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Abdulmajeed Mohammed M Alanazi[1]

HOW BLOCKCHAIN HELPS TO ENHANCE HEALTHCARE QUALITY: POTENTIAL IMPACT ON CRISIS SITUATIONS LIKE COVID-19 PANDEMIC

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Abstract: *A systematic review of blockchain application in healthcare quality improvement was undertaken in this paper. Google Scholar was used as the search engine. The title of the paper was used as the keyword and the search yielded 56 papers. Most papers were reviews or concepts. The review found that blockchain frameworks and models have been proposed for various healthcare contexts to improve quality, but, they remain concepts or just proof of concepts. None of these frameworks have been actually implemented in real world situations. This research has identified a need for a real world implementation of blockchain frameworks and models to enhance the quality of healthcare. The improvements in quality of healthcare by the implementation of blockchain frameworks and models can have a positive impact in crisis situations (e.g., Covid-19 pandemic).*

Keywords: *Blockchain technology, Healthcare quality improvement, Healthcare applications*

1. Introduction

Although many countries spend a substantial percentage of its GDP for healthcare, globally, the quality of healthcare has not improved despite countries spending a substantial percentage of their GDP for healthcare expenditure.

According to the data presented in Statista (Statista, 2019) for 2018, five of the topmost healthcare spending countries are USA (16.9%), Switzerland (12.2%), Germany and France (11.2%), Sweden (11%) and Japan (10.9%). The lowest spending countries include Indonesia (3.1%), India (3.6%), Turkey (4.2%), China (5%) and the Russian Federation (5.3%).

Rapidly increasing costs, inefficient healthcare practices, medical errors and data security problems compound the healthcare quality problems. The increasing expensive nature is both a challenge and an opportunity for innovative solution. One such solution appears to be blockchain.

2. Methodology

Google Scholar was used as the search engine. The title of the paper was used as the keyword with the 'anytime' option. The search yielded 56 papers. Most of the papers were reviews or concepts. The shortlisted papers were then classified based on the nature of application of the blockchain technology to healthcare quality improvement (e.g., application in healthcare management, in clinical trials, and smart health). These findings from the review are summarised in the subsequent section.

[1] Corresponding author: Abdulmajeed Mohammed M Alanazi
Email: Goda111@hotmail.com

3. Results

3.1 Scope of blockchain application in healthcare

Ledger technology of blockchain facilitates secure transfer of patient information and other healthcare data. It can be used for efficient management of medical supply chains and even unlock genetic codes. The ability of blockchain to "deflate the spending bubble" can help to reduce the cost pains. Giving these information, Daley (2020) cited the example of Estonia, more than 176 million patient records were exposed to data breaches during 2009-2017. The hackers stole credit card and banking information and records of health and genomic. These experiences made Estonia to adopt blockchain technology in 2012, to secure healthcare data and process transactions. Currently, all healthcare billing, 95% of health information, and 99% of all prescription information use blockchain technology. The author also provided 15 examples of successful blockchain application in these areas from developed western world. Thus usefulness of blockchain to enhance healthcare quality by securing data, is demonstrated practically. But what is blockchain technology?

A specific definition of blockchain may be, "a shared, immutable record of peer-to-peer transactions built from linked transaction blocks and stored in a digital ledger." as cited in Innovativemedtec (2020).

Blockchain is based on distributed ledger system. In their work, Haber and Stornetta (1991) showed how to time stamp a digital document, which cannot be tampered. In Fig 1 from Wikipedia, the black chain is the main chain. It is the longest chain of blocks formed from the green genesis (new chains added) chains. Orphan blocks (purple) are outside the main chain.

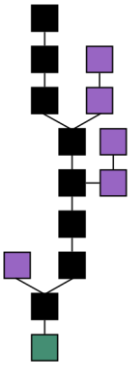

Figure 1. Blockchain concept

They incorporated the Merkle Tree in 1992. The Merkle Tree, named after its inventor Ralph Merkle (patented it 1979), is explained in Fig 2 from Wikipedia.

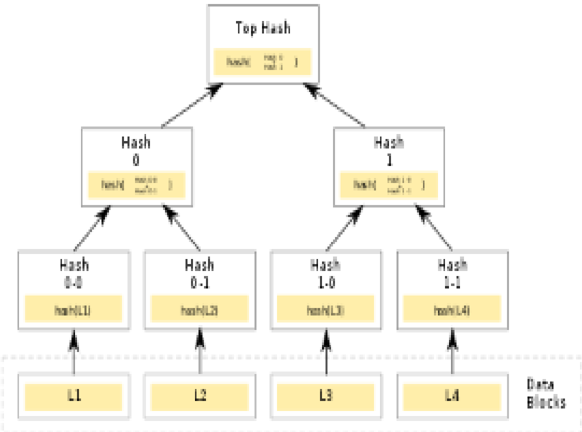

Figure 2. The Merkle Tree concept

Every leaf node is labelled with a cryptographic hash tag of a data block. Every non-leaf node is labelled with a cryptographic hash in the labels of its child node. Hash trees allow efficient and secure verification of the contents of large data structures. Hash trees are a generalization of hash lists and hash chains.

The first blockchain based on the distributed ledger technology, was invented by Satoshi Nakamoto in 2008, who improved the design by using a hashcash-like method to timestamp blocks without requirement of an authentication signature by a trusted third party. A difficulty parameter was introduced to stabilize rate of adding blocks to the chain. This concept was used in the first cryptocurrency, bitcoin by Nakamoto, as is shown in Fig 3 from Investopedia.

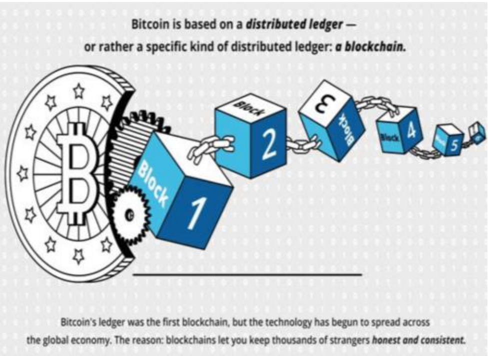

Figure 3. How blockchain technology is used in Bitcoin

Blockchain means, digital information (the block) stored in a public database (the chain). The complete transaction information is stored in the blocks including date, time, amount, buyer and seller. User name is coded. Hashtags are used to differentiate blocks from one another. Hashes are created by special algorithms cryptographically. Thus, even similar transactions have different codes. Each block can store thousands of transactions with distinct hashtags. The transactions stored in blocks are now visible in several thousands of computers and thus made public. This makes manipulation or hacking difficult, as all copies of the data need to be manipulated. Since the computers spread throughout the world this is practically impossible. Thus, publishing, rather than making the transaction secret, gives better security for the data.

