictions.[[60], [61]] The WannaCry attack of May 2017 infected many thousands of computers worldwide, including those of the NHS.[[62], [63], [64]] One earlier attack in LA targeted EHRs in particular, demanding thousands of dollars in ransom.[[65]] A blockchain is more secure than legacy methods which would issue patients with credentials.[29] It achieves this property by generating new encryption keys frequently, although this comes at the cost of storing and indexing those keys to allow efficient retrieval. More security flaws arise if a public blockchain is used: hackers could collude in a '51% attack', resulting in the rewriting of the chain structure.[[66], [67]] Thus to realise the advantages of a decentralised system, patients must have some trust that at least 50% of mining nodes would not want to violate the immutability of the blockchain. The public blockchain also leads to the possibility of deanonymisation, which would need to be avoided by pseudonymising data in order to protect patients' identities.[11, 46] If a private or consortium blockchain were to be used however, mining nodes would be limited to hospitals and other trusted health providers, eliminating these security flaws.

Other concerns

While the major concerns with blockchain are those of security, privacy and legal restrictions, for which various workarounds have been developed, there remain some further challenges to consider. Firstly, consolidating data from legacy systems will involve removing data that is duplicated in different parts of the system,[4] and converting outdated file formats. This introduces an implementation cost, in excess of the basic cost to introduce a blank system,[[68]] which a government may not be willing to spend.[[69]] Secondly, as with any system, it is necessary for users to input good quality information: the trustworthiness arising from blockchain's immutability and decentralisation concedes to the input of low quality (incorrect) information.[4, 27]. Thirdly, the issue of currency, used in blockchain to incentivise users to mine blocks in the new network. An ICO[33, 41, 47] could initiate this process by valuing the new token as funds are raised.[47] However extremes of price could deter miners, and so mining may need to be restricted to healthcare providers to avoid this. Another view is to remove all currency, as data is owned by the patient and is not in itself an exchangeable currency.[29] Based on this, we may assume that providers already have an incentive to secure patients' medical information, and so there would be no need to incentivise mining beyond the simple use of the system. Finally, the reliance of a blockchain on essentially arbitrary computation could be seen to introduce administrative inefficiency.[18] Transactions are therefore energy intensive, as each must be computationally verified and validated by the whole network.[33] Such a mechanism is still beneficial however, as rather than providing economic value it demonstrates proof-of-participation, which would be required for ongoing use of the system.

CONCLUSION

The storage and sharing of medical data (developing interoperability) are vital for improved health outcomes. Respecting privacy of sensitive information while doing this remains a big challenge in healthcare. The literature show that with the appropriate regulatory guidelines and use standards, blockchain can act as a vehicle to manage consented access to electronic health records. This will increase interoperability without compromising security, and while also protecting patient privacy. These issues would most effectively be tackled by the use of a private or consortium-led blockchain, however this would need to be regulated to ensure appropriate use of data. The improved interoperability and reduced long term administrative costs would lead to improved health outcomes.

Blockchain represents a new form of technology on which the current literature is expectedly poor, and no usage feedback or statistical comparisons with traditional systems exists. There are costs associated with transferring to a new system, and in educating health professionals and patients on how best to take advantage of it for improved health. Blockchain involves concepts unfamiliar to the vast majority of the population, such as cryptographic signature and key management. Investments into the new system would however be outweighed through returns. In the primary stages of implementation, the practical usefulness of the proposed system will likely depend on the end user experience - the complexities underlying the blockchain will need to be hidden behind a sufficiently user-friendly interface such as an online or mobile application in order to be adopted successfully. Short term trials will outline the most effective ways to implement such a user-friendly experience, which may be expanded thereafter.

PATIENT AND PUBLIC INVOLVEMENT

Research issues identified and prioritised by the members of the public in a workshop at the European Scientific Institute on July 2017 were used to guide the focus of this study.

ETHICS AND DISSEMINATION

As data collection was executed via published literature, ethical approval was not be required for this review.

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TRANSPARENCY DECLARATION

The authors declare that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

CONTRIBUTORSHIP STATEMENT

EM conceived the study topic and oversaw the project. AV investigated and executed bench research and completed manuscript drafting on his own. OD completed peer review of papers for analysis and gave helpful discussion on content. EM gave feedback on the completed manuscript to AV and AV incorporated all feedback. DB also provided feedback on iterations. The final manuscript was approved by all authors. EM is the guarantor.

COMPETING INTERESTS STATEMENT

All authors completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf. There are no relevant conflicts of interest, financial or other types of relationships that may influence the manuscript declared by authors. Authors do not have any patents and are not associated to any conditions or circumstances that may lead to conflicts of interest.

