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Digital Health

Supplementary appendix

This appendix formed part of the original submission and has been peer reviewed. We post it as supplied by the authors.

Supplement to: Ng WY, Tan T-E, Movva PVH, et al. Blockchain applications in health care for COVID-19 and beyond: a systematic review. *Lancet Digit Health* 2021; published online Oct 12. https://doi.org/10.1016/S2589-7500(21)00210-7.

Appendix

Overview of the Blockchain Architecture

A blockchain is a decentralized digital ledger, where transactions are stored immutably, in blocks of fixed data size, each linked cryptographically to its preceding block, to create an ever-growing chain. Each block is linked to its predecessor by a hash value – a fixed-length string of values computed from the blockchain's innate hash algorithm, based on the input data. This serves as a permanent identity marker (deterministic) for the set of stored transactions it represents, providing permanent tamper-proof transparency and traceability. This is a critical advantage as it allows the transacted data, which is usually large, to be stored off-chain. Data transfer is secured on blockchain platforms through asymmetric encryption technology (also known as public-key cryptography), that can be designed to keep on-chain data "anonymous", so as to protect data privacy. During the recording process of the blocks, some blockchain platforms are able to generate native tokens, which can be utilised for transactions, creating a digital asset known as cryptocurrency. We include a summary of common terms and definitions relating to blockchain technology in **Table 1**.

The architecture of a blockchain differs fundamentally from traditional distributed client-server database management systems (DDMSs) used in healthcare, such as EMR and medication supply chain management systems. A blockchain platform achieves secure disintermediation between untrusted parties, by replacing the traditional human intermediary with a hack-proof computational verification algorithm, hence creating a direct peer-to-peer (P2P) model of transactions in a network of computers. This allows direct exchange of data between multiple computers, regardless of their physical location without a single source of failure, using image- and collision-resistant hash algorithms to ensure that these transactions can be easily traced back to their original data provenance.

There are various types of blockchain platforms, but they can broadly be split into 3 categories – public, private, and hybrid/consortium blockchains (**Figure 1**). The key features differentiating these blockchain architectures are the restrictions applied to participating nodes, as well as consensus framework used. Permissionless public blockchain networks such as Bitcoin and Ethereum allow unrestricted participation. Bitcoin was the first blockchain technology introduced to the public in 2009. It was created as a platform to enable peer-to-peer money transfer using its own native token as an alternative to fiat currency. Bitcoin utilises Proof of Work (PoW), which involves a cryptographic puzzle based on a nonce that requires substantial computing power to solve, but for which the answer is easy to verify. The first node that successfully solves the puzzle is eligible to add a new block of transactions to the chain, and receive digital tokens in return – a process known as "mining". Each block contains a block header, as well as the hash of each individual transaction, linked by a Merkle root hash. The block header contains the hash of the preceding block, a timestamp, its own unique hash, the Merkle root hash, and nonce (**Figure 2**). PoW is extremely energy-consuming and suffers from long latency, yielding a maximum transactional rate of seven transactions per second. This led to the adoption of more cost- and energy-efficient consensus protocols without cryptographic puzzles, such as Ethereum's Proof of Stake (PoS). With PoS, a node that places a higher stake is more likely to be selected as a validator to determine the next block.

The private permissioned blockchain infrastructures utilize lightweight consensus protocols. Most of the consensus protocols reviewed in this study are either PoS or extensions of the Byzantine Fault Tolerance (BFT). In BFT, a consensus can be achieved so long as more than two thirds of the nodes are honest ($N = 3f + 1$ where N is total number of nodes and f is the number of malicious nodes). Notable BFT examples found in this study

include Quorum and Hyperledger Fabric. These consensus protocols promise greater scalability and functionality due to their higher efficiency and lower latency.

Hybrid blockchains, on the other hand, possess selected attributes of both public and private blockchains. These custom-built blockchain platforms are governed by multiple organizations, with high requirements for latency minimization and moderate requirements for horizontal scalability.

Following the introduction of Ethereum, smart contracts were developed and incorporated into the platform in 2013. This utilised programming codes that automatically execute and enforce contractual agreements between untrusted parties when pre-determined requirements are met, without the need for an intermediary. Continuous improvements to the smart contract designs have since spawned new variations such as Hashed Time-Lock Contracts, application logic contracts, and decentralized autonomous organizations. These have helped to imbue dynamic functionality into the blockchain architecture, allowing for execution of transactions beyond just monetary exchange. As a result, any digital matter of perceived value (e.g. personal data, certificate or digital art) can be represented and transacted on the blockchain, as exemplified by the emergence of non-fungible tokens.

Table 1. List of definitions for terminologies that are frequently encountered in blockchain-related articles

Ledger	Book or computer file for recording and totalling transactions
Blocks	Transactions cumulated and recorded into fixed sized blocks. Each block contains timestamp, a unique hash, the hash of the previous block and transaction data
Chain	List of blocks linked cryptographically
Hash	Cryptographically generated fixed length string of values, based on random input of transactions/data, that is easily verifiable
Mining	Validating of transactions and recording onto the decentralized ledger
Byzantine generals problem	Computer science description of a situation where involved parties must reach a decision to avoid failure, but some parties are dishonest or malicious
Consensus protocol	A form of rules to reach a common majority agreement on the present state of the ledger within a blockchain network
Fault tolerance	Level that allows a system to continue operating normally in the event of failure of some components or nodes
Nodes	Communicating points that may perform different functions on the blockchain platform
Permissioned	Access control layer governed by a central authority
Permissionless	Public access without restriction to participation
Hybrid/Consortium	Blockchain platform governed by multiple organizations
Immutable	Unchangeable ledger
Cryptoasset	Digital assets that utilizes cryptography as a medium for transactions
Smart contracts	Automated executions of complex transactions based on computational logic when certain conditions are met
Asymptotic security	Security if and only if the adversary's advantage is a negligible function of the security parameters i.e. a secure scheme that is conditionally proven to be harder than any polynomial for the attacker to break
Deterministic	Same operation performed by different nodes will produce the same result
Pre-image resistance	Computationally infeasible to derive the original transaction data from a given hash function
Collision resistance	Computationally infeasible for two distinct inputs to result in the same hash output
Non-repudiation	A statement's author cannot successfully dispute its authorship or the validity of an associated contract
Disintermediation	Removal of intermediaries from a decision-making process

This is a schematic illustration of 3 broad categories of blockchain platforms. Public blockchains are permission-less and fully decentralized, without central control. Anonymous parties can join a public blockchain to add and validate transactions without restrictions. Private blockchains, in contrast, are permissioned platforms where only participants with known identify can participate. These networks are partially decentralized, and often use simpler, more lightweight consensus protocols. Hybrid blockchains are platforms with selected attributes of both public and private blockchains, often custom-built to be optimized for specific use-cases.

Figure 1. Illustration of a blockchain. This schematic shows the technical structure of data in a blockchain. In this illustration, blocks N1 to N5 form a chain, where the block header of each block contains the hash of the preceding block (Hash_pre). Each block also contains a nounce, a timestamp, a Merkle root hash (Rcd_Root), and its own unique hash value (Hash_cur). A Merkle tree, which is a tree of hash values that allow for efficient verification of data, is also illustrated.

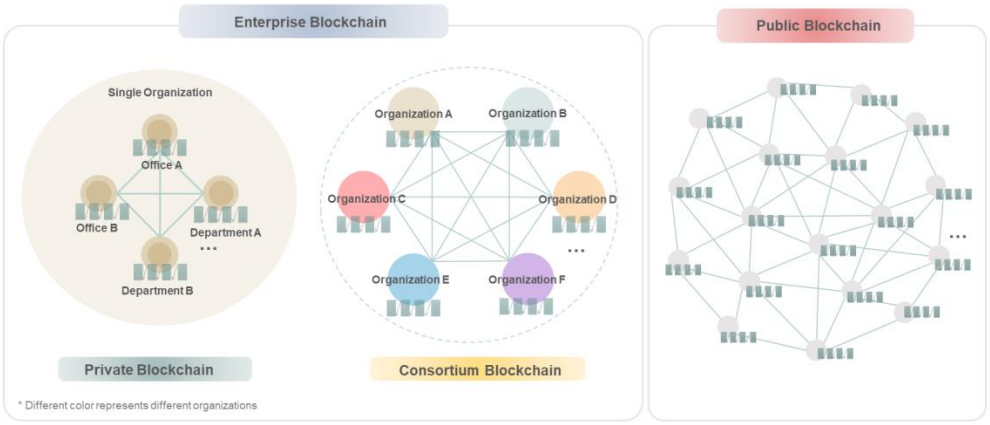
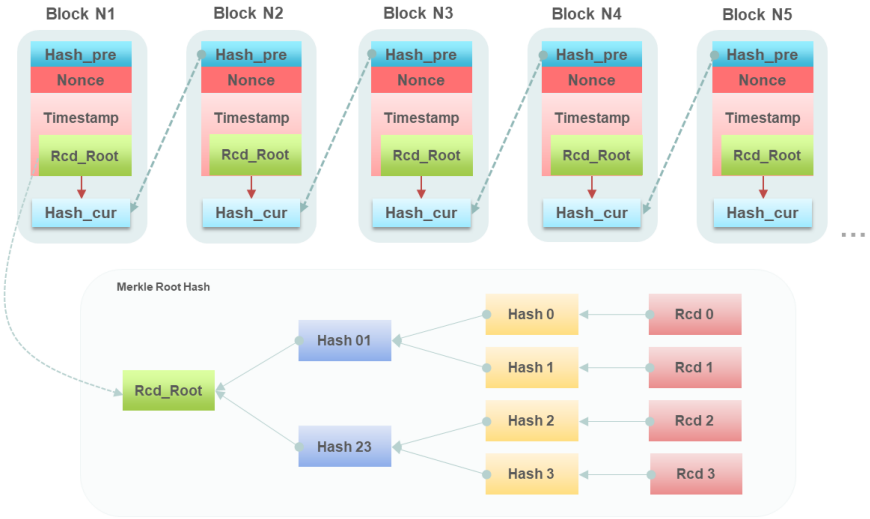


Figure 2. Illustration of the fundamental structure of a blockchain.