Differences among centralised, decentralised and distributed systems has been diagrammatised in Innovatemedtec (2020) as shown in Fig 4. Although there is distribution in decentralised system also, it is not interwoven to the extent seen in distributed systems. The traditional centralised system has no distribution as all transactions converge towards a centralised authority for verification and authentication.

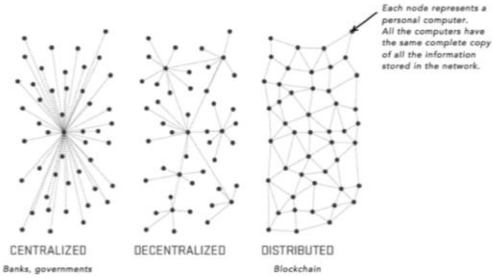

Figure 4. Differentiating centralised, decentralised and distributed systems

After the above background about blockchain technology as such, its healthcare applications to enhance its quality are reviewed in further sections.

A diagram from a Deloitte report of 2016 was used in Innovatemedtec (2020) to explain the scope of application of blockchain in healthcare. This is presented in Fig 5.

What is presented in Fig 5 covers only the application of blockchain by healthcare providers to patients. But, even if only this is implemented, tremendous differences can be made to improve healthcare quality.

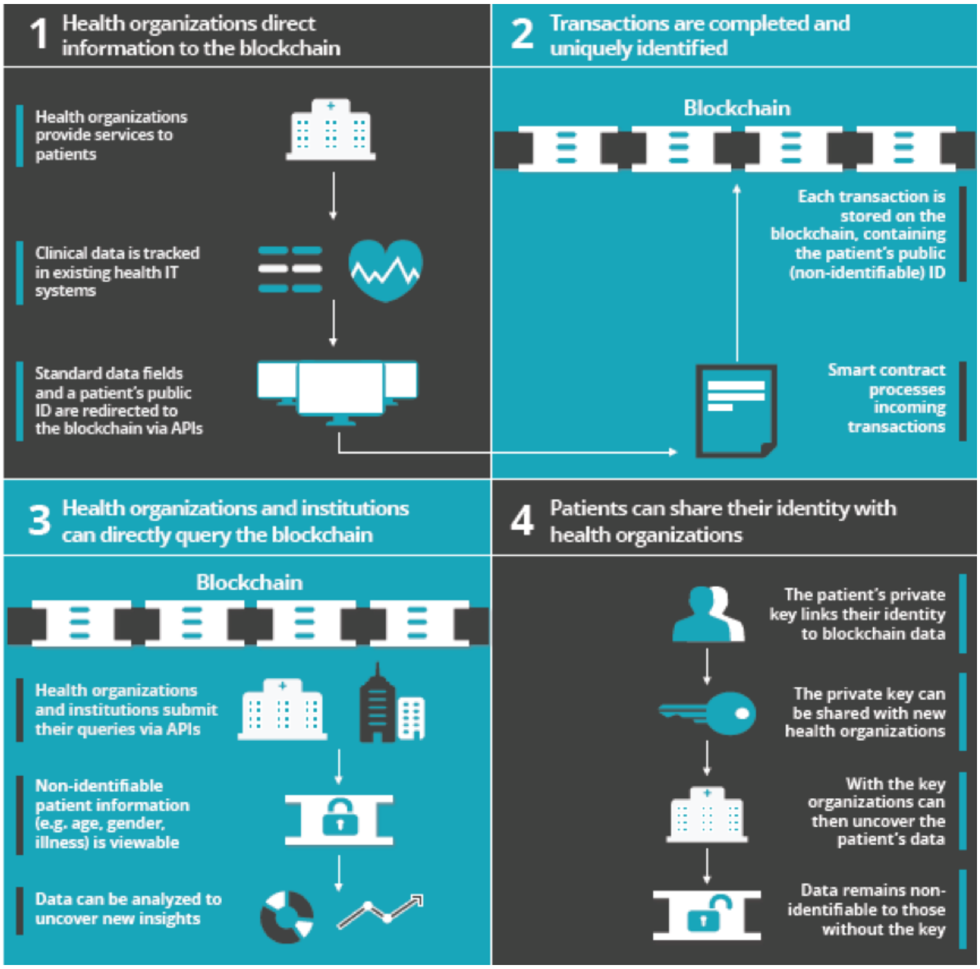

Figure 5. Application of blockchain technology in healthcare (Innovatemedtec, 2020)

3.2 Research works on blockchain technology in healthcare quality

Many reviews and white papers are available on BC applications in healthcare. Some of them are Kuo et al. (2017), Engelhardt (2017), Angraal et al. (2017) and Bell et al. (2018) general description, Zhang et al. (2018a) focusing the dual issues of the need to create an interoperable system for free clinical communications and data exchange and to provide patient-centric care with access and control of their complete medical data, Rabah (2017) and Mackey et al. (2019) on opportunities and challenges.

A framework to evaluate the need for use of BC in healthcare system proposed by Hussien et al. (2019) has been presented in Fig 6.

The need is assessed through a series of step-wise questions and their yes/no answers to proceed further in the assessment.

A generalised description of the benefits of BC application in healthcare, based on a systematic review, presented by Kassab et al. (2019) is reproduced in Fig 7.

