



## Medical Records System with Blockchain (Health Chain)

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### ARTICLE INFO

#### Article history:

Received 22 March 2024

Received in revised form 4 September 2024

Accepted 18 December 2024

Available online 31 December 2024

#### Keywords:

Blockchain; medical records; system; patient empowerment; data security; decentralization

### ABSTRACT

This study explores the potential of blockchain technology to address key challenges in Malaysia's healthcare system, such as fragmented data, security vulnerabilities and restricted patient data access rights. This paper presents Health Chain, a blockchain-enabled, patient-centric medical record system designed to overcome these significant issues. Health Chain enhances security for patient data by up to 63.2% compared to similar systems, leveraging the immutability and decentralization inherent in blockchain technology. The system employs cryptographic hashing and encryption methods to create a secure architecture and it empowers patients with greater control over their data through smart contracts. Comprehensive evaluation, including User Acceptance Testing (UAT), questionnaires and system testing, revealed promising results: users expressed 17% higher confidence in data security compared to other systems, with 85% finding data management tasks intuitive and easy. Health Chain also optimized administrative procedures, reducing manual data entry time, thereby enhancing healthcare efficiency and potentially leading to cost savings. These findings suggest that Health Chain could revolutionize the healthcare industry by prioritizing data security, empowering users and streamlining processes. Aligned with the vision of SDG 3, which promotes good health and well-being, Health Chain demonstrates significant potential in improving data security, enhancing patient control and reducing administrative burdens. However, further development is needed to address limitations in the scope of services provided. By overcoming these challenges and fostering continuous research and collaboration, Health Chain could play a crucial role in empowering patients, optimizing healthcare efficiency and contributing to a healthier future for all.

## 1. Introduction

The Blockchain first powered the infamous Bitcoin, however since then it has surpassed this role to greatness. The paper (Bitcoin: A Peer-to-Peer Electronic Cash System) was published by an anonymous called Satoshi Nakamoto in 2008, it really laid the foundation for what blockchain could do eventually. This was the beginning of realising that blockchain could be used, as a general tool for many industries [1]. Bitcoin has shown that it can enable direct financial transactions, as other

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<https://doi.org/10.37934/ard.123.1.108130>

platforms such as Ethereum have expanded the scope with capabilities like smart contracts and decentralized apps [2]. This makes it poised (alongside AI and 5G) to be the internet-level disruptor in what some have called a fourth industrial revolution.

This research project is aiming to describe the way in which blockchain technology can be applied within a fast-evolving healthcare sector. The COVID-19 pandemic has laid bare the necessity of strong health systems and innovative approaches to handling health data. This has resulted in significant progress, such as 3D printing, creation of artificial organs, robotic surgeries and employment of virtual reality among others that have greatly advancing patient care. Meanwhile, the handling of medicals is not keeping up. Reliable decision-support data also plays an important role to increase the effectiveness and efficiency of healthcare. However today, most current systems face a variety of issues in terms how safe it is to request or share this sort data given contemporary circumstances.