* "Rcd" refers to data records e.g. transaction

Table 2. Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) Checklist

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	1
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	3
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	4-5
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	5
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	5-6
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	6
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	6
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	6-7
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	7
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	7
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	7, Table 1
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	Not applicable
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	Not applicable
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	6-7

Section and Topic	Item #	Checklist item	Location where item is reported
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	7
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	5-7
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	5-7
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	Not applicable
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	Not applicable
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	Not applicable
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	Not applicable
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	Figure 2
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Figure 2
Study characteristics	17	Cite each included study and present its characteristics.	Appendix Page 9
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	Not applicable
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	Not applicable
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	8
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	Table 2 Figure 3 & 4
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	Appendix Page 8

Section and Topic	Item #	Checklist item	Location where item is reported
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	Not applicable
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	Not applicable
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	Not applicable
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	10-15
	23b	Discuss any limitations of the evidence included in the review.	16-17
	23c	Discuss any limitations of the review processes used.	16-17
	23d	Discuss implications of the results for practice, policy, and future research.	15-16
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	5
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	5
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	Not applicable
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	8
Competing interests	26	Declare any competing interests of review authors.	17
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	17

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71

For more information, visit: http://www.prisma-statement.org/

Article	Journal	Author Year	Title *Platform name*	Results
COVID related				
		Artificial intelligence/Big data/Federated learning		
C1	ArXiv	Kumar R. et al 2020	Blockchain-Federated-Learning and Deep Learning Models for COVID-19 Detection Using CT Imaging *Not specified*	Simulated
C2	ArXiv	Kumar R. et al 2021	Blockchain based Privacy-Preserved Federated Learning for Medical Images: A Case Study of COVID-19 CT Scans *DAG*	Simulated
C3	Pubmed	Peyvandi A. et al 2021	Computer-Aided-Diagnosis as a Service on Decentralized Medical Cloud for Efficient and Rapid Emergency Response Intelligence *Ethereum*	Simulated
		Clinical trials/Research		
C4	IEEE Xplore	Yu K. et al 2020	Efficient and Privacy-Preserving Medical Research Support Platform Against COVID-19: A Blockchain-Based Approach *Hyperledger*	Simulated
		Contact tracing		
C5	Pubmed	Aslam B. et al 2021	Blockchain and ANFIS empowered IoMT application for privacy preserved contact tracing in COVID-19 pandemic *Not specified*	Simulated
C6	ArXiv	Song J. et al 2020	Blockchain Meets COVID-19: A Framework for Contact Information Sharing and Risk Notification System *Ethereum*	Simulated
C7	ArXiv	Xu H. et al 2020	BeepTrace: Blockchain-enabled Privacy-preserving Contact Tracing for COVID-19 Pandemic and Beyond *Not specified*	Simulated
C8	Pubmed	Vangipuram S. et al 2021	CoviChain: A Blockchain Based Framework for Nonrepudiable Contact Tracing in Healthcare Cyber-Physical Systems During Pandemic Outbreaks *Not specified*	Simulated
C9	ArXiv	Lv W. et al 2020	Decentralized Blockchain for Privacy-Preserving Large-Scale Contact Tracing *Not specified*	Simulated
C10	ArXiv	Ahmed M. et al 2021	DIMY: Enabling Privacy-preserving Contact Tracing *Hyperledger*	Simulated
C11	IEEE Xplore	Klaine PV. et al 2020	Privacy-Preserving Contact Tracing and Public Risk Assessment Using Blockchain for COVID-19 Pandemic	Simulated

			Not specified	
C12	ScienceDirect	Zhang C. et al 2021	Privacy-Preserving Contact Tracing in 5G-Integrated and Blockchain-Based Medical Applications *Hyperledger*	Simulated
		Electronic medical records		
C13	IEEE Xplore	Ghani A. et al 2021	A Blockchain-based secure PHR data storage and sharing framework *Ethereum*	Simulated
C14	IEEE Xplore	Randhir K. et al 2020	A Secure and Distributed Framework for sharing COVID-19 patient Reports using Consortium Blockchain and IPFS *Ethereum*	Simulated
C15	IEEE Xplore	Christodoulou K. et al 2020	Health Information Exchange with Blockchain amid Covid-19-like Pandemics *Ethereum*	Nil
C16	Pubmed	Kumar M. et al 2021	MedHypChain: A patient-centered interoperability hyperledger-based medical healthcare system: Regulation in COVID-19 pandemic *Hyperledger*	Simulated
		Health/Vaccine Passport/Certificate related		
C17	ArXiv	Shamsi K. et al 2020	A Secure and Efficient Approach for Issuing KYC Token As COVID-19 Health Certificate Based on Stellar Blockchain Network *Stellar Consensus Protocol*	Nil
C18	IEEE Xplore	Hasan HR. et al 2020	Blockchain-Based Solution for COVID-19 Digital Medical Passports and Immunity Certificates *Ethereum*	Simulated
C19	ArXiv	Rotbi MF. et al 2021	Blockchain technology for a Safe and Transparent Covid-19 Vaccination *Ethereum*	Nil
C20	ArXiv	Eisenstadt M. et al 2020	COVID-19 Antibody Test / Vaccination Certification: There's an App for That *Ethereum*	Simulated
C21	ArXiv	Angelopoulos CM. et al 2020	DHP Framework: Digital Health Passports Using Blockchain -- Use case on International Tourism During the COVID-19 Pandemic *Not specified*	Nil
C22	ArXiv	Chaudhari S. et al 2020	Framework for a DLT Based COVID-19 Passport *Not specified*	Nil
C23	ArXiv	Dima SF. et al	Hygiea: A secure, smart, privacy-preserving and	Simulated

		2021	interoperable Blockchain solution for the Covid-19 pandemic *Ethereum*	
C24	Pubmed	Abid A. et al 2021	NovidChain: Blockchain-based privacy-preserving platform for COVID-19 test/vaccine certificates *Ethereum*	Simulated
C25	ArXiv	Hernández-Ramos JL. et al 2021	Sharing Pandemic Vaccination Certificates Through Blockchain: Case Study and Performance Evaluation *Hyperledger*	Simulated
		Pandemic control/surveillance		
C26	Pubmed	Ouyang L. et al 2021	A novel framework of collaborative early warning for COVID-19 based on blockchain and smart contracts *Ethereum*	Simulated
C27	ArXiv	Alsamhi SH. et al 2021	Blockchain for Decentralized Multi-Drone to Combat COVID-19 *Not specified*	Nil
C28	ArXiv	Alsamhi SH. et al 2020	Blockchain for Multi-Robot Collaboration to Combat COVID-19 and Future Pandemics *Ethereum*	Nil
C29	IEEE Xplore	Alsamhi SH. et al 2020	Blockchain-Empowered Multi-Robot Collaboration to Fight COVID-19 and Future Pandemics *Ethereum*	Nil
C30	IEEE Xplore	Gupta R. et al 2020	Blockchain-Envisioned Softwarized Multi-Swarming UAVs to Tackle COVID-I9 Situations *Ethereum*	Simulated
C31	ArXiv	Torky M. et al 2020	COVID-19 Blockchain Framework: Innovative Approach *Hyperledger*	Nil
C32	IEEE Xplore	Rimsan M. et al 2020	COVID-19: A Novel Framework to Globally Track Coronavirus Infected Patients using Blockchain *Ethereum*	Nil
C33	ArXiv	Choudhury H. et al 2020	CovidChain: An Anonymity Preserving Blockchain Based Framework for Protection Against Covid-19 *Not specified*	Nil
C34	ArXiv	Alansar SA. et al 2021	Efficient and Privacy-Preserving Infection Control System for Covid-19-Like Pandemics using Blockchain *RAFT*	Simulated
C35	Pubmed	Lee HA. et al 2020	Global Infectious Disease Surveillance and Case Tracking System for COVID-19: Development Study *Not specified*	Clinical case study
C11	IEEE Xplore	Klaine PV. et al	Privacy-Preserving Contact Tracing and Public Risk Assessment	Simulated

		2020	Using Blockchain for COVID-19 Pandemic *Not specified*	
		Supply chain		
C36	IEEE Xplore	Ahmad RW. et al 2021	Blockchain-Based Forward Supply Chain and Waste Management for COVID-19 Medical Equipment and Supplies *Ethereum*	Nil
C37	ArXiv	Antal CD. et al 2021	Blockchain Platform for COVID-19 Vaccine Supply Management *Ethereum*	Simulated
Non COVID related				
		Authentication/Authorisation		
N1	IEEE Xplore	Li CT. et al 2020	A Blockchain Based Data Aggregation and Group Authentication Scheme for Electronic Medical System *Not specified*	Nil
N2	IEEE Xplore	Zhu T. et al 2021	A Patient-Centric Key Management Protocol for Healthcare Information System based on Blockchain *Ethereum*	Simulated
N3	IEEE Xplore	Adlam R. et al 2019	A Permissioned Blockchain Approach to the Authorization Process in Electronic Health Records *Hyperledger*	Nil
N4	IEEE Xplore	Xiang X. et al 2020	A Permissioned Blockchain-Based Identity Management and User Authentication Scheme for E-Health Systems *Not specified*	Simulated
N5	ScienceDirect	Mohsin AH. et al 2019	Based Blockchain-PSO-AES Techniques in Finger Vein Biometrics: A Novel Verification Secure Framework for Patient Authentication *Not specified*	Simulated
N6	ScienceDirect	Gibson A. et al 2020	Protect Your Pacemaker: Blockchain based Authentication and Consented Authorization for Implanted Medical Devices *Hyperledger*	Simulated
		Artificial intelligence/Big data/Federated learning		
N7	ScienceDirect	Polap D. et al 2021	Agent Architecture of an Intelligent Medical System Based on Federated Learning and Blockchain Technology *Not specified*	Simulated
N8	ScienceDirect	Kumar R. et al 2021	An Integration of blockchain and AI for secure data sharing and detection of CT images for the hospitals *Not specified*	Simulated
N9	IEEE Xplore	Bhattacharya P. et al 2019	BinDaaS: Blockchain-Based Deep-Learning as-a-Service in Healthcare 4.0 Applications	Simulated

			Not specified	
N10	IEEE Xplore	Jain S. et al 2020	Blockchain and Machine Learning in Health Care and Management *Hyperledger*	Nil
N11	IEEE Xplore	Zerka F. et al 2020	Blockchain for Privacy Preserving and Trustworthy Distributed Machine Learning in Multicentric Medical Imaging (C-DistriM) *Ethereum*	Simulated
N12	Pubmed	Kuo TT. et al 2020	EXpectation Propagation LOgistic REgRession on permissioned blockCHAIN (ExplorerChain): decentralized online healthcare/genomics predictive model learning *MultiChain*	Simulated
N13	IEEE Xplore	Li B. et al 2019	Exploiting Computation Power of Blockchain for Biomedical Image Segmentation *Not specified*	Simulated
N14	IEEE Xplore	Juneja A. et al 2018	Leveraging blockchain for retraining deep learning architecture in patient-specific arrhythmia classification *Hyperledger*	Simulated
N15	IEEE Xplore	Zhang W. et al 2019	Medical Image Collaborative Training Based on Multi-Blockchain *Not specified*	Simulated
N16	ArXiv	Kuo TT. et al 2018	ModelChain: Decentralized Privacy-Preserving Healthcare Predictive Modeling Framework on Private Blockchain Networks *Not specified*	Nil
N17	Pubmed	Jones M. et al 2019	Privacy-Preserving Methods for Feature Engineering Using Blockchain: Review, Evaluation, and Proof of Concept *Oasis*	Nil
N18	ScienceDirect	Al-Marridi AZ. et al 2021	Reinforcement learning approaches for efficient and secure blockchain-powered smart health systems *Not specified*	Simulated
N19	Pubmed	Tan TE. et al 2021	Retinal photograph-based deep learning algorithms for myopia and a blockchain platform to facilitate artificial intelligence medical research: a retrospective multicohort study *Hyperledger*	Simulated
N20	IEEE Xplore	Rahman MA. et al 2020	Secure and Provenance Enhanced Internet of Health Things Framework: A Blockchain Managed Federated Learning Approach *Ethereum*	Simulated
N21	Pubmed	Warnat-Herresthal S. et al 2021	Swarm Learning for decentralized and confidential clinical machine learning *Ethereum*	Simulated