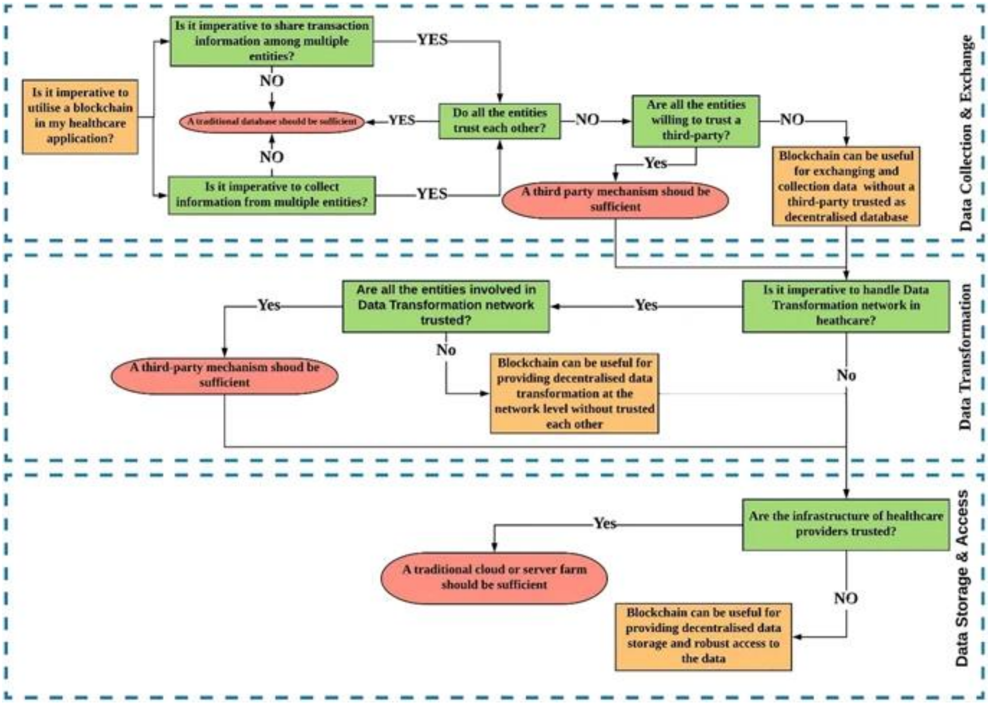

Figure 6. Framework for evaluation of the need for blockchain technology in healthcare system

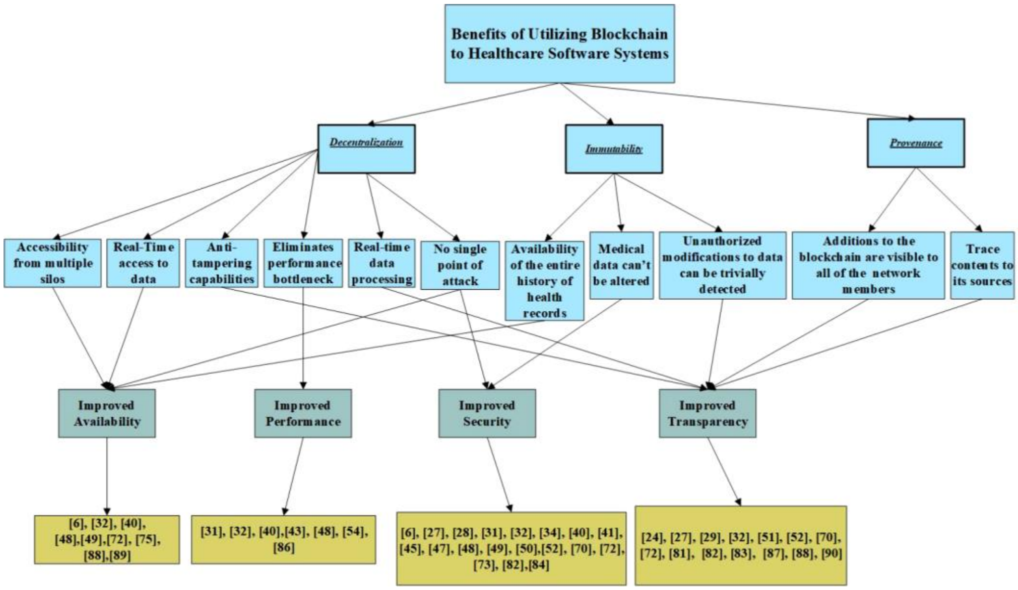

Figure 7. Benefits of blockchain in healthcare (Kassab et al., 2019)

A white paper on innovative uses of blockchain in healthcare was published by Freed Associates (Stagnaro, 2017). Five ways of using blockchain (BC) in healthcare were described:

1. Longitudinal health care records – Patient records can be securely linked and made accessible across non-affiliated providers by BC to improve care coordination.

2. Automated health claims adjudication – BC smart contract structure can be used for a more cost-efficient payment process for the providers.

3. Interoperability – BC can help to overcome the current problems of interoperability of patient data and gather the required information more effectively to support population health initiatives in large health systems.

4. Online patient access – More easy, effective and secure access to patients for their own records can be facilitated by BC.

5. Supply chain management – Healthcare contract management can be more effectively managed with the help of BC to reduce costs using real-time contract tracking and execution.

Further, BC is already used as the supporting technology for e-currency in financial and business applications like Bitcoin (Stagnaro, 2017). The special features of BC technology attracted healthcare professionals to examine and find out some potential uses for it. A comparison of BC architecture in Bitcoin and in healthcare transactions provided by the author, is reproduced in Fig 8.

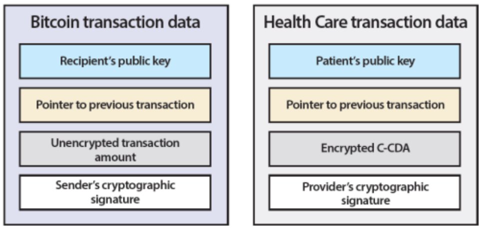

Figure 8. Comparison of Bitcoin and healthcare transactions using BC (Stagnaro, 2017)

It appears, there are some high level thoughts on which healthcare data can be included in a blockchain's transaction and how other data associated with a blockchain transaction can be stored off-chain. These thoughts are reproduced from Stagnaro (2017) in Fig 9 along with their source.

Only standardised summaries containing essential information is proposed to be included in BC. More expansive details will be stored off-chain.

	On-Chain data	Off-Chain data
Data types	• Standardized data fields containing summary information in text form (e.g. age, gender)	• Expansive medical details (e.g. notes) and abstract data types (e.g. MRI images, human genome)
Pros	• Data is immediately visible and ingestible to all connected organizations, making blockchain the single source of truth	• Storage of any format and size of data
Cons	• Constrained in the type and size of data that can be stored	• Data is not immediately visible or ingestible, requiring access to each health care organization's source system for each record • Requires Off-Chain micro-services and additional integration layers • Potential for information decay on the blockchain

Figure 9. Pros and cons of BC in health (Stagnaro, 2017)

Although, this differentiation may reflect the availability of space, some apprehensions about the privacy of widely published data seems inherent in such a categorisation. This observation is substantiated by the pros of both. Visibility is the determining factor for both on-chain and off-chain data. Constraints of size of data is mentioned as the cons aspect of on-chain data. Off-chain data storage is like any other traditional data storage and access systems and hence the pros and cons are the same.