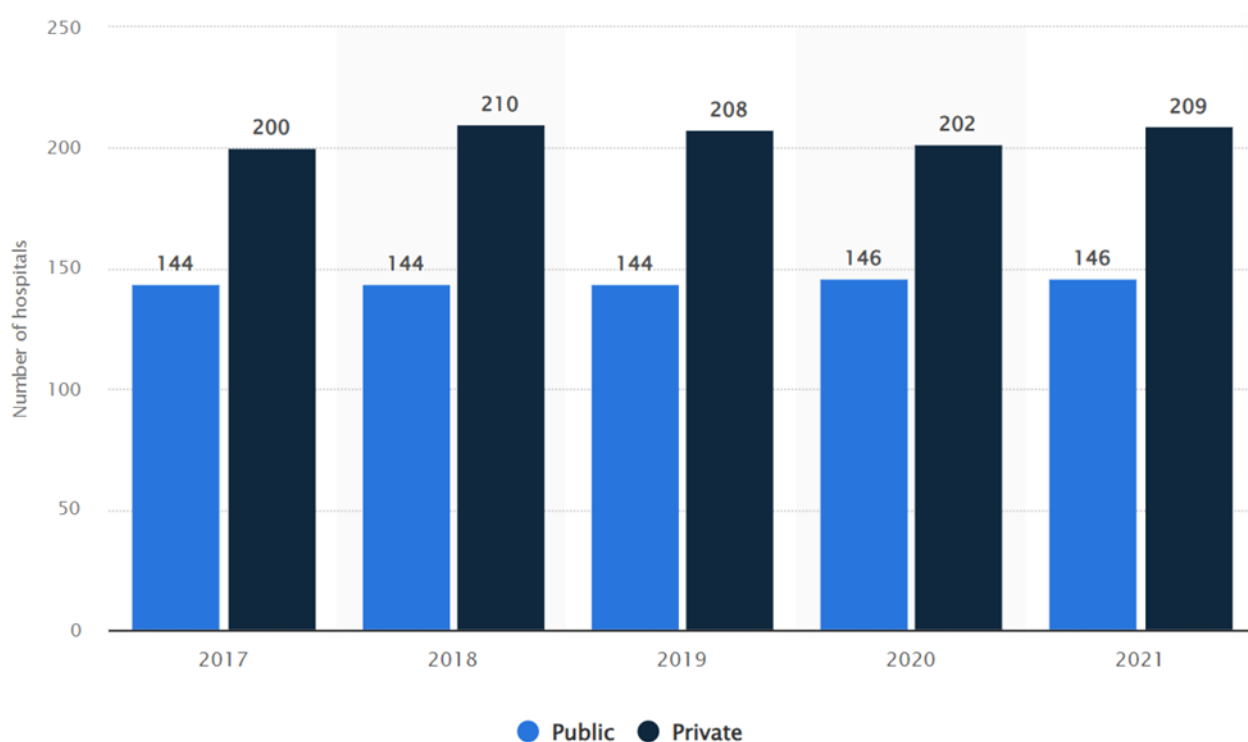
Health sector: health is no longer an orthodox card index system and the businesses are using modern electronic patient information systems for developing data management gains. However, the uptick in disparate digital local systems creates new difficulties to craft an integrated solution and maintain data security. Blockchain, as it turns out, provides an ideal solution by providing a secure and decentralized method for storing patient information. This will increase accessible information and mitigate local concerns about data security, a very valid concern given that adversarial attacks are rampant these days [3]. We then evolved these principles into Health Chain, a unified medical record system tailored to meet the Malaysian areas.

In order to alleviate these problems of healthcare data management, the researcher suggests Health Chain, a blockchain-backed medical record system. With Health Chain, data can be injected with an unprecedented level of encryption first before being placed on our secured infrastructure all to provide a complete interactive experience for patients providing them control over their medical information. Health Chain leverages blockchain technology to address these problems using decentralization and immutability, a solution for the common inefficiencies, limited distribution issues of traditional centralized medical record systems in Malaysia. This research paper will demonstrate the design, development and importance of Health-Chain for Malaysian healthcare area.

## 1.1 Background

### 1.1.1 Lack of standardization and its impact on efficiency

Regrettably, the healthcare data in Malaysia is very fragmented because of a centralized and decentralized delivery system that mixes public health facilities with an extensive set of private hospitals. Which has 209 private and 146 government hospitals as of the year 2021 [4], both usually using separate data management systems. This fragmentation, resulting from distinct data management systems across institutions, hinders efficient care coordination and directly impacts patient experiences. A key manifestation of this inefficiency is prolonged outpatient waiting times, with studies indicating average wait times of 1-2 hours, far exceeding patient tolerance levels [5]. McKinnon *et al.*, [6] report that wait times beyond 30 minutes significantly increase patient dissatisfaction. These extended waits, stemming from inefficient registration processes and the lack of standardized data exchange protocols, underscore the urgent need for systemic improvements in Malaysia's healthcare sector.