N22	IEEE Xplore	Shae Z. et al 2018	Transform Blockchain into Distributed Parallel Computing Architecture for Precision Medicine *Not specified*	Nil
		Clinical trials/Research		
N23	IEEE Xplore	Choudhury O. et al 2019	A Blockchain Framework for Ensuring Data Quality in Multi-Organizational Clinical Trials *Hyperledger*	Simulated
N24	Pubmed	Lima VC. et al 2021	A Permissioned Blockchain Network for Security and Sharing of De-identified Tuberculosis Research Data in Brazil *Kaleido*	Nil
N25	Pubmed	Zhuang Y. et al 2018	Applying Blockchain Technology for Health Information Exchange and Persistent Monitoring for Clinical Trials *Not specified*	Nil
N26	Pubmed	Zhuang Y. et al 2019	Applying Blockchain Technology to Enhance Clinical Trial Recruitment *Ethereum*	Simulated
N27	IEEE Xplore	Park J. et al 2018	CORUS: Blockchain-Based Trustworthy Evaluation System for Efficacy of Healthcare Remedies *Hyperledger*	Nil
N28	Pubmed	Hirano T. et al 2020	Data Validation and Verification Using Blockchain in a Clinical Trial for Breast Cancer: Regulatory Sandbox *Hyperledger*	Nil
N29	Pubmed	Zhuang Y. et al 2021	Development of A Blockchain Framework for Virtual Clinical Trials *Ethereum*	Simulated
N30	SpringerLink	Albanese G. et al 2020	Dynamic consent management for clinical trials via private blockchain technology *Hyperledger*	Nil
N31	Pubmed	Omar IA. et al 2020	Ensuring protocol compliance and data transparency in clinical trials using Blockchain smart contracts *Ethereum*	Nil
N32	Pubmed	Nugent T. et al 2016	Improving data transparency in clinical trials using blockchain smart contracts *Ethereum*	Simulated
N33	IEEE Xplore	Rupa C. et al 2020	Preserve Security to Medical Evidences using Blockchain Technology *Ethereum*	Simulated
N34	IEEE Xplore	Ghadamyari M. et al 2019	Privacy-Preserving Statistical Analysis of Health Data Using Paillier Homomorphic Encryption and Permissioned Blockchain *Hyperledger*	Simulated

N35	IEEE Xplore	Angeletti F. et al 2017	The Role of Blockchain and IoT in Recruiting Participants for Digital Clinical Trials *Ethereum*	Simulated
N36	Pubmed	Maslove DM. et al 2018	Using Blockchain Technology to Manage Clinical Trials Data: A Proof-of-Concept Study *Ethereum*	Nil
		Contact tracing		
N37	ScienceDirect	Bandara E. et al 2021	A blockchain empowered and privacy preserving digital contact tracing platform *Mystiko*	Simulated
N38	ScienceDirect	Zhu P. et al 2021	Enhancing Traceability of Infectious Diseases: A Blockchain-Based Approach *Not specified*	Simulated
		Electronic medical records		
N39	IEEE Xplore	Chen J. et al 2018	A Blockchain Application for Medical Information Sharing *Hyperledger*	Nil
N40	IEEE Xplore	Daniel IA. et al 2020	A Blockchain based solution for Managing Transplant Waiting Lists and Medical Records *Ethereum*	Simulated
N41	ScienceDirect	Lusetti M. et al 2020	A Blockchain Based Solution for the Custody of Digital Files in Forensic Medicine *Hyperledger*	Simulated
N42	IEEE Xplore	Deka SK. et al 2020	A Blockchain Based Technique for Storing Vaccination Records *Ethereum*	Simulated
N43	Pubmed	Hylock RH. et al 2019	A Blockchain Framework for Patient-Centered Health Records and Exchange (HealthChain): Evaluation and Proof-of-Concept Study *Not specified*	Simulated
N44	IEEE Xplore	Yang X. et al 2020	A Blockchain-Assisted Verifiable Outsourced Attribute-Based Signcryption Scheme for EHRs Sharing in the Cloud *Ethereum*	Simulated
N45	Google Scholar	Peterson K. et al 2016	A Blockchain-Based Approach to Health Information Exchange Networks *Not specified*	Nil
N46	Google Scholar	Yang G. et al 2019	A Blockchain-based Architecture for Securing Electronic Health Record Systems *Hyperledger*	Simulated
N47	IEEE Xplore	Zhuang Y. et al 2020	A Blockchain-based Architecture Framework for Secure Sharing of Personal Health Data	Nil

			Ethereum	
N48	IEEE Xplore	Krishnan SSR. et al 2020	A Blockchain-based Credibility Scoring Framework for Electronic Medical Records *Hyperledger*	Nil
N49	Pubmed	Sun J. et al 2020	A Blockchain-based Framework for Electronic Medical Records Sharing with Fine-grained Access Control *Ethereum*	Simulated
N50	IEEE Xplore	Alsharif A. et al 2020	A Blockchain-based Medical Data Marketplace with Trustless Fair Exchange and Access Control *Ethereum*	Simulated
N51	IEEE Xplore	Liu X. et al 2019	A Blockchain-Based Medical Data Sharing and Protection Scheme *Not specified*	Simulated
N52	ScienceDirect	Huang H. et al 2020	A blockchain-based scheme for privacy-preserving and secure sharing of medical data *Hyperledger*	Simulated
N53	Pubmed	Rajput AR. et al 2021	A Blockchain-Based Secret-Data Sharing Framework for Personal Health Records in Emergency Condition *Hyperledger*	Simulated
N54	IEEE Xplore	Jaiman V. et al 2020	A Consent Model for Blockchain-Based Health Data Sharing Platforms *Ethereum*	Simulated
N55	IEEE Xplore	Yang G. et al 2018	A Design of Blockchain-Based Architecture for the Security of Electronic Health Record (EHR) Systems *Not specified*	Nil
N56	IEEE Xplore	Poonguzhali N. et al 2020	A Framework For Electronic Health Record Using Blockchain Technology *Ethereum*	Simulated
N57	IEEE Xplore	Malamas V. et al 2020	A Hierarchical Multi Blockchain for Fine Grained Access to Medical Data *Ethereum*	Simulated
N58	Pubmed	Lima V. et al 2021	A Mechanism for Verifying the Integrity and Immutability of Tuberculosis Data Using IOTA Distributed Ledger Technology *IOTA*	Simulated
N59	IEEE Xplore	Du Y. et al 2018	A Medical Information Service Platform Based on Distributed Cloud and Blockchain *Hyperledger*	Nil
N60	ScienceDirect	Hussein AF. et al 2020	A Medical Records Managing and Securing Blockchain Based System Supported by a Genetic Algorithm and Discrete Wavelet Transform	Nil

			Not specified	
N61	IEEE Xplore	Li J. et al 2020	A New Blockchain-based Electronic Medical Record Transferring System with Data Privacy *Not specified*	Nil
N62	SpringerLink	Chelladurai U. et al 2021	A novel blockchain based electronic health record automation system for healthcare *Not specified*	Simulated
N63	IEEE Xplore	Singh AP. et al 2020	A Novel Patient-Centric Architectural Framework for Blockchain-Enabled Healthcare Applications *Hyperledger*	Simulated
N64	IEEE Xplore	Stamatellis C. et al 2020	A Patient-Centric Health Information Exchange Framework Using Blockchain Technology *Ethereum*	Simulated
N65	IEEE Xplore	Sabir A. et al 2020	A Practical Universal Consortium Blockchain Paradigm for Patient Data Portability on the Cloud Utilizing Delegated Identity Management *Hyperledger*	Nil
N66	Pubmed	Rodriguez-Garcia M. et al 2021	A privacy-preserving design for sharing demand-driven patient datasets over permissioned blockchains and P2P secure transfer *Hyperledger*	Simulated
N67	Pubmed	Stamatellis C. et al 2020	A Privacy-Preserving Healthcare Framework Using Hyperledger Fabric *Hyperledger*	Simulated
N68	IEEE Xplore	Liu J. et al 2020	A Privacy-Preserving Medical Data Sharing Scheme Based on Consortium Blockchain *Not specified*	Simulated
N69	SpringerLink	Latif RMA. et al 2020	A remix IDE: smart contract-based framework for the healthcare sector by using Blockchain technology *Ethereumn*	Nil
N70	IEEE Xplore	Hasavari S. et al 2019	A Secure and Scalable Data Source for Emergency Medical Care using Blockchain Technology *Hyperledger*	Nil
N71	ScienceDirect	Shamshad S. et al 2020	A Secure Blockchain-based e-Health Records Storage and Sharing Scheme *Not specified*	Simulated
N72	Pubmed	Qin Q. et al 2021	A Secure Storage and Sharing Scheme of Stroke Electronic Medical Records Based on Consortium Blockchain *Not specified*	Nil

N73	ScienceDirect	Garrido A. et al 2021	A simulation-based AHP approach to analyze the scalability of EHR systems using blockchain technology in healthcare institutions *Ethereum and Bitcoin*	Simulated
N74	Google Scholar	Kim K. et al 2017	A Trusted Sharing Model for Patient Records based on Permissioned Blockchain *Ethereum*	Simulated
N75	Pubmed	Zheng X. et al 2019	Accelerating Health Data Sharing: A Solution Based on the Internet of Things and Distributed Ledger Technologies *IOTA*	Simulated
N76	IEEE Xplore	Guo H. et al 2019	Access Control for Electronic Health Records with Hybrid Blockchain-Edge Architecture *Hyperledger*	Simulated
N77	Pubmed	Dubovitskaya A. et al 2020	ACTION-EHR: Patient-Centric Blockchain-Based Electronic Health Record Data Management for Cancer Care *Hyperledger*	Nil
N78	Google Scholar	Hussein AF. et al 2019	An Adaptive Biomedical Data Managing Scheme Based on the Blockchain Technique *Not specified*	Nil
N79	Pubmed	Lee HA. et al 2020	An Architecture and Management Platform for Blockchain-Based Personal Health Record Exchange: Development and Usability Study *Ethereum*	Nil
N80	IEEE Xplore	Du M. et al 2020	An Optimized Consortium Blockchain for Medical Information Sharing *Not specified*	Simulated
N81	ScienceDirect	Roehrs A. et al 2019	Analyzing the Performance of a Blockchain-based Personal Health Record Implementation *Not specified*	Simulated
N82	ScienceDirect	Dagher GG. et al 2018	Ancile: Privacy-preserving Framework for Access Control and Interoperability of Electronic Health Records Using Blockchain Technology *Ethereum*	Nil
N83	Pubmed	Mendes D. et al 2018	Anonymized Distributed PHR Using Blockchain for Openness and Non-Repudiation Guarantee *Hyperledger*	Nil
N84	IEEE Xplore	Peng Li 2019	Application of BlockChain in the Field of Traditional Chinese Medicine *Not specified*	Nil
N85	Pubmed	Tith D. et al	Application of Blockchain to Maintaining Patient Records in	Nil