3.3 BC-based applications to enhance healthcare quality

Many examples of BC-based applications to enhance healthcare quality are available in the literature. Some of them are just conceptual and others are just futuristic visions only (Angraal, Krumholz, & Schulz, 2017). No attempt to validate and actually use them in the real world contexts seem to have been tried in any of these papers. The available literature on these topics are reviewed below. Many short-term proposals offered in the idea challenge posed by the Office of the National Coordinator for Health Information Technology, in 2016, focused only on the validation, auditing, and authorization of patient healthcare data. Guardtime, a Netherlands-Estonia collaboration validated patient identities. MedRec was a project started between MIT Media Lab and Beth Israel Deaconess Medical Centre, to manage permissions, authorization, and data sharing between healthcare systems and is a proof-of-concept project (Ekblaw et al., 2016). Automated validation of claims is another application. Another conceptual application, a BC-based access control manager to EHR in USA was described by Linn and Koo (2016) The application is claimed to solve interoperability problems highlighted by the Office of the National Coordinator for Health Information Technology’s (ONC) Shared Nationwide Interoperability Roadmap. No validation or example of practical application of this application has been stated in the paper.

Healthcare intelligence system consists of preservation of the privacy and confidentiality of patient healthcare data by patients owning, controlling, and sharing. For this purpose, Yue et al. (2016) developed a blockchain technology based App called Healthcare Data Gateway (HGD). A unified Indicator-Centric Schema (ICS) simplifies the organization of all kinds of personal healthcare data in a practical manner. Also, there is a MPC (Secure Multi-Party Computing) as a solution to enable untrusted third-party to use patient data for computational purposes without violating privacy. No information is available whether the App was tested and validated for general use.

3.4 Supply chain management

Supply chain management in healthcare has the added risk of compromising patient safety and health outcomes if things go wrong. Based on a review of literature, Clauson et al. (2018) found BC to be suitable to address these critical challenges. Some use cases have been emerging slowly. BC has been shown to be useful to reduce fake medicines, to secure medical devices, to optimise IoHT functionality and to improve the public health supply chain. Although these clear opportunities have been identified most of the BC-based initiatives remain in as proof-of-concept or do not progress beyond pilot phase. Sadly, only reviews happen, no primary research. In a review on BC applications in SCM in healthcare, Queiroz et al. (2019) found that the disintermediation provided by blockchain applications has the potential to disrupt traditional industries like health care. To successfully implement trace and track system and prevent spurious drugs, Alangot and Achuthan (2017) introduced an IoT-based framework known as GDP (Global Data Plane) integrated with blockchain. This facilitates communication and management of data between untrusted parties. As an unchangeable record of drugs each party holds and transactions the parties make amongst themselves is maintained by BC, it becomes harder to substitute genuine drugs with counterfeit drugs into the supply chain.

3.5 Smart health

The applicability of BC in smart health was discussed by Dasaklis et al. (2018). Other points are fairly repetitive of most other articles and reviews. The smart contract features of BC which can be applied to improve healthcare quality, were discussed by Kumar et al. (2018). Smart contract is an agreement among the various parties involved in the defined system. Essentially, it is a computer protocol that follows specific rules, codes and constraints. These are to be agreed by all participants in the network before entering into the contract.

In contrast to the painstaking writing of traditional contracts, smart contracts are self-generated by the computer system. When the required terms are fulfilled, the smart contract digital programme executes the contract by itself. As healthcare system involves diverse stakeholders, who need to work collaboratively and efficiently, appropriate rules need to be defined for each party in the contract. In the case of healthcare blockchain, there is need for the patient and other stakeholders in the network to set up their details and sign the agreement stating that they accept the terms to develop the smart contract requirements.

These requirements may be related to the hospitals assigned to store and share the patient data, the list of doctors who can access and append the data and the nature of data to be made available to the pharmacy and laboratory. A diagram of how BC can be used for smart contracts in healthcare provided by the authors is reproduced in Fig 10. The diagram virtually explains what was described above.

Another model of using BC for smart contracts was given by Stagnaro (2017) as reproduced in Fig 11.

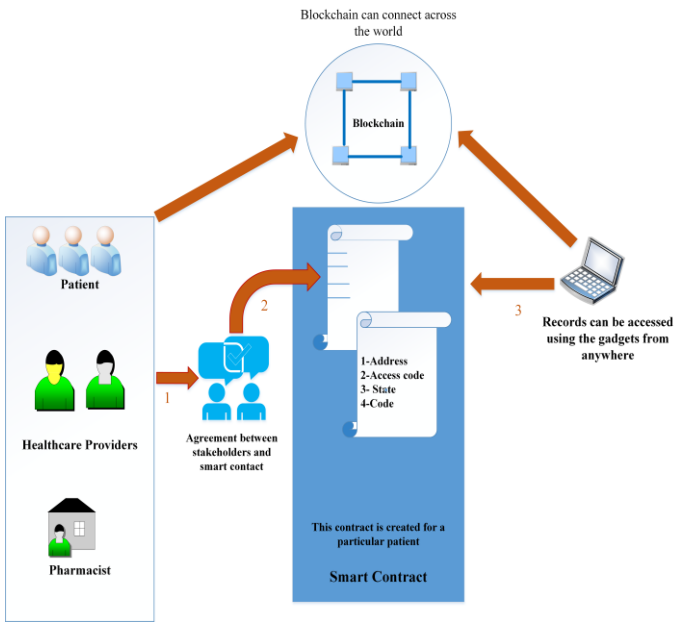

Figure 10. Using blockchain for smart contracts in healthcare (Kumar et al., 2018)

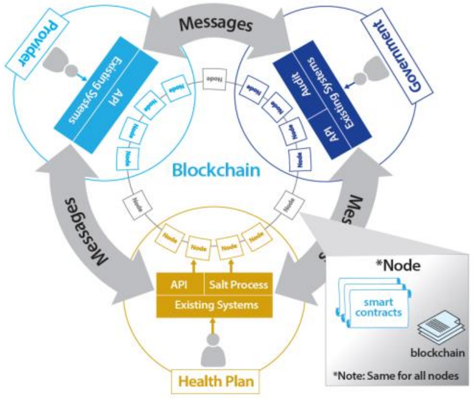

Figure 11. Blockchain application of smart contracts in healthcare (Stagnaro, 2017)

3.6 Agile application

Salahuddin et al. (2017) proposed agile softwarized infrastructure for a smart healthcare applications and services. This system consisted of flexible, cost effective, secure and privacy preserving deployment of Internet of Things (IoT) integrating state-of-the-art networking and virtualization techniques across IoT, fog and cloud domains, BC, Tor and message brokers to provide security and privacy for patients and healthcare providers. A machine-to-machine (M2M) messaging platform and rule-based beacons for seamless data management were also used as parts of the system. Although these high-sounding terms were used for description of the system, there was no evaluation of its practical use and real time studies. In another paper on smart healthcare, Capossele et al. (2018) suggested including the non-personal smart city data to improve prediction, prevention, and prescriptive care in mobile smart health applications. Feedbacks generated in the system can be used to make cities smarter as it accounts for and adapts for individual needs. The impact of mobile-facilitated efforts to reduce pollution in cities make them smarter and also contributes to better health of their citizens.