**Fig. 1.** Number of public and private hospitals in Malaysia from 2017 to 2021

The lack of standardized data exchange processes significantly contributes to these inefficiencies. Despite the implementation of Electronic Health Record (EHR) systems in 1999 to modernize record-keeping and facilitate information sharing [7], the healthcare data landscape in Malaysia remains fragmented. The Total Hospital Information System (THIS), while automating processes within individual hospitals, has not fully resolved inter-institutional data sharing challenges. Many hospitals continue to maintain parallel paper and electronic records [8] and policy restrictions limit data sharing between institutions. Consequently, patients often face redundant registration processes and repeated medical history inquiries during each visit, further extending wait times and compromising care continuity.

Recognizing these limitations, the Twelfth Malaysia Plan prioritizes the development and sharing of Electronic Medical Records (EMRs) [9]. This initiative aims to provide all hospitals with access to precise and uniform patient data. However, the lack of uniform data standards in existing information systems continues to impede effective information exchange and care coordination [10]. Moreover, inaccurate matching of patient records across facilities exacerbates these issues, with studies indicating that up to half of shared records are incorrectly linked [11]. This not only potentially compromises patient safety but also causes treatment delays. The implementation of standardized EMRs is thus crucial for facilitating seamless data exchange, eliminating redundant procedures, reducing waiting times and ultimately enhancing the overall quality of healthcare services in Malaysia.

### 1.1.2 Data breach risk and vulnerabilities in Malaysian healthcare systems

The nature of medical information being sensitive raises a significant concern about data breaches in Malaysian. There are millions of patients' records stored in different healthcare platforms. Therefore, there is a need for assured data protection practices on these platforms. In Malaysian context, data breach refers to wrong access, use or exposure of confidential health

information which compromises its privacy and security and may be possible threat to the affected individuals [12]. This definition aligns with other countries' definition such as that of the Department of Health and Human Services, among others. In Malaysia, Personal Data Protection Act 2010 [13]. This regulatory legislation protects personal data in commercial transactions and especially private and confidential data in health sectors. However, it has limitations concerning health specific issues, hence the need for a specialized regulation in Malaysia.

Health data breaches in Malaysian are increasing at an equal rate with the global trends. In a report from Fam [14], Malaysia was ranked 11th globally with cybersecurity vulnerability. The vulnerability aspect prominently came into the limelight when one Malaysian-based organization breached and exposed 1 million medical scan images of 20,000 patients in 2019. One of the leading firms in cybersecurity, Greenbone, discovered that some of the systems were not secure, allowing unauthorized access to such critical personal private data as X-rays, CT scans and MRI. A total of 24 million scanned records with persons' information such as names, DOB and medical information were exposed. Recently, in February 2023, there were reports about possible data leakages on MySejahtera app, which is Malaysian's Covid-19 vaccination and contact tracing platform. Approximated data of 3 million residents was leaked and this concerns how healthcare data is a susceptible area [15].

### *1.1.3 Limited patient data access rights and their implications*

Healthcare providers in Malaysia store patient information across various systems, including primary care facilities, specialist clinics and medical tracking platforms. Unfortunately, patients often lack control over the access and use of their personal data. The Total Hospital Information System (THIS), implemented in Malaysian public hospitals, aims to consolidate data within these institutions but falls short in two critical areas: patient access and interoperability with external healthcare systems. This limited access poses substantial challenges for patient care and data management. Uncertainty about where data is stored and for what it's being used may also lead some patients to withhold critical health information. The Khazanah Research Institute also notes that the fragmented nature of Malaysia's healthcare system, split between public and private sector providers is creating a major obstacle to any national e-health record platform. This fragmentation results in incomplete patient histories and potential test duplications, diminishing healthcare quality and efficiency [16].