		2020	Electronic Health Record for Enhanced Privacy, Scalability, and Availability *Hyperledger*	
N86	IEEE Xplore	Ghaffaripour S. et al 2019	Application of Blockchain to Patient-Centric Access Control in Medical Data Management Systems *Hyperledger*	Nil
N87	Pubmed	Zhang L. et al 2021	Application of Laparoscopy in Comprehensive Staging Operation of Ovarian Cancer Based on Electronic Medical Blockchain Technology *Not specified*	Clinical trial
N25	Pubmed	Zhuang Y. et al 2018	Applying Blockchain Technology for Health Information Exchange and Persistent Monitoring for Clinical Trials *Not specified*	Nil
N88	Pubmed	Tanaka K. et al 2019	Assessment of Traceability Implementation of a Cross-Institutional Secure Data Collection System Based on Distributed Standardized EMR Storage *Hyperledger and BigchainDB*	Simulated
N89	IEEE Xplore	Chen X. et al 2019	Asynchronous Blockchain-based Privacy-preserving Training Framework for Disease Diagnosis *Not specified*	Simulated
N90	IEEE Xplore	Guo H. et al 2020	Attribute-based Multi-Signature and Encryption for EHR Management: A Blockchain-based Solution *Hyperledger*	Simulated
N91	IEEE Xplore	Vora J. et al 2018	BHEEM: A Blockchain-Based Framework for Securing Electronic Health Records *Ethereum*	Nil
N92	IEEE Xplore	Ai Baqari M. et al 2020	Biometric-Based Blockchain EHR System (BBEHR) *Not specified*	Nil
N93	IEEE Xplore	Jiang S. et al 2018	BlocHIE: A BLOCkchain-Based Platform for Healthcare Information Exchange *Not specified*	Simulated
N94	IEEE Xplore	Zhang X. et al 2018	Block-Based Access Control for Blockchain-Based Electronic Medical Records (EMRs) Query in eHealth *Not specified*	Simulated
N95	Pubmed	Hussien YM. et al 2021	Blockchain-Based Access Control Scheme for Secure Shared Personal Health Records over Decentralised Storage *Ethereum*	Simulated
N96	Pubmed	Horng JH. et al 2021	Blockchain-Based Reversible Data Hiding for Securing Medical Images	Simulated

			Not specified	
N97	IEEE Xplore	Nguyen DC. et al 2020	Blockchain and Edge Computing for Decentralized EMRs Sharing in Federated Healthcare *Hyperledger*	Simulated
N98	ScienceDirect	Bhavin M. et al 2021	Blockchain and Quantum Blind Signature-based Hybrid Scheme for Healthcare 5.0 Applications *Hyperledger*	Simulated
N99	Google Scholar	Cyran MA. et al 2018	Blockchain as a Foundation for Sharing Healthcare Data *Ethereum*	Nil
N100	IEEE Xplore	Pussewalage HSG. et al 2019	Blockchain Based Delegatable Access Control Scheme for a Collaborative E-Health Environment *Not specified*	Simulated
N101	ScienceDirect	Chen L. et al 2019	Blockchain Based Searchable Encryption for Electronic Health Record Sharing *Ethereum*	Simulated
N102	IEEE Xplore	Maddine MM. et al 2020	Blockchain for Giving Patients Control Over Their Medical Records *Ethereum*	Simulated
N103	IEEE Xplore	Jabbar R. et al 2020	Blockchain Technology for Healthcare: Enhancing Shared Electronic Health Record Interoperability and Integrity *Ethereum*	Simulated
N104	ScienceDirect	Aruna Sri PSG. et al 2020	Blockchain Technology for Secure Medical Data Sharing Using Consensus Mechanism *Not specified*	Simulated
N105	SpringerLink	Gan C. et al 2020	Blockchain-based access control scheme with incentive mechanism for eHealth systems: patient as supervisor *Ethereum*	Nil
N106	IEEE Xplore	Hirtan L. et al 2019	Blockchain-Based Approach for e-Health Data Access Management with Privacy Protection *Hyperledger*	Simulated
N107	IEEE Xplore	Li C. et al 2019	Blockchain-Based Bidirectional Updates on Fine-Grained Medical Data *Ethereum*	Nil
N108	Pubmed	Li H. et al 2018	Blockchain-Based Data Preservation System for Medical Data *Ethereum*	Simulated
N109	ArXiv	Jabarulla MY. et al 2020	Blockchain-Based Distributed Patient-Centric Image Management System *Ethereum*	Simulated
N110	ScienceDirect	Huang H. et al	Blockchain-based eHealth System for Auditable EHRs Manipulation	Simulated

		2020	in Cloud Environments *Not specified*	
N111	ScienceDirect	Tanwar S. et al 2020	Blockchain-based Electronic Healthcare Record System for Healthcare 4.0 Applications *Hyperledger*	Simulated
N112	IEEE Xplore	Jiamsawat W. et al 2021	Blockchain-Based Electronic Medical Records Management of Hospital Emergency Ward *Not specified*	Simulated
N113	IEEE Xplore	Carter G. et al 2019	Blockchain-Based Interoperable Electronic Health Record Sharing Framework *Ethereum*	Nil
N114	IEEE Xplore	Sharma B. et al 2020	Blockchain-based Interoperable Healthcare using Zero-Knowledge Proofs and Proxy Re-Encryption *Ethereum*	Simulated
N115	IEEE Xplore	Zheng X. et al 2018	Blockchain-based Personal Health Data Sharing System Using Cloud Storage *Ethereum*	Nil
N116	IEEE Xplore	Wang S. et al 2019	Blockchain-Based Personal Health Records Sharing Scheme With Data Integrity Verifiable *Ethereum*	Simulated
N117	IEEE Xplore	Xiaodong Y. et al 2019	Blockchain-Based Secure and Searchable EHR Sharing Scheme *Not specified*	Simulated
N118	IEEE Xplore	Sun J. et al 2020	Blockchain-Based Secure Storage and Access Scheme For Electronic Medical Records in IPFS *Not specified*	Simulated
N119	IEEE Xplore	Aggarwal S. et al 2021	Blockchain-Based UAV Path Planning for Healthcare 4.0: Current Challenges and the Way Ahead *Not specified*	Simulated
N120	ArXiv	Nkenyereye L. et al 2020	Blockchain-Enabled EHR Framework for Internet of Medical Things *Ethereum*	Simulated
N121	ScienceDirect	Chen M. et al 2021	Blockchain-Enabled Healthcare System for Detection of Diabetes *Not specified*	Simulated
N122	Pubmed	Lo YS. et al 2019	Blockchain-Enabled iWellChain Framework Integration With the National Medical Referral System: Development and Usability Study *Ethereum*	Clinical application
N123	IEEE Xplore	Wang S. et al 2018	Blockchain-Powered Parallel Healthcare Systems Based on the ACP Approach *Not specified*	Nil

N124	Google Scholar	Rahmadika S. et al 2018	Blockchain Technology for Providing an Architecture Model of Decentralized Personal Health Information *Not specified*	Nil
N125	ArXiv	Rojo J. et al 2021	Blockchains' Federation for Integrating Distributed Health Data Using a Patient-centered Approach *Hyperledger*	Simulated
N126	IEEE Xplore	Liu J. et al 2018	BPDS: A Blockchain Based Privacy-Preserving Data Sharing for Electronic Medical Records *Not specified*	Nil
N127	Pubmed	Abunadi I. et al 2021	BSF-EHR: Blockchain Security Framework for Electronic Health Records of Patients *Ethereum*	Simulated
N128	IEEE Xplore	Cao S. et al 2020	CEPS: A Cross-Blockchain based Electronic Health Records Privacy-Preserving Scheme *Polkadot*	Simulated
N129	SpringerLink	Munoz DJ. et al 2019	ClinicAppChain: A Low-Cost Blockchain Hyperledger Solution for Healthcare *Hyperledger*	Simulated
N130	Pubmed	Zhu S. et al 2019	Cloud Health Resource Sharing Based on Consensus-Oriented Blockchain Technology: Case Study on a Breast Tumor Diagnosis Service *Ethereum*	Simulated
N131	IEEE Xplore	Wang Y. et al 2019	Cloud-Assisted EHR Sharing With Security and Privacy Preservation via Consortium Blockchain *Ethereum*	Simulated
N132	ScienceDirect	Cao S. et al 2019	Cloud-assisted Secure eHealth Systems for Tamper-proofing EHR Via Blockchain *Ethereum*	Simulated
N133	Pubmed	Mense A. et al 2018	Concept for Sharing Distributed Personal Health Records with Blockchains *Ethereum*	Nil
N134	Pubmed	Margheri A. et al 2020	Decentralised Provenance for Healthcare Data *Hyperledger*	Simulated
N135	IEEE Xplore	Reen G. et al 2019	Decentralized Patient Centric e- Health Record Management System using Blockchain and IPFS *Ethereum*	Simulated
N136	Google Scholar	Tong SJ. et al 2019	Decentralized Privacy-Preserving Platform for Clinical Data Sharing and Analysis	Simulated

			Hyperledger	
N137	SpringerLink	Mubarakali A. 2019	Design a Secure and Efficient Health Record Transaction Utilizing Block Chain (SEHRTB) Algorithm for Health Record Transaction in Block Chain *Hyperledger*	Simulated
N138	IEEE Xplore	Xu L. et al 2019	Design of a Credible Blockchain-Based E-Health Records (CB-EHRS) Platform *Not specified*	Simulated
N139	Pubmed	Cheng X. et al 2020	Design of a Secure Medical Data Sharing Scheme Based on Blockchain *Not specified*	Simulated
N140	Pubmed	Sung M. et al 2020	Developing a Mobile App for Monitoring Medical Record Changes Using Blockchain: Development and Usability Study *Tendermint*	Clinical trials - User experience
N141	Pubmed	Park S. et al 2020	Developing a Mobile App for Patients to Monitor Medical Record Changes Using Blockchain *Tendermint*	Nil
N142	Pubmed	Li P. et al 2019	DMMS: A Decentralized Blockchain Ledger for the Management of Medication Histories *Hyperledger*	Simulated
N143	IEEE Xplore	Rajput AR. et al 2019	EACMS: Emergency Access Control Management System for Personal Health Record Based on Blockchain *Hyperledger*	Simulated
N144	IEEE Xplore	Akkaoui R. et al 2020	EdgeMediChain: A Hybrid Edge Blockchain-Based Framework for Health Data Exchange *Ethereum*	Simulated
N145	IEEE Xplore	Mukherji A. et al 2020	Efficient and Scalable Electronic Health Record Management using Permissioned Blockchain Technology *Hypeledger*	Nil
N146	Pubmed	Kanagi K. et al 2021	Efficient Clinical Data Sharing Framework Based on Blockchain Technology *Ethereum*	Clinical trial
N147	IEEE Xplore	Hyla T. et al 2019	eHealth Integrity Model Based on a Permissioned Blockchain *Not specified*	Nil
N148	IEEE Xplore	Niu S. et al 2019	Electronic Health Record Sharing Scheme With Searchable Attribute-Based Encryption on Blockchain *Not specified*	Simulated
N149	IEEE Xplore	Martínez A. et al	Electronic Medical Records Management in Health Organizations	Simulated