3.7 Specific diseases

Based on a review, Dubovitskaya et al. (2019) concluded that in the case of cancer care, BC can facilitate quick and timely data sharing to achieve optimization of the pharmaceutical supply chain through transparency, traceability, and immutability to the applications. But privacy can be ensured only when combined with cryptographic methods. Legal, technological, and social barriers exist for real time evaluation of conceptual models.

A BC-enabled diabetes data for better access management was explained by Cichosz et al. (2019). Diabetes patients data consist of both disease-specific and general health data. Cross-institutional sharing of these data can contribute to more efficient care of these patients. However, such data sharing is complex. BC comes to the rescue here by providing a safe and secure platform with the patient at the centre. Access to the data are limited to the patients and those authorised by them only. This is the principle followed in every BC-backed data sharing platforms.

A BC approach for tele-dermatology platform to improving access to dermatological care by enabling connection to several medical centres and exchange of information about skin conditions over long distances in Italy was proposed by Mannaro et al. (2018). A teledermatology project was implemented to promote and facilitate the diagnosis of skin diseases and improve the quality of care in rural and remote areas. New functionalities were added to it using BC. The whole system was tested in Sardinia region of Italy.

3.8 Trust and privacy

One of the basic concept behind using BC in healthcare is the co-creation of trust in a pluralistic morality environment consisting of several claimants to the data apart from the patient, albeit in the interest of effective interventions for the benefit of the patient. According to Nichol and Brandt (2016), the co-creation of trust has direct positive impact on patient satisfaction, fraud prevention, healthcare outcomes, and reduction of security involved in interoperability. A concept of cryptocitizen is applied in all the discussions on trust and interoperability. In the absence of trust, interoperability is zero. Security, interoperability, and payment reforms are the main concerns when healthcare improvement is sought. All these problems can be solved with the help of BC.

In a conceptual treatment of BC application in medicine, Stawicki et al. (2018) provided and discussed the frameworks of patient care, academic achievements, tokenisation of asset evaluation and management applied to medical faculties and departments of hospitals.

3.9 Country cases

Estonia had been in the forefront of introduction of new technologies as soon as they became available. These include internet, making of all schools online, declaring internet access as a human right all before 2000. Although Estonia suffered from severe cyberattacks during 2007, it continued with internet and cyber technologies for its development with strong security measures. In 2016, Estonia reinforced its global leadership in innovative by announcing its use of BC to secure the health records of over a million citizens. Estonia's systematic method of applying blockchain technologies through GovTech partnerships demonstrates how innovation is a process. The blockchain based proprietary Keyless Signature Infrastructure is being utilized to guarantee record security simultaneously with wide availability to authorized parties. These facts were analysed in a case study of Estonian use of BC in healthcare by Heston (2017).

In another case study of Tunisia, the scope of using BC to solve risks associated with counterfeit medicines, vaccines "drugs" and issues related to drug availability and wastage, fragmented healthcare information system, lack of collaboration between stakeholders in setting priorities and moving the sector towards a patient-focused model of healthcare and preventative medicine were discussed by Rejeb and Bell (2019).

3.10 Remote patient monitoring

Remote patient monitoring (RPM) is a more powerful and flexible patient observation through wearable sensors at anytime and anywhere. This facilitates getting real-time information of patient to doctors remotely using wireless communication system. RPM reduces the time and cost of the patient while ensuring the quality care to the patient. Hathaliya et al. (2019) proposed a BC based permissioned healthcare architecture for this purpose.

3.11 Decision making frameworks

Medication Administration Records (MAR) are important care quality documents aimed at service users. To ensure, high levels of care quality, audits and inspections of registered hospitals, care and residential homes spread across the country of these MAR sheets impact on the outcome of Medication Management significantly. To build confidentiality and trust with these auditors, BC based permission and access can be built into the MAR data platforms. Encouraging results were obtained by Mitchell and Hara (2019) on testing a prototype of this concept, BMAR, in two scenarios. In a related paper, Mitchell and Hara (2019) described the procedures of quality audits by UK Care Quality Commission (CQC) which is empowered to audit all registered institutional and individual medical professionals of general and specialised practices. In these audits, the integrity of data and records is the main concern. Detection of retrospective editing is an important auditing task. Prevention of retrospective editing is possible with the use of BC. The specific privacy and authentication features of BC can be used for this purpose. BMAR was a result of search for a solution.

In designing a collaborative decision making system, Yang et al. (2019) used the BC properties. The authors used the experience, skill, and collaborative success rate of the four main stakeholders- patient, cured patient, doctor, and insurance company- for a local reference-based consortium blockchain scheme with an associated algorithm to collect consensus in the proof-of-familiarity (PoF) framework. In PoF, these stakeholders make a transparent and tenable medical decision through to high level of interoperability among collaborators. A prototype of PoF was tested with multichain 2.0, which is a blockchain implementing framework. The BC ensures that the privacy of identities, EMRs and decisions are protected by a two-layer storage, encryption, and a timestamped storing mechanism. The superiority of PoF over the current schemes was confirmed through patient-centric outcomes research (PCOR).

What should be the decision framework for BC-enabled healthcare system? The answer to this was provided by Stagnaro (2017) giving a framework for the same, shown in Fig12.

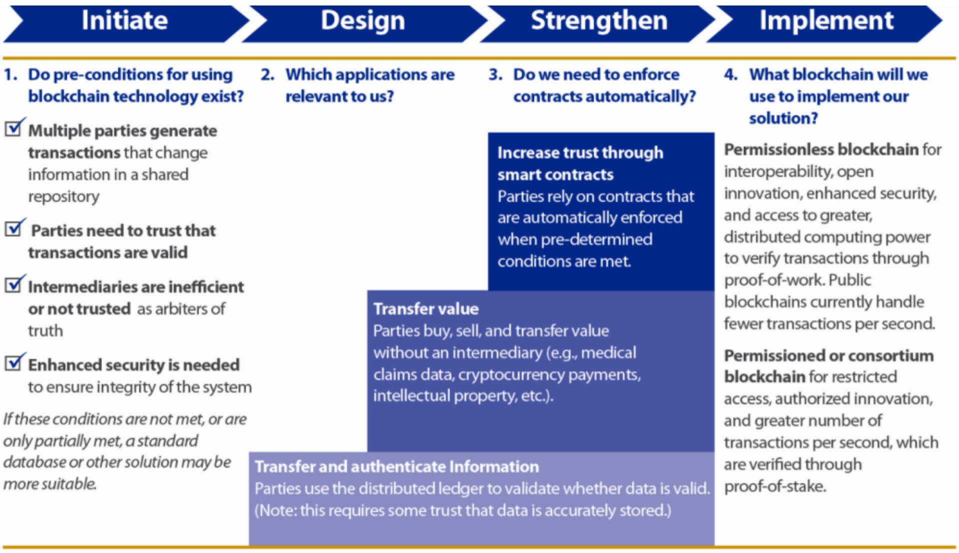

Figure 12. A blockchain enabled decision framework for healthcare systems (Stagnaro, 2017)

3.12 Implementation issues

The conceptual block-chain enabled healthcare ecosystem to be implemented by national healthcare agencies should consist of mapping and convening of the ecosystem, establishing a consortium of experts to experiment and guide initial phases of implementation, design and develop and implement proof-of-concept for specific use cases involving different stakeholders and covering the full transaction lifecycles, invest in short-term projects first and expand promising results, prescribe standards and issue national guidelines on using BC-based healthcare transactions, evaluation and reporting (Stagnaro, 2017).