Restricted patient access contradicts the Malaysian Medical Council guidelines, which advocate for patient comprehension, accuracy and control over medical records [17]. International studies show that patient access to medical records enhances understanding of illnesses and strengthens patient-doctor relationships [18]. This requires a collaborative effort by multiple stakeholders, namely healthcare professionals, policy makers, tech experts and patient representatives. Malaysia still faces major challenges in its health information systems with respect to integration, standardization and interoperability between public-private sectors up-to 2023 [16]. Priority agendas in Malaysia for data access need to incorporate concepts of data ownership, transparencies and user-friendly interfaces when developing and implementing healthcare solutions that are aligned with the world's best practices of health information management.

## *1.2 Aim*

The aim of this project is to investigate how blockchain technology can enhance the medical record system in Malaysia by developing a secure and decentralized medical records system.

### 1.3 Objective

- i. To develop a secure and decentralized blockchain-based medical records system.
- ii. To empower patients with control over their own health information securely.
- iii. To streamline administrative processes and reduce duplication of medical records.

## 2. Related Work

The healthcare system in Malaysia is often described as fragmented, which generates several problems in terms of data sharing, data security and patient privacy and autonomy. In practice, the above-mentioned issues manifest in low efficiency and substantial data security risk, which is a concern for patients who have restricted access to critical medical information. Luckily, the current advancement of blockchain technology allows the deployment of new secure decentralized data management solution that is applicable to patient records. This research study will critically evaluate the possibility to adopt blockchain technology to improve the decision-making process in the Malaysia healthcare sector and develop an innovative approach for decentralized secure data management, which will be referred to as “Health Chain”.

### 2.1 Current Challenges in Malaysia's Healthcare System

Datuk Dr Jacob Thomas aptly highlights the transformative potential of integrated public-private healthcare systems in Malaysia, which promise wider access to high-quality health information and enhanced economic competitiveness [19]. But achieving it relies on getting past an important barrier: fragmented, unsafe data sharing. This fragmentation creates inefficiencies, reduces continuity of care for the patients and has very significant privacy concerns. This finding is in line with analysis by the World Health Organization and suggests there has been little improvement to data-systems coordination to meet increased public demand for health information or resource duplication avoidance within Malaysia's pluralistic healthcare system [20]. The system proposed by Health Chain targets to reduce these gaps and links public and private healthcare institutions through a secure, interoperable platform with the capability of seamless data exchange.

Fulfilling the promise of integrated healthcare requires solving how public and private organizations securely exchange data from all parts of a person's journey. In such a scenario, deploying this technology is confusion with its inherent security and transparency that no one can tampered data without the acknowledged of every participant also make it to emerge as an obvious contender. Through the Health Chain platform built on blockchain technology, it can facilitate a secure and seamless data exchange that later result in better collaboration efforts amongst authorities leading to optimized resources usage at the end of the day providing an improved healthcare experience for all Malaysians.

***Key Takeaway:** Malaysia's healthcare system faces significant challenges in data integration and security, presenting opportunities for blockchain-based solutions.*

### 2.2 Security and Privacy Issues in Malaysia's Current Healthcare System

In the case of health data privacy management, they are neither synonyms nor means to justify each other. Privacy: Defines who can access private info and under which circumstances [21]. Confidentiality is “the property that data or information are not made available or disclosed to

unauthorized persons, entities, through unauthorized channels and mechanisms” [22]. Security refers to technical measures protecting data from unauthorized access, modification or misuse [23]. This forms a certainly important argument when it comes to developing holistic data protection strategies for healthcare systems.

These are crucial in the context of a Malaysian healthcare system that is moving towards digital medical records. Cyberattack is on the rise in various sectors of which healthcare has the most records and identities are stolen, making it a danger to data integrity and security in Asia-Pacific. More recent surveys have underscored Malaysian patients' apprehension that unnecessary protection of their medical notes and potential unauthorized access. A study from 2018 showed that up to 59% of Malaysian were worried by their data could be used without consent implying lack of trust had gone unchecked [24]. This reflects the increasing importance of strong data protection in Malaysia healthcare. It is important to address these concerns if we are ever going to build trust and ensure the safety of patients. If we are to achieve this goal, the health system must give immediate priority to adopting high levels of security, openness in handling data and power for all people over their own information. The Health Chain system will theoretically address these problems by providing patients with control of their medical data using the security features native to blockchain.