		2018	using a Technology Architecture based on Blockchain *Hyperledger*	
N150	ArXiv	Shevkar S. et al 2020	EMRs with Blockchain : A distributed democratised Electronic Medical Record sharing platform *Hyperledger*	Nil
N151	IEEE Xplore	Xiao Z. et al 2018	EMRShare: A Cross-Organizational Medical Data Sharing and Management Framework Using Permissioned Blockchain *Hyperledger*	Simulated
N152	Pubmed	Cunningham J. et al 2019	Enabling Patient Control of Personal Electronic Health Records Through Distributed Ledger Technology *Ethereum*	Simulated
N153	Pubmed	Liu H. et al 2020	Enhancing Privacy and Data Security across Healthcare Applications Using Blockchain and Distributed Ledger Concepts *Not specified*	Simulated
N154	IEEE Xplore	Palani U. et al 2020	Ethereum Blockchain Based Healthcare Industry Ecosystem *Ethereum*	Nil
N155	ScienceDirect	Zhang P. et al 2018	FHIRChain: Applying Blockchain to Securely and Scalably Share Clinical Data *Ethereum*	Nil
N156	ScienceDirect	Wang Z. et al 2020	GuardHealth: Blockchain Empowered Secure Data Management and Graph Convolutional Network Enabled Anomaly Detection in Smart Healthcare *Not specified*	Simulated
N157	IEEE Xplore	Parameswari CD. et al 2020	Healthcare Data Protection Based on Blockchain using Solidity *Ethereum*	Nil
N158	Pubmed	Chenthara S. et al 2020	Healthchain: A novel framework on privacy preservation of electronic health records using blockchain technology *Hyperledger*	Simulated
N159	Pubmed	Gutiérrez O. et al 2020	HealthyBlock: Blockchain-Based IT Architecture for Electronic Medical Records Resilient to Connectivity Failures *Ethereum*	Simulated
N160	ScienceDirect	Miyachi K. et al 2021	hOCBS: A Privacy-Preserving Blockchain Framework for Healthcare Data Leveraging an On-Chain and Off-Chain System Design *Ethereum*	Nil
N161	IEEE Xplore	Ito K. et al 2018	i-Blockchain: A Blockchain-Empowered Individual-Centric Framework for Privacy-Preserved Use of Personal Health Data *Not specified*	Nil
N162	ScienceDirect	Guimarães T. et al	ICU Data Management - A Permissioned Blockchain Approach	Nil

		2020	*Hyperledger*	
N163	IEEE Xplore	Mikula T. et al 2018	Identity and Access Management with Blockchain in Electronic Healthcare Records *Hyperledger*	Simulated
N164	Pubmed	Koptyra K. et al 2021	Imagechain-Application of Blockchain Technology for Images *Not specified*	Nil
N165	Pubmed	Roehrs A. et al 2021	Integrating multiple blockchains to support distributed personal health records *Hyperledger*	Simulated
N166	Pubmed	Park YR. et al 2019	Is Blockchain Technology Suitable for Managing Personal Health Records? Mixed-Methods Study to Test Feasibility *Ethereum*	Simulated
N167	IEEE Xplore	Alamir O. et al 2019	M-Blocks (Medical Blocks): A blockchain based approach for patient record management using IBM Hyperledger *Hyperledger*	Nil
N168	IEEE Xplore	Misbhauddin M. et al 2020	MedAccess: A Scalable Architecture for Blockchain-based Health Record Management *Ethereum*	Nil
N169	IEEE Xplore	Huang J. et al 2019	MedBloc: A Blockchain-Based Secure EHR System for Sharing and Accessing Medical Data *Hyperledger*	Simulated
N170	Pubmed	Fan K. et al 2018	MedBlock: Efficient and Secure Medical Data Sharing Via Blockchain *Not specified*	Simulated
N171	IEEE Xplore	Daraghmi E. et al 2019	MedChain: A Design of Blockchain-Based System for Medical Records Access and Permissions Management *Ethereum*	Simulated
N172	IEEE Xplore	Abdellatif AA. et al 2021	MEdge-Chain: Leveraging Edge Computing and Blockchain for Efficient Medical Data Exchange *Not specified*	Simulated
N173	Pubmed	Tian H. et al 2020	Medical Data Management on Blockchain with Privacy *Hyperledger*	Simulated
N174	IEEE Xplore	Yang X. et al 2020	Medical Data Sharing Scheme Based on Attribute Cryptosystem and Blockchain Technology *Not specified*	Simulated
N175	IEEE Xplore	Seo J. et al 2020	Medical Image Sharing System using Hyperledger Fabric Blockchain *Hyperledger*	Nil
N176	Pubmed	Zhou T. et al	Med-PPPHIS: Blockchain-Based Personal Healthcare Information	Simulated

		2019	System for National Physique Monitoring and Scientific Exercise Guiding *DAG, Quorum*	
N177	IEEE Xplore	Azaria A. et al 2016	MedRec: Using Blockchain for Medical Data Access and Permission Management *Ethereum*	Nil
N178	SpringerLink	Pournaghi SM. et al 2020	MedSBA: a Novel and Secure Scheme to Share Medical Data Based on Blockchain Technology and Attribute-Based Encryption *Not specified*	Simulated
N179	ScienceDirect	Guimarães T. et al 2020	Modular Blockchain Implementation in Intensive Medicine *Hyperledger*	Nil
N180	Pubmed	Sun B. et al 2021	Obstetrics Nursing and Medical Health System Based on Blockchain Technology *Not specified*	Simulated
N181	Pubmed	Roehrs A. et al 2017	OmniPHR: A distributed architecture model to integrate personal health records *Not specified*	Simulated
N182	IEEE Xplore	Buzachis A. et al 2019	On the Design of a Blockchain-as-a-Service-Based Health Information Exchange (BaaS-HIE) System for Patient Monitoring *Not specified*	Simulated
N183	IEEE Xplore	Toshniwal B. et al 2019	PACEX: PAtient-Centric EMR eXchange in Healthcare Systems using Blockchain *Ethereum*	Simulated
N184	Pubmed	Cernian A. et al 2020	PatientDataChain: A Blockchain-Based Approach to Integrate Personal Health Records *Modex BCDB*	Simulated
N185	IEEE Xplore	Jiang S. et al 2019	Patients-Controlled Secure and Privacy-Preserving EHRs Sharing Scheme Based on Consortium Blockchain *Ethereum*	Simulated
N186	IEEE Xplore	Al Asad N. et al 2020	Permission-Based Blockchain with Proof of Authority for Secured Healthcare Data Sharing *Not specified*	Nil
N187	ScienceDirect	Sharma Y. et al 2020	Preserving the Privacy of Electronic Health Records using Blockchain *Hyperledger*	Simulated
N188	IEEE Xplore	Juyal S. et al 2020	Privacy and Security of IoT based Skin Monitoring System using Blockchain Approach *Not specified*	Nil
N189	IEEE Xplore	Nortey RN. et al	Privacy Module for Distributed Electronic Health Records(EHRs)	Nil

		2019	Using the Blockchain *Hyperledger*	
N190	ScienceDirect	Al Omar A. et al 2019	Privacy-friendly platform for healthcare data in cloud based on blockchain environment *Ethereum*	Simulated
N191	IEEE Xplore	Shen M. et al 2019	Privacy-Preserving Image Retrieval for Medical IoT Systems: A Blockchain-Based Approach *Ethereum*	Simulated
N192	IEEE Xplore	Bak S. et al 2019	Protection of EEG Data using Blockchain Platform *Ethereum*	Simulated
N193	IEEE Xplore	Wutthikarn R. et al 2018	Prototype of Blockchain in Dental care service application based on Hyperledger Composer in Hyperledger Fabric framework *Hyperledger*	Nil
N194	IEEE Xplore	Navaratna L. et al 2020	Providing Electronic Health Care Services Through A Private Permissioned Blockchain *Hyperledger*	Simulated
N195	ArXiv	Wang H. et al 2021	Que Bian: An Electronic Medical Record Management System on Blockchain *Hyperledger*	Nil
N196	SpringerLink	Kumar R. et al 2020	Scalable and Secure Access Control Policy for Healthcare System Using Blockchain and Enhanced Bell–LaPadula Model *Hyperledger*	Simulated
N197	IEEE Xplore	Fernandes A. et al 2020	Scalable Architecture for sharing EHR using the Hyperledger Blockchain *Hyperledger*	Simulated
N198	IEEE Xplore	Donawa A. et al 2019	Scaling Blockchains to Support Electronic Health Records for Hospital Systems *Not specified*	Simulated
N199	IEEE Xplore	Ramani V. et al 2018	Secure and Efficient Data Accessibility in Blockchain Based Healthcare Systems *Ethereum*	Simulated
N200	IEEE Xplore	Mahore V. et al 2019	Secure and Privacy Focused Electronic Health Record Management System using Permissioned Blockchain *Hyperledger*	Simulated
N201	Pubmed	Dubovitskaya A. et al 2017	Secure and Trustable Electronic Medical Records Sharing using Blockchain *Hyperledger*	Nil
N202	Pubmed	Wang H. et al	Secure Cloud-Based EHR System Using Attribute-Based	Nil

		2018	Cryptosystem and Blockchain *Not specified*	
N203	ScienceDirect	Shuaib K. et al 2021	Secure decentralized electronic health records sharing system based on blockchains *Hyperledger*	Simulated
N204	ScienceDirect	Usman M. et al 2020	Secure Electronic Medical Records Storage and Sharing Using Blockchain Technology *Hyperledger*	Nil
N205	IEEE Xplore	Kumar N. et al 2020	Secure Sharing of Health Data Using Hyperledger Fabric Based on Blockchain Technology *Hyperledger*	Nil
N206	SpringerLink	Nagasubramanian G. et al 2020	Securing e-Health Records Using Keyless Signature Infrastructure Blockchain Technology in the Cloud *KSI Blockchain*	Simulated
N207	IEEE Xplore	Zghaibeh M. et al 2020	SHealth: A Blockchain-Based Health System With Smart Contracts Capabilities *Hyperledger*	Nil
N208	IEEE Xplore	Andola N. et al 2019	SHEMB: A Secure Approach for Healthcare Management System Using Blockchain *Ethereum*	Simulated
N209	IEEE Xplore	Rahman MA. et al 2018	Spatial Blockchain-Based Secure Mass Screening Framework for Children With Dyslexia *Ethereum and Hyperledger*	Simulated
N210	ScienceDirect	Zou RP. et al 2021	SPChain: Blockchain-based medical data sharing and privacy-preserving eHealth system *RepuCoin*	Simulated
N211	IEEE Xplore	Abdellatif AA. et al 2020	ssHealth: Toward Secure, Blockchain-Enabled Healthcare Systems *Not specified*	Simulated
N212	Pubmed	Kuo TT. et al 2020	The Anatomy of a Distributed Predictive Modeling Framework: Online Learning, Blockchain network, And consensus algorithm *MultiChain*	Nil
N213	Pubmed	Xiao Y. et al 2021	The HealthChain Blockchain for Electronic Health Records: Development Study *Not specified*	Simulated
N214	IEEE Xplore	Misic VB. Et al 2019	Towards a Blockchain-Based Healthcare Information System : Invited Paper *Not specified*	Nil
N215	IEEE Xplore	De Oliveria MT. et al	Towards a Blockchain-Based Secure Electronic Medical Record for	Simulated