3.13 A model of healthcare ecosystem

Finally, a conceptual, BC-supported, holistic healthcare ecosystem, will look like the system described in the diagram provided by Stagnaro (2017), as given in Fig13.

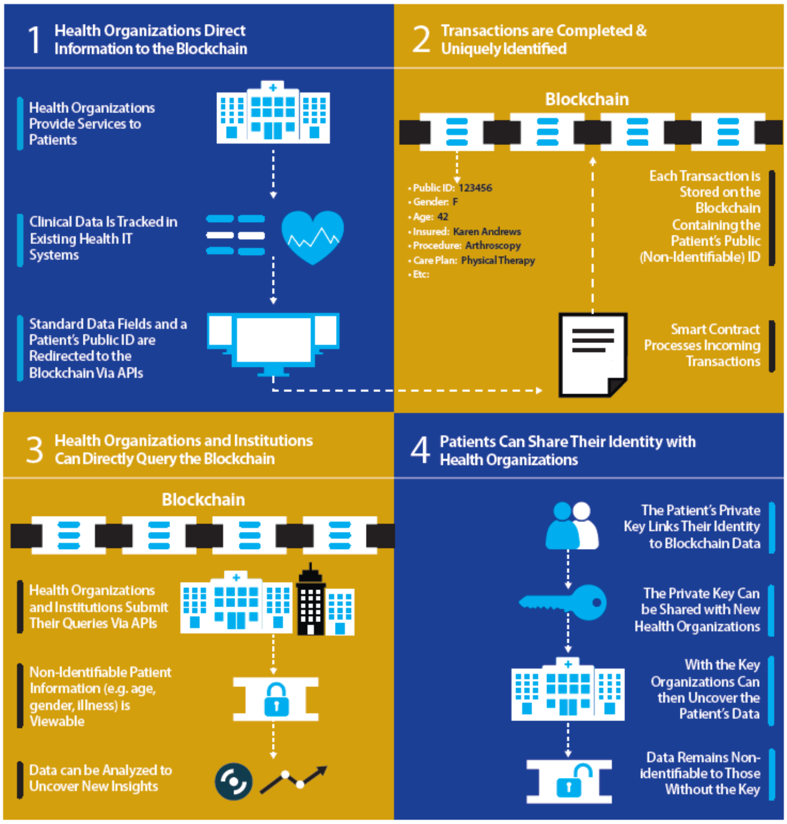

Figure 13. A conceptual blockchain-based healthcare ecosystem (Stagnaro, 2017)

3.14 Management issues

With increasing popularity of remote patient monitoring systems, there is also increasing security concerns about the transfer and logging of data. To handle the protected health information (PHI) generated by these devices, a blockchain-based smart contract was proposed by Griggs et al. (2018), which can facilitate secure analysis and management of these medical sensors. An Ethereum-based technology was used for communication of the sensors with a smart devices for calling smart contracts and writing records of all events on the blockchain. This smart contract system send notifications to patients and medical professionals to ensure real-time patient monitoring and medical interventions.

The smart contract applications of BC based vendor management inventory framework suggested by Casino et al. (2019) can be useful in healthcare applications, as its features are match healthcare system requirements. A functional implementation of the framework was successfully tried using it in a local private blockchain and various smart contracts to implement a set of functions to realise the benefits of VMI implementation. Thus, a use case of the framework was demonstrated.

3.15 Disease surveillance

Scope of BC in disease surveillance was explored by Chattu et al. (2019) due to its advantages in disease surveillance over the other widely used real-time and machine learning techniques. The other real-time surveillance systems lack scalability, security, interoperability, thus making blockchain as the preferred choice for surveillance. It ensures anonymity of patient data to maintain ethical aspect of surveillance research. Recent global level epidemics like Ebola, Zika and Corona viruses raises concerns regarding health security. This highlights the importance of sound surveillance systems. BC can help in identifying such threats early and report them to health authorities for implementing early preventive measures. This is linked to the Global Health Security Agenda aimed at reducing global public health threats (both infectious and NCDs), strengthening the workforce and the systems, rapidly and effectively detecting, and responding to the disease threats and elevate global health security as a top priority. The BC has considerable potential to disrupt many of the current traditional disease surveillance practices. Unfortunately, the model presented in this article does not explain how exactly BC is used for disease surveillance. The scope of using BC for production and use of medical electronics in healthcare settings was discussed by Pilkington (2017).

3.16 Interoperability and date sharing

In an effort to address interoperability challenges using software patterns, Zhang et al. (2017) described the challenges that arose when they tried to implement their DApp for Smart Health (DASH). The implementation challenges arose when they tried to extend the app and included the challenges of tightly coupled designs, duplicated resources, and lack of scalability. To solve these problems, four software patterns, namely-Abstract Factory, Flyweight, Proxy, and the Publisher-Subscriber- to decouple the creation and access of entities, maximize sharing of resources and improve application scalability. These results need to be validated and tested in real life contexts. Thus time-proven design practices were combined with BC to make DApps more modular, easier to integrate and maintain, and more or less resistant to change. To address the issue of data sharing, which exists fragmented across decentralised hospitals, Liu et al. (2018) designed a BC based privacy preserving data sharing application, BPDS. In this system, the original EMRs are held under secure storage in the cloud. Their indexes are stored in consortium BC. Predetermined access permissions of patients facilitate secure data sharing through BC enabled smart contracts. Other methods to strengthen privacy preservation can be added.

The importance of checking the integrity of data, when securely sharing patient healthcare data was pointed out and a BC based software capability was integrated into the data acquisition stage to accept only data with proven integrity. The system can be leveraged in frames of the healthcare data exchange and interoperability between contact points of national healthcare. However, the system is yet to be validated for real life use (Theodouli et al., 2018).