***Key Takeaway:** Malaysia's healthcare system faces significant challenges in data security and privacy, necessitating innovative solutions that prioritize patient trust and data control.*

### 2.3 Data Security Concept of Blockchain

The centralized approach of existing healthcare data management systems in Malaysia makes the patient information at risk from issues concerning security, such as breaches, tampering and unauthorized access. Blockchain technology brings a novel concept in the form of decentralization with secureness along trustable and transparency nature for health data security protocols [25]. Fundamentally, blockchain works as a kind of decentralized database (i.e. distributed ledger system) or shared record book that exists on multiple machines. In the context of healthcare, each transaction represents patient data permanently recorded within a block on this ledger. The key security feature lies in the interconnection of these blocks, each block references the preceding one, forming an immutable chain [26]. It is particularly applicable as a structure to isolate sensitive medical data in Malaysia's healthcare system. It is this quality which lies at the very heart of blockchain security and why blockchains are such a strong potential solution for keeping Malaysian medical records safe. The only way to change it would be for most of the system of uncertain amount which must necessarily have been engaging maliciously.

Additionally, every block is cryptographically hashed creating a unique ID or digital fingerprint. This feature allows authorized parties to verify that the data is authentic and has not been tampered with. What this means in the healthcare context of Malaysia is that any unauthorized modification to patient records, can be easily identified and subsequently promoting trust and accountability. The alternative to immutability and transparency that blockchain provides is granular access control. Authorization to share any of this patient data could be implemented using cryptographic keys. In Malaysia healthcare system, this feature is important as it will encrypt the information which can only be decrypted and utilized by people that have a valid key (Figure 2) [27].



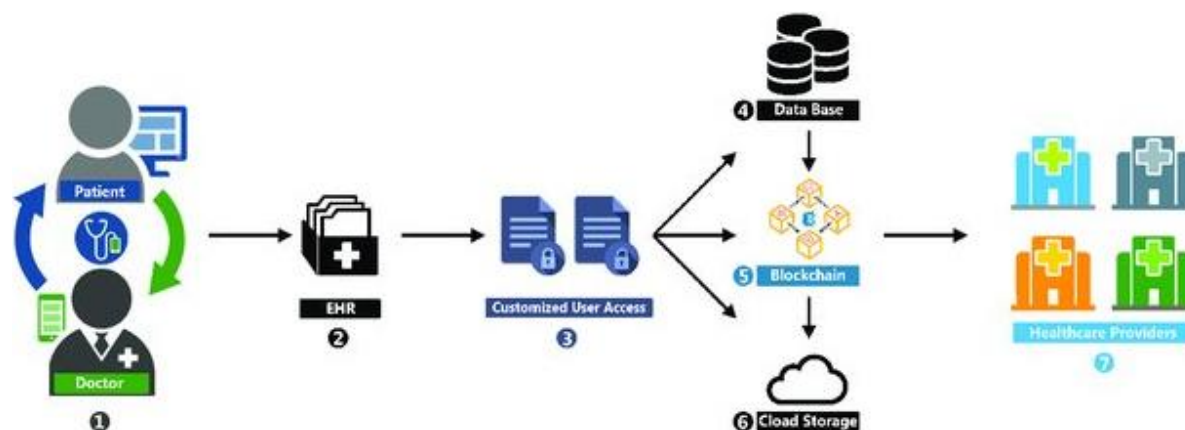


Fig. 2. Healthcare data management in blockchain

These features of blockchain technology highlight its potential in addressing diverse healthcare data security challenges in Malaysia. With Health Chain system we revolutionize the security of data with blockchain which is decentralized, immutable and transparent. Health Chain provides a cryptography key-based access security for protecting sophisticated health care data in the Malaysian healthcare system, thus ensuring prevention from unauthorized information disclosure. The Health Chain system requires further exploration and implementation, but it stands as an interesting model in deployment to make the digital healthcare ecosystem everywhere both secure and reliable.