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This manuscript summarised information from publicly available literature. Any questions on source data can be forwarded to the corresponding author.

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Appendix A: Full search strategy used

Supplementary Table 1 - Search terms and keywords

Intervention/Outcome term	**MeSH Heading**	**Similar search terms**
Blockchain	N/A	Blockchain*
Efficiency	Efficiency	Organisation, organization, productivity
Health outcomes	Health	Normality
Cost effectiveness	Cost-benefit analysis	Cost-benefit data, cost-utility analysis, economic evaluation, marginal analysis, cost benefit, cost-effectiveness analysis
Electronic health records	Electronic health records	Computerised health records, computerized health records, computerised medical records, computerized medical records, electronic medical records, electronic healthcare records

Supplementary Table 2 - Search strings

Database(s)	Exact search string	Number of results
Pubmed	"blockchain*"[All Fields] AND ("efficien*"[All Fields] OR "cost-benefit analysis"[All Fields] OR "EMR"[All Fields] OR "EHR"[All Fields] OR (("electronic"[All Fields] OR "computer*"[All Fields]) AND "record*"[All Fields]))	6
Scopus	ALL ("blockchain*" AND ("efficien*" OR "organis*" OR "organiz*" OR "cost*" OR "EMR" OR "EHR" OR (("electronic" OR "computer*") AND "record*") OR "health*" OR "medic*"))	1365
CINAHL	TX "blockchain*" AND ("efficien*" OR "organis*" OR "organiz*" OR "cost*" OR "EMR" OR "EHR" OR (("electronic" OR "computer*") AND ("record*" OR "data")) OR "health*" OR "medic*")	34
Books@Ovid, AMED, Embase, Global Health, Medline (accessed together via Ovid)	"blockchain*" AND ("efficien*" OR "organis*" OR "organiz*" OR "cost-benefit analysis" OR "EMR" OR "EHR" OR (("electronic" OR "computer*") AND ("record*" OR "data")) OR "health*" OR "medic*") {Including Limited Related Terms}	5408
Proquest	"blockchain*" AND ("health*" or "medic*") AND ("efficien*" OR "organis*" OR "organiz*" OR "cost*" OR "EMR" OR "EHR" OR (("electronic" OR "computer*") AND ("record*" OR "data")))	5483
Cochrane Library (full text)	“blockchain*”	0
	("efficien*" OR "organis*" OR "organiz*" OR "cost*") AND ("EMR" OR "EHR" OR (("electronic" OR "computer*") AND ("record*" OR "data")))	14273 (excluded - see below)

The Cochrane Library was searched for the term “blockchain”, but this returned no results. A search for the second string listed in the table returned 14273 results, including 7671 Cochrane Reviews, 1669 Other reviews, 3335 Trials, 122 Method studies, 115 Technology assessments, 1306 Economic evaluations, and 55 Cochrane groups. These were imported and screened using Endnote, with none containing the term “blockchain” in their full text, and so all were discarded.

A search for the term “blockchain” on PROSPERO returned only the protocol cited for the current systematic review.

Supplementary Table 3 - Electronic screening

Term	Field	Criteria	Articles remaining	Notes
“blockchain*”	Full text	Articles without blockchain in the entire text are unlikely to be relevant	1546	8165 excluded
“health*” OR “med*”	Full text	Articles need to relate to blockchain specifically in healthcare	688	(317 health, 574 med), 858 excluded
“record*” OR “data”	Full text	Articles must relate to the use of blockchain specifically for EHR	448	(336 record, 320 data), 240 excluded
“blockchain*”	Abstract	Articles without blockchain in the abstract are unlikely to be relevant	370	78 excluded
“health*” OR “medic*”	Abstract	Articles without some direct health or medical link in the abstract are likely to be focussed on other blockchain applications	191	(144 health, 96 medic), 179 excluded
REMOVE “financ*”	Abstract	Likely to be too related to cryptocurrency	149	42 excluded (many of which would also have contained “currenc*”, see following screen)
REMOVE “currenc*”	Abstract		138	9 excluded

Supplementary Table 4 - Title and abstract screening

The following outlines the full text screening process carried out by two reviewers independently:

Agreements - Yes	69
Agreements - No	53
Disagreements - AV Yes/OO No	11
Disagreements AV No/OO Yes	5

Supplementary Table 5 - Data extraction items

#	Data Item	Description
1	Research question	What was the author's research question(s)?
2	Sources	What data sources did they draw upon?
3	Analysis	What method of analysis did they use?
4	Results	What were the main findings?
5	Conclusion	What is their conclusion