		2019	Healthcare Applications *MultiChain*	
N216	IEEE Xplore	Jin H. et al 2019	Toward Secure, Privacy-Preserving, and Interoperable Medical Data Sharing via Blockchain *Ethereum*	Simulated
N217	Pubmed	Zhang A. et al 2018	Towards Secure and Privacy-Preserving Data Sharing in e-Health Systems via Consortium Blockchain *Ethereum*	Simulated
N218	IEEE Xplore	Cao S. et al 2020	Toward Secure Storage in Cloud-based eHealth Systems: A Blockchain-Assisted Approach *Ethereum*	Simulated
N22	IEEE Xplore	Shae Z. et al 2018	Transform Blockchain into Distributed Parallel Computing Architecture for Precision Medicine *Not specified*	Nil
N219	ArXiv	Gupta P. et al 2019	Usage of Permissioned Blockchain Architecture for Big Data in Electronic Medical Records *BigChain*	Nil
N220	IEEE Xplore	Zhou X. et al 2020	User-Controlled, Auditable, Cross-Jurisdiction Sharing of Healthcare Data Mediated by a Public Blockchain *Ethereum*	Nil
N221	IEEE Xplore	Goel U. et al 2019	Using Healthcare Authority and Patient Blockchains to Develop a Tamper-Proof Record Tracking System *Ethereum*	Nil
		Epidemic/Infection control		
N222	IEEE Xplore	Khan MS. et al 2020	Prediction of Dengue Infected Areas using A Novel Blockchain based Crowdsourcing Framework *Ethereum*	Nil
N211	IEEE Xplore	Abdellatif AA. et al 2020	ssHealth: Toward Secure, Blockchain-Enabled Healthcare Systems *Not specified*	Simulated
		Foundational healthcare framework		
N223	IEEE Xplore	Quasim MT. et al 2020	A Blockchain based Secured Healthcare Framework *Not specified*	Simulated
N224	IEEE Xplore	Swetha MS. et al 2020	Blockchain enabled secure healthcare Systems *Hyperledger*	Nil
N225	IEEE Xplore	Curbera F. et al 2019	Blockchain: An enabler for healthcare and life sciences transformation *Hyperledger*	Simulated
N226	Pubmed	Ghayvat H. et al 2021	CP-BDHCA: Blockchain-based Confidentiality-Privacy preserving Big Data scheme for healthcare clouds and applications	Simulated

			Not specified	
N227	Pubmed	Zhuang Y. et al 2020	Generalizable Layered Blockchain Architecture for Health Care Applications: Development, Case Studies, and Evaluation *Ethereum*	Simulated
N228	Pubmed	Purohit S. et al 2021	HonestChain: Consortium blockchain for protected data sharing in health information systems *Hyperledger*	Simulated
		Genomics		
N229	IEEE Xplore	Shuaib K. et al 2020	A Layered Blockchain Framework for Healthcare and Genomics *Ethereum and Hyperledger*	Nil
N230	Pubmed	Jin XL. et al 2019	Application of a Blockchain Platform to Manage and Secure Personal Genomic Data: A Case Study of LifeCODE.ai in China *Ethereum*	Simulated
N231	Google Scholar	Lee S. et al 2018	BAQALC: Blockchain Applied Lossless Efficient Transmission of DNA Sequencing Data for Next Generation Medical Informatics *Not specified*	Simulated
N232	Pubmed	Glicksberg BS. et al 2020	Blockchain-Authenticated Sharing of Genomic and Clinical Outcomes Data of Patients With Cancer: A Prospective Cohort Study *Ethereum*	Clinical trial
N233	IEEE Xplore	Aung STY. et al 2020	Blockchain-Based Implementation for Integration of DNA Profiles Information Systems *Ethereum*	Simulated
N234	Pubmed	Pattengale ND. et al 2020	Decentralized genomics audit logging via permissioned blockchain ledgering *MultiChain*	Simulated
N235	Pubmed	Ma S. et al 2020	Efficient logging and querying for blockchain-based cross-site genomic dataset access audit *MultiChain*	Simulated
N12	Pubmed	Kuo TT. et al 2020	EXpectation Propagation LOgistic REgRession on permissioned blockCHAIN (ExplorerChain): decentralized online healthcare/genomics predictive model learning *MultiChain*	Simulated
N236	Pubmed	Kuo TT. et al 2020	iDASH secure genome analysis competition 2018: blockchain genomic data access logging, homomorphic encryption on GWAS, and DNA segment searching *MultiChain*	Simulated
N237	Pubmed	Ozdayi MS. et al 2020	Leveraging blockchain for immutable logging and querying across multiple sites	Simulated

			MultiChain	
N238	IEEE Xplore	Neto MM. et al 2020	Research Opportunities for E-health Applications with DNA Sequence Data using Blockchain Technology *BigchainDB*	Simulated
N239	IEEE Xplore	Genesy Project Srl 2020	The Genesy Model for a Blockchain-based Fair Ecosystem of Genomic Data *Hyperledger*	Nil
N240	Pubmed	Gürsoy G. et al 2020	Using Blockchain to Log Genome Dataset Access: Efficient Storage and Query *MultiChain*	Simulated
N241	Pubmed	Gürsoy G. et al 2020	Using Ethereum Blockchain to Store and Query Pharmacogenomics Data Via Smart Contracts *Ethereum*	Simulated
N212	Pubmed	Kuo TT. et al 2020	The Anatomy of a Distributed Predictive Modeling Framework: Online Learning, Blockchain Network, and Consensus Algorithm *MultiChain*	Nil
		Healthcare services		
N40	IEEE Xplore	Daniel IA. et al 2020	A Blockchain based solution for Managing Transplant Waiting Lists and Medical Records *Ethereum*	Simulated
N242	IEEE Xplore	Kaurav RS. et al 2021	Blockchain for Emergency Vehicle Routing in Healthcare Services: An Integrated Secure and Trustworthy System *Ethereum*	Simulated
N243	IEEE Xplore	Khezr S. et al 2020	Blockchain-based Model for Sharing Activities of Daily Living in Healthcare Applications *Hyperledger*	Simulated
N244	IEEE Xplore	Li P. et al 2019	ChainSDI: A Software-Defined Infrastructure for Regulation-Compliant Home-Based Healthcare Services Secured by Blockchains *Ethereum*	Simulated
N245	Pubmed	Niu Y. et al 2021	Influence of Standardized Nursing Management of Hospital Based on Smart Electronic Medical Blockchain on Nursing Quality of Digestive Endoscopy Room *Not specified*	Clinical trial
N236	IEEE Xplore	Gupta R. et al 2020	VAHAK: A Blockchain-based Outdoor Delivery Scheme using UAV for Healthcare 4.0 Services *Ethereum*	Simulated
N247	Pubmed	Paglialonga A. et al 2019	Use of Alternative Currencies, Blockchain Technology, and Predictive Analytics for Chronic Disease Prevention: A Conceptual Model	Nil

			Ethereum	
		Insurance		
N248	IEEE Xplore	Gera J. et al 2020	Blockchain Technology for Fraudulent Practices in Insurance Claim Process *Hyperledger*	Simulated
N249	Pubmed	Mackey TK. et al 2020	Combating Health Care Fraud and Abuse: Conceptualization and Prototyping Study of a Blockchain Antifraud Framework *Ethereum*	Nil
N250	IEEE Xplore	Saldamli G. et al 2020	Health Care Insurance Fraud Detection Using Blockchain *BigchainDB*	Nil
N251	ScienceDirect	Thenmozhi M. et al 2021	Implementing Blockchain Technologies for Health Insurance Claim Processing in Hospitals *Ethereum*	Nil
N252	Pubmed	Zhou L. et al 2018	MIStore: a Blockchain-Based Medical Insurance Storage System *Ethereum*	Simulated
N202	Pubmed	Wang H. et al 2018	Secure Cloud-Based EHR System Using Attribute-Based Cryptosystem and Blockchain *Not specified*	Nil
		Medical diagnostics		
N253	ArXiv	Samaniego M. et al 2020	Access Control Management for Computer-Aided Diagnosis Systems using Blockchain *Ethereum*	Simulated
N254	IEEE Xplore	Talukder AK. et al 2018	Proof of Disease: A Blockchain Consensus Protocol for Accurate Medical Decisions and Reducing the Disease Burden *Ethereum*	Nil
		Medical education		
N255	IEEE Xplore	Rathod J. et al 2020	Using Blockchain Technology for Continuing Medical Education Credits System *Ethereum*	Nil
		Mobile health/Remote monitoring/Internet of Things		
N256	IEEE Xplore	Paliokas I. et al 2019	A Blockchain Platform in Connected Medical-Device Environments: Trustworthy technology to guard against cyberthreats *Ethereum*	Nil
N257	ScienceDirect	Wang J. et al 2020	A Blockchain-based eHealthcare System Interoperating with WBANs *Hyperledger*	Simulated
N258	ScienceDirect	Islam N. et al 2019	A Blockchain-based Fog Computing Framework for Activity Recognition as an Application to e-Healthcare Services *Not specified*	Simulated