**Key Takeaway:** Health data sharing in Malaysia could be made much more secure and efficient with blockchain technology.

#### 2.4 Importance of Data Standardization in Malaysian Healthcare

Healthcare data management has come a long way in Malaysia, shifting from stacks of labour-intensive card indexes to its digital iteration. Though this has greatly enhanced health data availability and retrieval, it also uncovered an important problem; the non-standardized nature in which data are kept by Malaysian healthcare institutions. Mismatch of data standards in the Malaysian healthcare system could cause inaccuracies, patient misidentification and lead to inefficient workflows that ultimately can affect quality care provision. One of the ways to tackle these challenges is by learning about medical standards and this article intends to explain data standards in healthcare. These standards include a diverse set of rules, classification and guidelines that aim at ensuring the effective flow of healthcare service delivery in Malaysia through proper data collection, sharing storage and retrieval as well from medical to radiology image up until administrative related information [27].

In Malaysia, where people may require medical attention in various settings, patients seek medical attention from public hospitals and, after discharge or referral, from private clinics offering low-cost professional treatment followed by consultations in a specialized imaging centre before being finally referred for an operating session at a major hospital. Each encounter would record required information on the patient's electronic health record system creates enormous amounts of digital documentation including but not limited to doctors' information related to patients, test results, as well as notes from discharge. For optimal outcomes, accurate information must be provided to every provider with a standard operational format in compliance with access procedures that allow seamless transfer from one provider to another without corruption of data facilitating patient information flow [28]. This ability to share information between entities without corruption of data or modification of system integrity is known as interoperability. In the Malaysian setting,

interoperability helps Malaysians, their families and teams to conduct better research on medical responses and look ahead to their next consultation or treatment.

Data standardization in healthcare offers benefits that extend beyond clinical care, significantly enhancing clinical research capabilities [29]. In the Malaysian context, standardization improves data quality by ensuring uniformity and precision, enabling researchers to conduct more reliable studies and draw robust conclusions. This approach minimizes inconsistencies and misinterpretations arising from varied formats or terminologies. Furthermore, it facilitates data integration and reuse, allowing Malaysian researchers to combine information from multiple sources without compatibility issues. This promotes collaboration and information exchange among scientists, leading to a more comprehensive understanding of healthcare challenges specific to Malaysia. Standardized data also optimizes software tool utilization, enabling Malaysian researchers to leverage specialized analytical tools more effectively. This efficiency results in faster, more insightful research outcomes relevant to the Malaysian healthcare landscape. The clarity and consistency of standardized data enhance team communication, allowing Malaysian researchers and healthcare professionals to collaborate more efficiently.

A study highlighted that standardized systems provide secure real-time information retrieval with superior interoperability, maintainability and scalability compared to traditional paper-based systems [16]. For Malaysian hospitals and healthcare providers, this leads to increased efficiency and effectiveness, enabling them to share a common data infrastructure for various purposes. Ultimately, data standardization paves the way for a patient-centred, data-driven healthcare ecosystem in Malaysia, meeting diverse data collection and reporting needs more effectively.

***Key Takeaway:** Data standardization transforms Malaysian healthcare through improved data exchange, research and patient-centricity.*

## *2.5 Applications and Implications of Blockchain Technology in Malaysian Healthcare*

Blockchain technology is transforming the healthcare industry and Malaysia's one of them. With its pioneering method, it provides answers to urgent problems in the healthcare scene of Malaysia removing itself from centralized systems with a decentralized secure and transparent landscape. For instance, in Malaysia, where it is crucial to ensure the authenticity of medicines during emergencies and such emergency again cause disarray among digital healthcare apps. Blockchain as an inherently immutable infrastructure can help keep drug producers to patients chain safe, ensuring the legitimacy of drugs preventing counterfeit drugs and enhance patient safety in Malaysia healthcare ecosystem.