Supplementary Table 6: Eligibility stage search exclusions

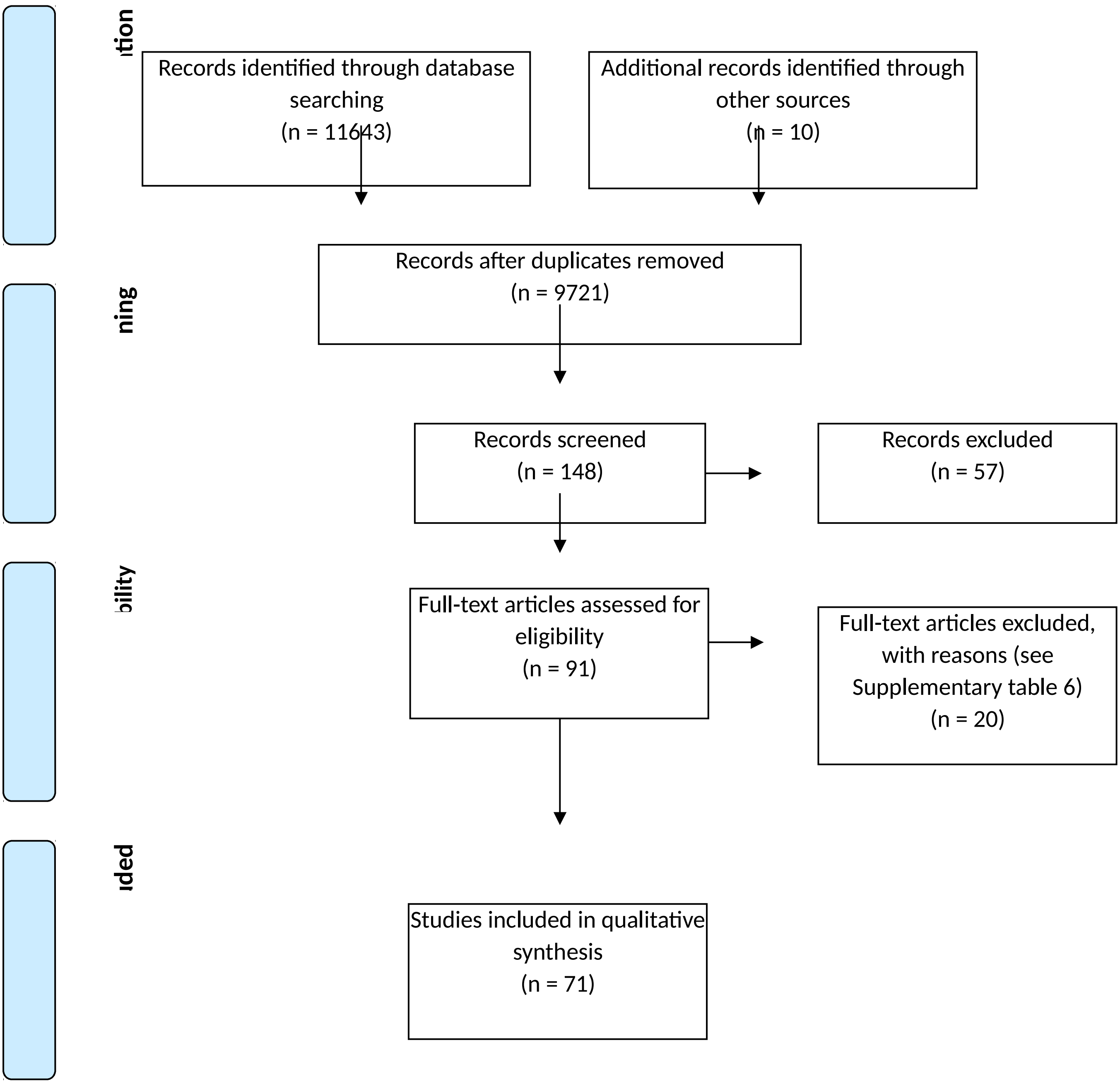
Reason for exclusion	**Number of articles excluded**
Duplicates	6
Inaccessible	7
Too focussed on financial aspects	7

Supplementary Table 7

Company / System Name
MedRec
Factom
Medicalchain
Medvault
phrOS
Guardtime
PokitDok / DokChain
GemHealth / GemOS
Patientory
Blockchain Health Co
Healthcombix
IBM Watson (Health)
BurstHQ
YouBase
HealthNautica
Philips Blockchain Lab
Hashed Health
Humana, Optum, United Healthcare, Multiplan, Quest Diagnostics (collaboration)
SimplyVital
Medable (Insight)

Supplementary Figure A

PRISMA 2009 Flow Diagram



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