N259	ScienceDirect	Islam A. et al 2020	A Blockchain-based Secure Healthcare Scheme With the Assistance of Unmanned Aerial Vehicle in Internet of Things *Hyperledger*	Nil
N260	IEEE Xplore	Fotopoulos F. et al 2020	A Blockchain-enabled Architecture for IoMT Device Authentication *Hyperledger*	Nil
N261	Pubmed	Taralunga DD. et al 2021	A Blockchain-Enabled Framework for mHealth Systems *Ethereum*	Simulated
N262	ArXiv	Nguyen DC. et al 2021	A Cooperative Architecture of Data Offloading and Sharing for Smart Healthcare with Blockchain *Ethereum*	Simulated
N263	IEEE Xplore	Uddin MA. et al 2019	A Decentralized Patient Agent Controlled Blockchain for Remote Patient Monitoring *Not specified*	Simulated
N264	Pubmed	Ali MS. et al 2020	A Decentralized Peer-to-Peer Remote Health Monitoring System *Ethereum*	Simulated
N265	Pubmed	Dwivedi AD. et al 2019	A Decentralized Privacy-Preserving Healthcare Blockchain for IoT *Not specified*	Nil
N266	IEEE Xplore	Aujla GS. et al 2020	A Decoupled Blockchain Approach for Edge-Envisioned IoT-Based Healthcare Monitoring *Not specified*	Simulated
N267	IEEE Xplore	Malamas V. et al 2019	A Forensics-by-Design Management Framework for Medical Devices Based on Blockchain *Ethereum*	Nil
N268	SpringerLink	Rathee G. et al 2019	A hybrid framework for multimedia data processing in IoT-healthcare using blockchain technology *Not specified*	Simulated
N269	IEEE Xplore	Srivastava G. et al 2019	A Light and Secure Healthcare Blockchain for IoT Medical Devices *Not specified*	Nil
N270	IEEE Xplore	Rahman MA. et al 2020	A Natural User Interface and Blockchain-Based In-Home Smart Health Monitoring System *Hyperledger*	Simulated
N271	Pubmed	Karakaya A. et al 2021	A novel IoT-based health and tactical analysis model with fog computing *Not specified*	Simulated
N272	IEEE Xplore	Wahdud MAH. et al 2020	A Patient Centric Agent Assisted Private Blockchain on Hyperledger Fabric for Managing Remote Patient Monitoring *Hyperledger*	Simulated
N273	Pubmed	Abdur Rahman M. et al	A Secure Occupational Therapy Framework for Monitoring Cancer	Simulated

		2019	Patients' Quality of Life *Not specified*	
N274	IEEE Xplore	Pham HL. et al 2018	A Secure Remote Healthcare System for Hospital Using Blockchain Smart Contract *Ethereum*	Nil
N7	ScienceDirect	Polap D. et al 2021	Agent Architecture of an Intelligent Medical System Based on Federated Learning and Blockchain Technology, *Not specified*	Simulated
N275	IEEE Xplore	Vasilateanu A. et al 2020	Ambient Assisted Living Environment based on Blockchain for Elderly Care *Ethereum*	Nil
N276	Pubmed	Shu H. et al 2020	An Efficient Certificateless Aggregate Signature Scheme for Blockchain-Based Medical Cyber Physical Systems *Not specified*	Simulated
N277	SpringerLink	Veeramakali T. et al 2021	An intelligent internet of things-based secure healthcare framework using blockchain technology with an optimal deep learning model *Not specified*	Simulated
N278	IEEE Xplore	Muofhe M. et al 2019	An Internet of Things-Based System Integrated with Blockchain to Manage Patient Data in the Healthcare Sector *Ethereum*	Nil
N279	IEEE Xplore	Attia O. et al 2019	An IoT-Blockchain Architecture Based on Hyperledger Framework for Healthcare Monitoring Application *Hyperledger*	Nil
N280	ScienceDirect	Brogan J. et al 2018	Authenticating Health Activity Data Using Distributed Ledger Technologies *IOTA*	Simulated
N281	ArXiv	Srivastava G. et al 2018	Automated Remote Patient Monitoring: Data Sharing and Privacy Using Blockchain *Not specified*	Simulated
N282	IEEE Xplore	Garg N. et al 2020	BAKMP-IoMT: Design of Blockchain Enabled Authenticated Key Management Protocol for Internet of Medical Things Deployment *Not specified*	Simulated
N283	IEEE Xplore	Islam A. et al 2019	BHMUS: Blockchain Based Secure Outdoor Health Monitoring Scheme Using UAV in Smart City *Ethereum*	Simulated
N284	IEEE Xplore	Saliem M. et al 2019	BIoMT: Blockchain for the Internet of Medical Things *Not specified*	Simulated
N285	IEEE Xplore	Ray PP. et al	BIoTHR: Electronic Health Record Servicing Scheme in IoT-	Simulated

		2021	Blockchain Ecosystem *Not specified*	
N286	IEEE Xplore	Azbeg K. et al 2018	Blockchain and IoT for Security and Privacy: A Platform for Diabetes Self-management *Not specified*	Nil
N287	IEEE Xplore	Nehra V. et al 2021	Blockchain Enabled Ambient Assisted Living for Critically ill Patients *Not specified*	Simulated
N288	IEEE Xplore	Nguyen DC. et al 2019	Blockchain for Secure EHRs Sharing of Mobile Cloud Based E-Health Systems *Ethereum*	Simulated
N289	ScienceDirect	Uddin M. et al 2020	Blockchain Leveraged Decentralized IoT eHealth Framework *Ethereum*	Simulated
N290	SpringerLink	Alqaralleh BAY. et al 2021	Blockchain-assisted secure image transmission and diagnosis model on Internet of Medical Things Environment *Not specified*	Simulated
N291	IEEE Xplore	Rahman MDA. et al 2018	Blockchain-Based Mobile Edge Computing Framework for Secure Therapy Applications *Ethereum and Hyperledger*	Simulated
N292	IEEE Xplore	Alblooshi M. et al 2018	Blockchain-based Ownership Management for Medical IoT (MIoT) Devices *Ethereum*	Nil
N293	IEEE Xplore	Hossein KM. et al 2019	Blockchain-Based Privacy-Preserving Healthcare Architecture *Not specified*	Nil
N294	IEEE Xplore	Hathaliya J. et al 2019	Blockchain-Based Remote Patient Monitoring in Healthcare 4.0 *Not specified*	Nil
N295	IEEE Xplore	Shynu PG. et al 2021	Blockchain-Based Secure Healthcare Application for Diabetic-Cardio Disease Prediction in Fog Computing *Not specified*	Simulated
N296	Pubmed	Liu X. et al 2020	Blockchain-Enabled Contextual Online Learning under Local Differential Privacy for Coronary Heart Disease Diagnosis in Mobile Edge Computing *Not specific*	Simulated
N120	ArXiv	Nkenyereye L. et al 2020	Blockchain-Enabled EHR Framework for Internet of Medical Things *Ethereum*	Simulated
N297	Pubmed	Gonzalez-Amarillo C. et al 2021	Blockchain-IoT Sensor (BIoTS): A Solution to IoT-Ecosystems Security Issues *Ethereum*	Simulated
N298	IEEE Xplore	Ray PP. et al	BLWN: Blockchain-Based Lightweight Simplified Payment	Simulated

		2020	Verification in IoT-Assisted e-Healthcare *Bitcoin*	
N299	IEEE Xplore	Yazdinejad A. et al 2020	Decentralized Authentication of Distributed Patients in Hospital Networks Using Blockchain *Not specified*	Simulated
N300	Pubmed	Hawig D. et al 2019	Designing a Distributed Ledger Technology System for Interoperable and General Data Protection Regulation-Compliant Health Data Exchange: A Use Case in Blood Glucose Data *IOTA*	Simulated
N301	IEEE Xplore	Wang R. et al 2019	Distributed Security Architecture Based on Blockchain for Connected Health: Architecture, Challenges, and Approaches *RAFT*	Simulated
N302	IEEE Xplore	Abou-Nassar EM. et al 2020	DITrust Chain: Towards Blockchain-Based Trust Models for Sustainable Healthcare IoT Systems *Ripple*	Nil
N303	Pubmed	Pawar P. et al 2021	eHealthChain-a blockchain-based personal health information management system *Hyperledger*	Nil
N304	Pubmed	Fernández-Caramés TM. et al 2019	Enabling the Internet of Mobile Crowdsourcing Health Things: A Mobile Fog Computing, Blockchain and IoT Based Continuous Glucose Monitoring System for Diabetes Mellitus Research and Care *Ethereum*	Simulated
N305	IEEE Xplore	Meng W. et al 2019	Enhancing Medical Smartphone Networks via Blockchain-Based Trust Management Against Insider Attacks *Not specified*	Simulated
N306	IEEE Xplore	Egala BS. et al 2021	Fortified-Chain: A Blockchain Based Framework for Security and Privacy Assured Internet of Medical Things with Effective Access Control *Ethereum*	Simulated
N307	IEEE Xplore	Bhattacharya P. et al 2020	HeaL: A Blockchain-Envisioned Signcryption Scheme for Healthcare IoT Ecosystems *Not specified*	Simulated
N308	IEEE Xplore	Ni W. et al 2019	HealChain: A Decentralized Data Management System for Mobile Healthcare Using Consortium Blockchain *Not specified*	Simulated
N309	Pubmed	Ejaz M. et al 2021	Health-BlockEdge: Blockchain-Edge Framework for Reliable Low-Latency Digital Healthcare Applications *Not specified*	Simulated

N310	Pubmed	Javed IT. et al 2021	Health-ID: A Blockchain-Based Decentralized Identity Management for Remote Healthcare *Ethereum*	Simulated
N311	IEEE Xplore	Singh HS. et al 2020	Health Monitoring and Analysis using IPFS and Blockchain *DAG*	Nil
N312	Pubmed	Griggs KN. et al 2018	Healthcare Blockchain System Using Smart Contracts for Secure Automated Remote Patient Monitoring *Ethereum*	Nil
N313	IEEE Xplore	Xu J. et al 2019	Healthchain: A Blockchain-Based Privacy Preserving Scheme for Large-Scale Health Data *Hyperledger*	Simulated
N314	IEEE Xplore	Dey T. et al 2017	HealthSense: A medical use case of Internet of Things and blockchain *Not specified*	Nil
N315	ArXiv	Abdellatif A. et al 2020	I-Health: Leveraging Edge Computing and Blockchain for Epidemic Management *Not specified*	Simulated
N316	ScienceDirect	Shukla S. et al 2021	Identification and Authentication in Healthcare Internet-of-Things Using Integrated Fog Computing Based Blockchain Model *Ethereum*	Simulated
N317	IEEE Xplore	Liang X. et al 2017	Integrating blockchain for data sharing and collaboration in mobile healthcare applications *Not specified*	Simulated
N318	Pubmed	Hameed K. et al 2021	Integration of 5G and Block-Chain Technologies in Smart Telemedicine Using IoT *Not specified*	Simulated
N319	Google Scholar	Wang H. et al 2020	IoT based Clinical Sensor Data Management and Transfer using Blockchain Technology *Ethereum*	Simulated
N320	Pubmed	Kumar A. et al 2020	Lightweight Proof of Game (LPoG): A Proof of Work (PoW)'s Extended Lightweight Consensus Algorithm for Wearable Kidneys *Not specified*	Simulated
N172	IEEE Xplore	Abdellatif AA. et al 2021	MEdge-Chain: Leveraging Edge Computing and Blockchain for Efficient Medical Data Exchange *Not specified*	Simulated
N321	Pubmed	Rosa BMG. et al 2021	NFC-Powered Implantable Device for On-Body Parameters Monitoring With Secure Data Exchange Link to a Medical Blockchain Type of Network *Not specified*	Simulated