In the Malaysian context, blockchain facilitates secure information sharing among healthcare stakeholders. Unlike traditional isolated systems, blockchain enables Malaysian patients to control their health data [30], allowing them to share electronic health records (EHRs) with authorized providers easily. This could significantly improve care coordination and reduce administrative burdens in Malaysian healthcare institutions. Beyond patient data management, blockchain can streamline insurance claims processing in Malaysia's healthcare system, enabling faster and more transparent procedures.

The suitability of blockchain for healthcare data management in Malaysia stems from its inherent characteristics [31]. Its decentralized nature could enhance the resilience and security of Malaysia's healthcare data systems. The immutability of blockchain ensures data integrity, crucial for maintaining the credibility of health information in Malaysia. Furthermore, data provenance allows for clear tracking of data origins and modifications, promoting transparency and accountability in the Malaysian healthcare sector.



While MedRec and MedBlock can be seen as examples of how blockchain could be used in healthcare globally [32,33] around the world this has not been done in Malaysia. These could be related to targeting the specialized issues confronted by our healthcare system, for example, access which is more uneven in rural and urban areas or coordination between public and private providers. Initiatives like this would go a long way in ensuring Malaysia has an environment which are secure, transparent and patient-centred healthcare provision.

***Key Takeaway:** Blockchain technology offers transformative potential for Malaysian healthcare through enhanced security, patient empowerment and system efficiency.*

The fragmented state of medical records in Malaysia presents a challenge that is not exclusive to this country. Similar issues of ineffective information exchange, breaches of data security and restricted patient control are faced by healthcare systems worldwide. Fortunately, a few initiatives have surfaced both globally and within Malaysia itself, aiming to tackle these challenges by employing various methods, one of which is blockchain technology.

## 2.6 Global Initiatives

### 2.6.1 Medicalchain

Medicalchain is a pioneering patient-controlled platform that enables individuals to manage and share their medical records across healthcare institutions globally [34]. By leveraging blockchain, Medicalchain ensures data ownership and robust access control mechanisms [35], aligning with the core principles of Health Chain. However, Medicalchain's primary focus on individual record management may limit its integration with existing healthcare systems in different countries, including Malaysia.

### 2.6.2 MedRec

Similar to Medicalchain, MedRec has developed a blockchain-based medical record solution that emphasizes data ownership and secure sharing, aligning with the Health Chain philosophy [32,36]. While MedRec offers robust security features, its limited scope may hinder widespread adoption within national healthcare infrastructures like Malaysia's [32]. Customizing the solution to the specific requirements of the Malaysian healthcare landscape through further investigation and collaboration with local stakeholders is crucial [37].