Another secure data sharing method, Fast Healthcare Interoperability Resources (FHIR) was proposed by Zhang et al. (2018b). The steps involved analysing the ONC requirements and assessing their implications for BC based systems, presentation of the proposed system FHIRChain to meet ONC requirements meeting H7 standards for FHIT systems, demonstration of the app using a case study of digital health identities to authenticate participants of a collaborative decision making for remote cancer care. Therefore, this app is almost implementation-ready.

Shen et al. (2019) noted that the current data sharing approaches can be used only for medical examination records. They are not useful to share data streams continuously generated from sensors and other monitoring devices. IoT devices and sensors and mobile applications are used for continuously monitoring health conditions of patients. The collected data are shared among laboratories and institutions for diagnosis and further study. But the current approaches are not suitable for metadata changes as they are too rigid. The authors described an efficient data-sharing scheme, MedChain, combining BC, digest chain, and structured P2P network techniques to overcome these problems. Using MedChain, a session-based data sharing scheme was developed for sufficient flexibility. In the evaluation studies, MedChain achieved higher efficiency and satisfied the security requirements in data sharing. Some interesting data given by the authors are reproduced in Fig 14 to 16. These are self-explanatory.

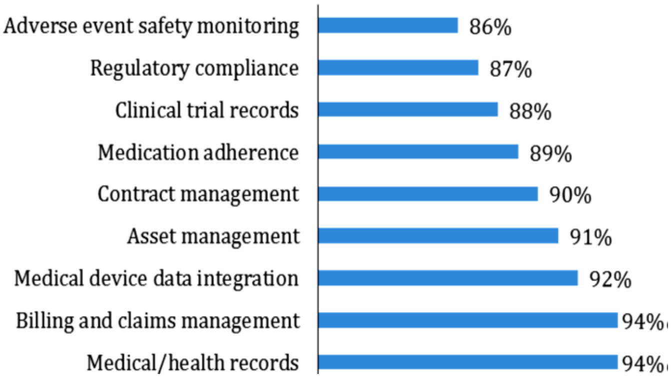

Figure 14. Blockchain investments in healthcare 2018 (Shen et al., 2019)

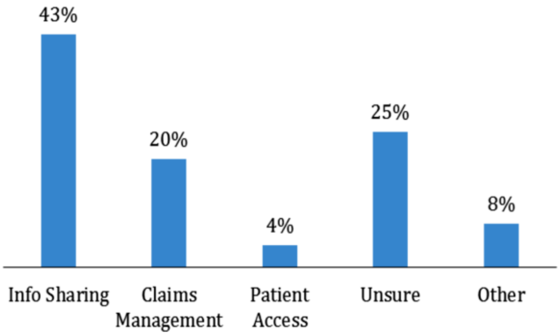

Figure 15. Level of awareness about blockchain applications (Shen et al., 2019)

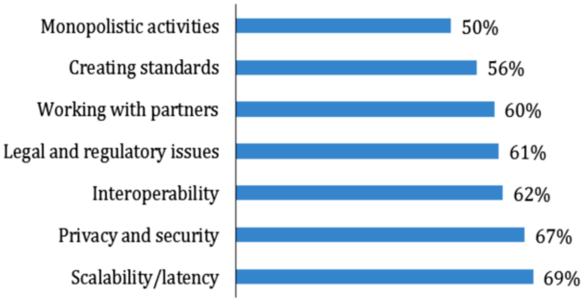

Figure 16. Main external barriers for adoption of blockchain in healthcare (Shen et al., 2019)

The Medchain architecture and its modules for super peer are reproduced in Fig 17. It can e seen that super peer activities are applied at clinical level, small company, large company and national hospital. The system can be enlarge to national healthcare level from national hospital level. Here, super peer refers to the dynamic P2P high speed data exchange. Since it is applied in different levels, the super peer is hierarchical in nature. Medchain is adaptable to session-based data sharing also. Both theoretical and experimental evaluations were done using assumed patient data from real repots.

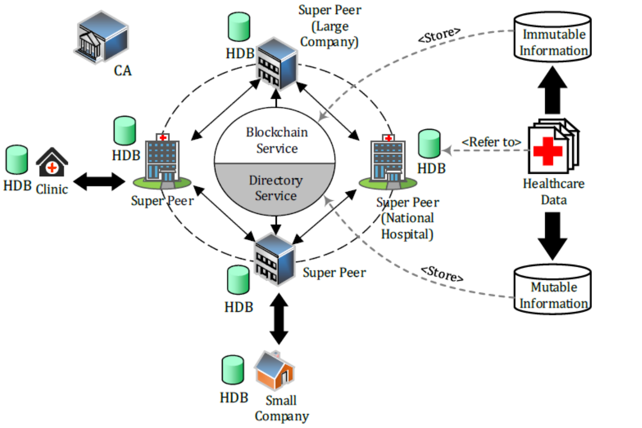

Figure 2. MedChain architecture.

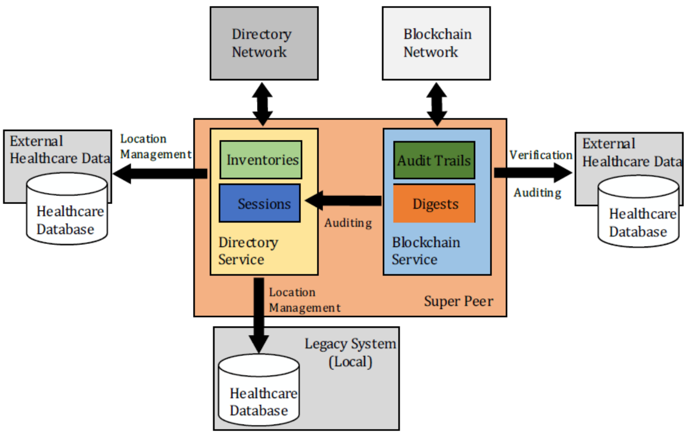

Figure 17. Medchain architecture and its super peer modules (Shen et al., 2019)

3.17 Mobile applications

Use of Mobile Edge Computing system in healthcare with BC for authentication was investigated by Zubaydi et al. (2018). A Mobile edge computing (MEC) for an in-home therapy management context, was proposed by Rahman et al. (2018). The MEC leverages IoT nodes and BC to support low-latency, secure, anonymous and spatiotemporal multimedia therapeutic data (always available) communication in a scenario of on-demand data-sharing. It can also provide motion data for a range of full-body joint for physically challenged individuals in a decentralized way.