N322	IEEE Xplore	Saha S. et al 2020	On the Design of Blockchain-Based Access Control Protocol for IoT-Enabled Healthcare Applications *Not specified*	Simulated
N184	Pubmed	Cernian A. et al 2020	PatientDataChain: A Blockchain-Based Approach to Integrate Personal Health Records *Modex BCDB*	Simulated
N323	IEEE Xplore	Tomaz AEB. et al 2020	Preserving Privacy in Mobile Health Systems Using Non-Interactive Zero-Knowledge Proof and Blockchain *Ethereum*	Simulated
N191	IEEE Xplore	Shen M. et al 2019	Privacy-Preserving Image Retrieval for Medical IoT Systems: A Blockchain-Based Approach *Ethereum*	Simulated
N324	Pubmed	Satamraju KP. et al 2020	Proof of Concept of Scalable Integration of Internet of Things and Blockchain in Healthcare *Ethereum*	Simulated
N325	IEEE Xplore	Rachakonda L. et al 2020	SaYoPillow: Blockchain-Integrated Privacy-Assured IoMT Framework for Stress Management Considering Sleeping Habits *Ethereum*	Simulated
N326	Pubmed	Motohashi T. et al 2019	Secure and Scalable mHealth Data Management Using Blockchain Combined With Client Hashchain: System Design and Validation *Hyperledger*	Simulated
N327	Pubmed	Kim HJ. et al 2021	Smart Decentralization of Personal Health Records with Physician Apps and Helper Agents on Blockchain: Platform Design and Implementation Study *Ethereum*	Nil
N328	Pubmed	Lakhan A. et al 2021	Smart-Contract Aware Ethereum and Client-Fog-Cloud Healthcare System *Ethereum*	Simulated
N211	IEEE Xplore	Abdellatif AA. et al 2020	ssHealth: Toward Secure, Blockchain-Enabled Healthcare Systems *Not specified*	Simulated
N329	Pubmed	Ichikawa D. et al 2017	Tamper-Resistant Mobile Health Using Blockchain Technology *Hyperledger*	Simulated
N330	Pubmed	Jamil F. et al 2020	Towards a Remote Monitoring of Patient Vital Signs Based on IoT-Based Blockchain Integrity Management Platforms in Smart Hospitals *Hyperledger*	Simulated
N331	SpringerLink	Randhir K. et al 2021	Towards Design and Implementation of Security and Privacy Framework for Internet of Medical Things (IoMT) by Leveraging Blockchain and IPFS Technology	Simulated

			Ethereum	
N332	Pubmed	Jamil F. et al 2021	Towards Secure Fitness Framework Based on IoT-Enabled Blockchain Network Integrated with Machine Learning Algorithms *Hyperledger*	Simulated
		Notarisation		
N333	ScienceDirect	Kleinaki AS. et al 2018	A Blockchain-Based Notarization Service for Biomedical Knowledge Retrieval *Ethereum*	Simulated
		Patient consent		
N334	Pubmed	Velmovitsky PE. et al 2020	A Blockchain-Based Consent Platform for Active Assisted Living: Modeling Study and Conceptual Framework *Hyperledger*	Nil
N335	Pubmed	Benchoufi M. et al 2017	Blockchain protocols in clinical trials: Transparency and traceability of consent *Bitcoin*	Clinical trial
N336	IEEE Xplore	Lee AR. et al 2020	Coded Dynamic Consent framework using blockchain for healthcare information exchange *Not specified*	Nil
N337	IEEE Xplore	Agbo CC. et al 2020	Design and Implementation of a Blockchain-Based E-Health Consent Management Framework *Hyperledger*	Nil
N338	Google Scholar	Kim TM. et al 2021	DynamiChain: Development of Medical Blockchain Ecosystem Based on Dynamic Consent System *Hyperledger*	Simulated
N30	SpringerLink	Albanese G. et al 2020	Dynamic consent management for clinical trials via private blockchain technology *Hyperledger*	Nil
N339	Google Scholar	Despotou G. et al 2020	Evaluation of Patient Perception Towards Dynamic Health Data Sharing Using Blockchain Based Digital Consent with the Dovetail Digital Consent Application: A Cross Sectional Exploratory Study *Not specified*	Clinical trial
N340	Pubmed	Tith D. et al 2020	Patient Consent Management by a Purpose-Based Consent Model for Electronic Health Record Based on Blockchain Technology *Hyperledger*	Nil
		Supply chain		
N341	IEEE Xplore	Sahoo M. et al 2019	A Blockchain Based Framework Secured by ECDSA to Curb Drug Counterfeiting *Not specified*	Nil

N342	IEEE Xplore	Chenthara S. et al 2020	A Blockchain based model for Curbing Doctors Shopping and Ensuring Provenance Management *Hyperledger*	Simulated
N343	IEEE Xplore	Zhu P. et al 2020	A Blockchain Based Solution for Medication Anti-Counterfeiting and Traceability *Not specified*	Simulated
N344	IEEE Xplore	Musamih A. et al 2021	A Blockchain-Based Approach for Drug Traceability in Healthcare Supply Chain *Ethereum*	Nil
N345	Google Scholar	Jamil F. et al 2019	A novel medical blockchain model for drug supply chain integrity management in a smart hospital *Hyperledger*	Simulated
N346	Pubmed	Qiu Z. et al 2021	A Novel Structure of Blockchain Applied in Vaccine Quality Control: Double-Chain Structured Blockchain System for Vaccine Anticounterfeiting and Traceability *Ethereum*	Simulated
N347	IEEE Xplore	Ying B. et al 2019	A Secure Blockchain-based Prescription Drug Supply in Health-care Systems *Not specified*	Simulated
N348	Pubmed	Wang Z. et al 2021	A Traditional Chinese Medicine Traceability System Based on Lightweight Blockchain *Not specified*	Simulated
N349	IEEE Xplore	Peng S. et al 2020	An Efficient Double-Layer Blockchain Method for Vaccine Production Supervision *Not specified*	Simulated
N350	ScienceDirect	Yong B. et al 2020	An Intelligent Blockchain-based System for Safe Vaccine Supply and Supervision *Ethereum*	Simulated
N351	IEEE Xplore	Omar IA. et al 2021	Automating Procurement Contracts in the Healthcare Supply Chain Using Blockchain Smart Contracts *Ethereum*	Simulated
N352	Pubmed	Uddin M. et al 2021	Blockchain for drug traceability: Architectures and open challenges *Hyperledger*	Nil
N353	ScienceDirect	Uddin M. et al 2021	Blockchain Medledger: Hyperledger Fabric Enabled Drug Traceability System for Counterfeit Drugs in Pharmaceutical Industry *Hyperledger*	Nil
N354	Pubmed	Sylim P. et al 2018	Blockchain Technology for Detecting Falsified and Substandard Drugs in Distribution: Pharmaceutical Supply Chain Intervention	Simulated

			Ethereum and Hyperledger	
N355	IEEE Xplore	Sadri S. et al 2021	Blockchain Traceability in Healthcare: Blood Donation Supply Chain *Ethereum*	Simulated
N356	IEEE Xplore	Garcia HM. et al 2020	Blockchain-based Website Solution for Controlling the Authorized Sale of Drugs in Peru *Hyperledger*	Simulated
N357	IEEE Xplore	Bocek T. et al 2017	Blockchains everywhere - a use-case of blockchains in the pharma supply-chain *Ethereum*	Nil
N358	ArXiv	Mendonca RD. et al 2021	BlockColdChain: Vaccine Cold Chain Blockchain *Ethereum*	Simulated
N359	IEEE Xplore	Subramanian G. et al 2021	Crypto Pharmacy – Digital Medicine: A Mobile Application Integrated With Hybrid Blockchain to Tackle the Issues in Pharma Supply Chain *NEM*	Simulated
N360	Pubmed	Tseng JH. et al 2018	Governance on the Drug Supply Chain via Gcoin Blockchain *Gcoin*	Nil
N361	Pubmed	Singh R. et al 2020	Internet of Things Based Blockchain for Temperature Monitoring and Counterfeit Pharmaceutical Prevention *RAFT*	Simulated
N362	IEEE Xplore	Thatcher C. et al 2018	Pharmaceutical uses of Blockchain Technology *Ethereum*	Nil
N363	IEEE Xplore	Saxena N. et al 2020	PharmaCrypt: Blockchain for Critical Pharmaceutical Industry to Counterfeit Drugs *Ethereum*	Simulated
N364	Pubmed	Steinwandter V. et al 2019	Provable Data Integrity in the Pharmaceutical Industry Based on Version Control Systems and the Blockchain *Ethereum*	Simulated
N365	IEEE Xplore	Kumiawan H. et al 2020	Utilization of the Blockchain Network in The Public Community Health Center Medicine Supply Chain *Hyperledger*	Simulated
N366	IEEE Xplore	Hu X. et al 2019	vGuard: A Spatiotemporal Efficiency Supervision Method For Vaccine Production Based On Double-level Blockchain *Hyperledger*	Simulated
N367	SpringerLink	Pandey P. et al 2020	Securing E-health Networks from Counterfeit Medicine Penetration Using Blockchain *Hyperledger*	Simulated
		Telemedicine		

N368	SpringerLink	Lee T. et al 2020	A blockchain-based Medical Data Preservation Scheme for Telecare Medical Information Systems *Not specified*	Simulated
N369	SpringerLink	Lin H. et al 2020	A Secure Online Treatment Blockchain Service *Not specified*	Simulated
N370	IEEE Xplore	Gupta R. et al 2020	BITS: A Blockchain-driven Intelligent Scheme for Telesurgery System *Ethereum*	Simulated
N371	ScienceDirect	Wang W. et al\ 2021	Blockchain-assisted Handover Authentication for Intelligent Telehealth in Multi-Server Edge Computing Environment *Not specified*	Simulated
N372	Pubmed	Celesti A. et al 2020	Blockchain-Based Healthcare Workflow for Tele-Medical Laboratory in Federated Hospital IoT Clouds *Ethereum*	Simulated
N373	SpringerLink	Ji Y. et al 2018	BMPLS: Blockchain-Based Multi-level Privacy-Preserving Location Sharing Scheme for Telecare Medical Information Systems *Not specified*	Simulated
N374	IEEE Xplore	Guo R. et al 2019	Flexible and Efficient Blockchain-Based ABE Scheme With Multi-Authority for Medical on Demand in Telemedicine System *Not specified*	Simulated
N375	IEEE Xplore	Gupta R. et al 2019	HaBiTs: Blockchain-based Telesurgery Framework for Healthcare 4.0 *Hyperledger*	Nil
N376	IEEE Xplore	Kordestani H. et al 2020	HapiChain: A Blockchain-based Framework for Patient-Centric Telemedicine *Ethereum*	Nil
N377	IEEE Xplore	Hewa T. et al 2020	Multi-Access Edge Computing and Blockchain-based Secure Telehealth System Connected with 5G and IoT *Hyperledger*	Simulated
N378	Google Scholar	Rensaa JH. et al 2020	VerifyMed-A blockchain platform for transparent trust in virtualized healthcare: Proof-of-concept *Ethereum*	Simulated

Figure 3. Our review demonstrated significant cross-application of blockchain technology between the two categories such as EMR management and supply chain encryption. Unique indications for large-scale disease outbreaks such as the COVID-19 pandemic included pandemic surveillance and reporting, contact tracing and movement management, as well as verifiable health/vaccine passports and certificates. In comparison, applications beyond the scope of COVID-19 had greater diversity, ranging from areas such as genomics to patient consent management.