The scope of the framework is very large as it can provide on demand diagnostic therapy and analytical data to a large population with disabilities either at birth itself or became disabled due to old age, accidents, or war-time injuries. This scope of use was revealed by actual implementation data. No increase in mean processing time was observed. The software components of the MEC are reproduced in Fig 18. The secure data flows through cloud, fog, mobile and therapy environments. The architecture of different components of the system have also been presented.

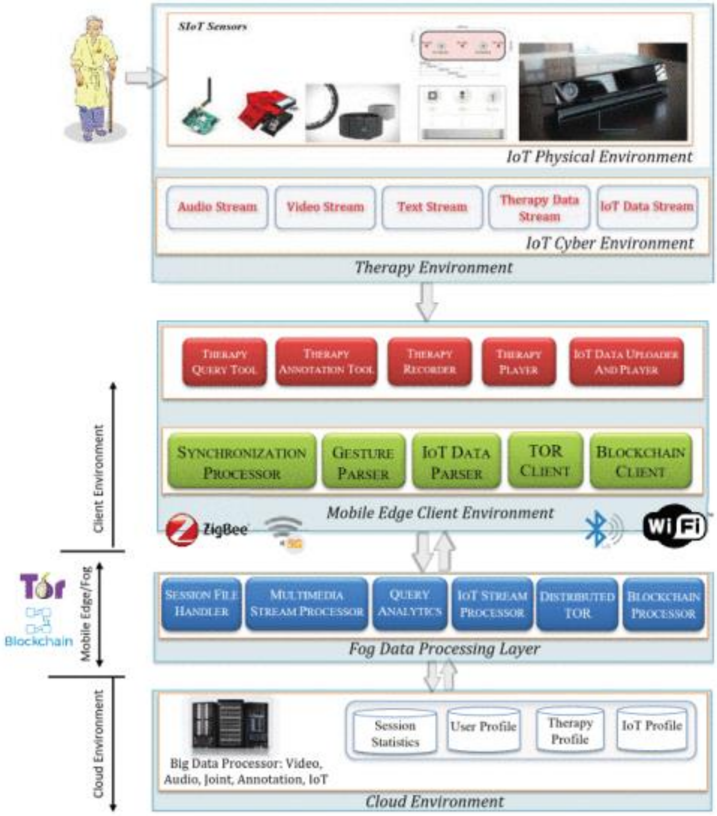

Figure 18. Secure data flow of MEC therapy application through different environments (Rahman et al., 2018)

3.18 Medical education

The potential of BC for health educational purposes was discussed by Funk et al. (2018). There is an urgent need for health education to adapt to new technologies. The recent development of many massive online courses and education through social media have led to problems of ascertaining their origin, validity, and accountability of the knowledge that is created, shared, and acquired. BC can be used effectively for solving these problems. BC facilitates improved tracking of content and its creators. It can also quantify educational impact on many generations of learners and assess the relative values of educational interventions. The smart contract facility of BC can be used for issuing certification and credentialing of health care professionals without the need for intermediaries.

3.19 Digital identity

A SWOT analysis of BC in healthcare was presented by Siyal et al. (2019) and is reproduced in Fig 19. The chart is self-explanatory and most of the points included in each component have been discussed in the reviewed works.

As identities migrate through different digital platforms, there is a need for organizations and citizens to transact without friction, as online service delivery replaced counter-bound services fast. An ecosystem approach to digital identity was used by Wolfond (2017) to address the current and emerging challenges of identity verification and authentication within a Canadian healthcare context.

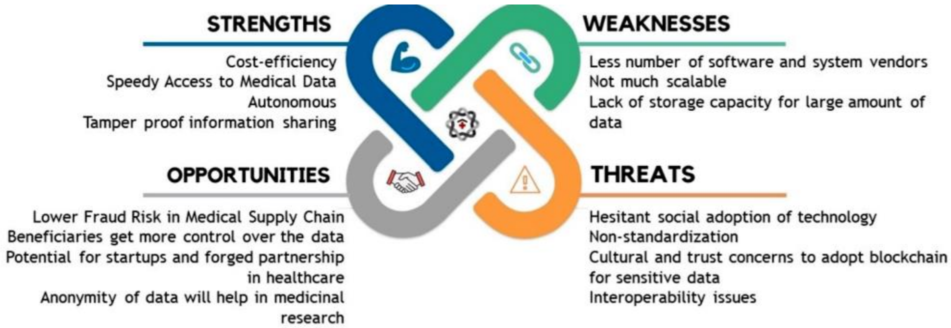

Figure 19. SWOT Analysis (Siyal et al., 2019)

3.20 Clinical trials

To improve the outcome of clinical trials, Borioli and Couturier (2018) applied 'outcome-driven innovation' methodology originally developed by Anthony Ulwick (Ulwick, 2005) and popularised by Clayton Christensen (Christensen & Raynor, 2013). In-depth, open interviews with doctors, nurses and researchers in the UK, France and Italy were used for data collection. Points of difficulties for key players of the value chain were identified. The need was identified for a multi-stakeholder approach to exploit the transformative potential of BC to resolve issues. There exists a set of opportunities for innovators to improve the way of conducting clinical trials by hospitals using smart contracts and BC.

3.21 Medical irregularities

Even in IoT devices used in healthcare, many threats are possible. Problems like doctors compelling patients to buy medicines from particular shops arise. To provide security for IoT devices in such situations, Griggs et al. (2018) designed a BC based security framework and tested in simulated conditions. Compared to conventional systems, the BC based system recorded 86% success rates of product drop ratio, falsification attack, worm hole attack and probabilistic authentication scenarios.

3.22 Future of BC in healthcare

Application of BC in healthcare 4.0 was discussed by Mukherjee and Singh (2020). Some conceptual and experimental results on the future possible applications of BC in healthcare are hybrid multimedia data processing in IoT backed by BC (Rathee et al., 2019), PlaTIBART platform for transactive IoT BC applications with repeatable testing (which was experimentally evaluated and compared with current systems) (Walker et al., 2017). Some of these were not necessarily developed for healthcare, but are possible to be applied.

4. Conclusions

A systematic review of blockchain application in healthcare quality improvement was undertaken in this paper. The shortlisted papers were classified based on the nature of application of the blockchain technology to healthcare quality improvement (e.g., application in healthcare management, in clinical trials, and smart health). The review found that blockchain frameworks and models have been proposed for various healthcare contexts to improve quality, but, they remain concepts or just proof of concepts. None of these frameworks have been actually implemented in real world situations. This research has identified a need for a real world implementation of blockchain frameworks and models to enhance the quality of healthcare. The improvements in quality of healthcare by the implementation of blockchain frameworks and models can have a positive impact in crisis situations (e.g., Covid-19 pandemic).

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Abdulmajeed
Mohammed M Alanazi
Goda111@hotmail.com