## 2.7 Local Initiatives

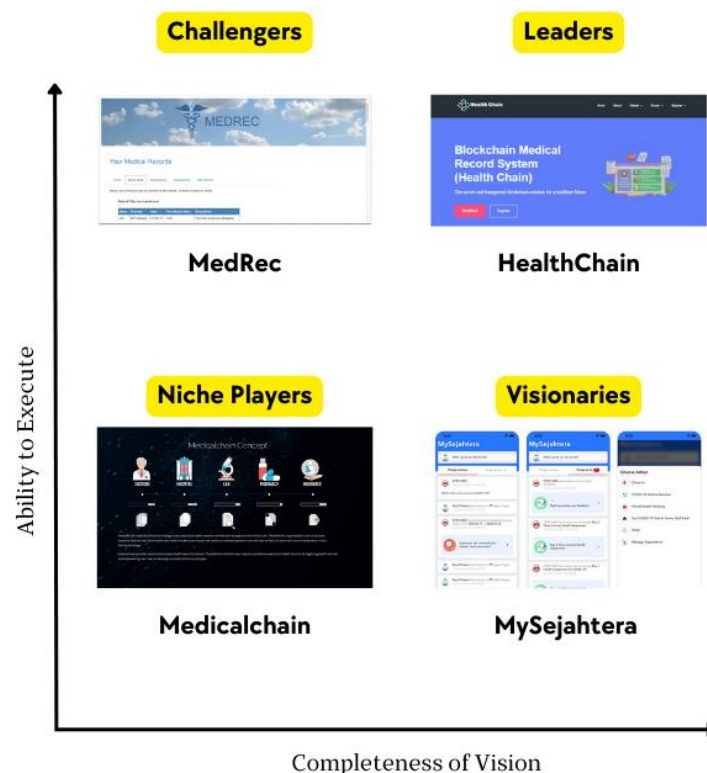
Healthcare sector seems to be the most lagging behind in adopting blockchain technology although Malaysia has already been taking steps for utilizing this industry. The MySejahtera mobile app has been effectively applied and the blockchain technology is adopted for issuing stable COVID-19 vaccination certificates [38]; indicating that this application can provide certain important advantages. However, MySejahtera also raises concerns about the limited application of blockchain, data privacy and inclusivity [39]. While there are obstacles, the story of MySejahtera is a good example that blockchain can indeed work to protect data blocks even if it means retrofitting existing systems. Moving forward, the top three priorities are to secure data properly, extend use cases far beyond Covid-19 applications seen early on and make sure that any ecosystem is inclusive enough to realize blockchain's full potential for making healthcare safer, more efficient and fairer in Malaysia.

The selling of MySejahtera to a private company followed by the data privacy concerns form examples that illustrate the crucial role strict data protection in healthcare applications [42]. The

solution to all these problems comes in the form of Blockchain technology with its intrinsic nature and inherent immutability decentralized process is a way out. When used to store health data on a secure, distributed ledger, blockchain can dramatically reduce the risks of storing that many sensitive personal information in a centralized location where if unauthorized access occurs or worse tampering it will be truly disastrous. In addition, blockchain-based protocols which include inherent transparency and privacy-preserving mechanisms can give patients control of their data as well as the ability to enable responsible governance rights.

### 2.8 Differentiating Health Chain

In its endeavour to revolutionize the Malaysian healthcare landscape, the Health Chain project aims to enhance operational efficiency, reinforce data security and empower patients while confronting significant challenges. As shown in Figure 3, the Health Chain project positions itself to address these goals, differentiating itself from related initiatives. By introducing a user-friendly web application, the Health Chain project strives to expedite healthcare processes, optimizing patient interactions and minimizing registration delays. The incorporation of a secure digital ledger ensures streamlined access to medical records, potentially reducing treatment waiting times by up to two weeks and enhancing the overall patient experience.



**Fig. 3.** Market positioning of related work and Health Chain

Furthermore, the Health Chain project goes beyond efficiency, proactively addressing security and privacy concerns within the healthcare system. The project uses blockchain technology to create an immutable transaction log which prevents fraud and unauthorized access. Since blockchain is decentralized, medical records stored using this technology can never be hacked and are much less likely to fall into the wrong hand as opposed to traditional data storage. Additionally, the implementation of anonymization and controlled access mechanisms further strengthens privacy safeguards, surpassing the capabilities of traditional computer systems. This project is thus driven by

a vision to empower patients, allowing them to take control of their health data and ultimately provide better patient-practitioner relationships. Empower patients and give them control of their health data to enhance relationships between patient and health provider.

Health Chain is a transformative catalyst for the Malaysian healthcare landscape and it builds on existing mechanisms to overcome their limitations by upping its deliverables. The project also plans to develop use cases beyond what the COVID-19 pandemic allows for. Understanding the concerns surrounding data management and usage, one of the core objectives behind Health Chain Project is to enforce sound data security practices which can only add in building reliability while harnessing blockchain technology in a responsible manner. In addition, there is an overarching commitment to inclusivity in this project that meets a wide range of access needs and potential analogue solutions for those who do not have online capabilities. By ensuring its seamless integration with the existing healthcare infrastructure, Health Chain paves a path that reduces any disruption by giving way to easier adoption leading towards an efficient and inclusive Healthcare System in Malaysia.

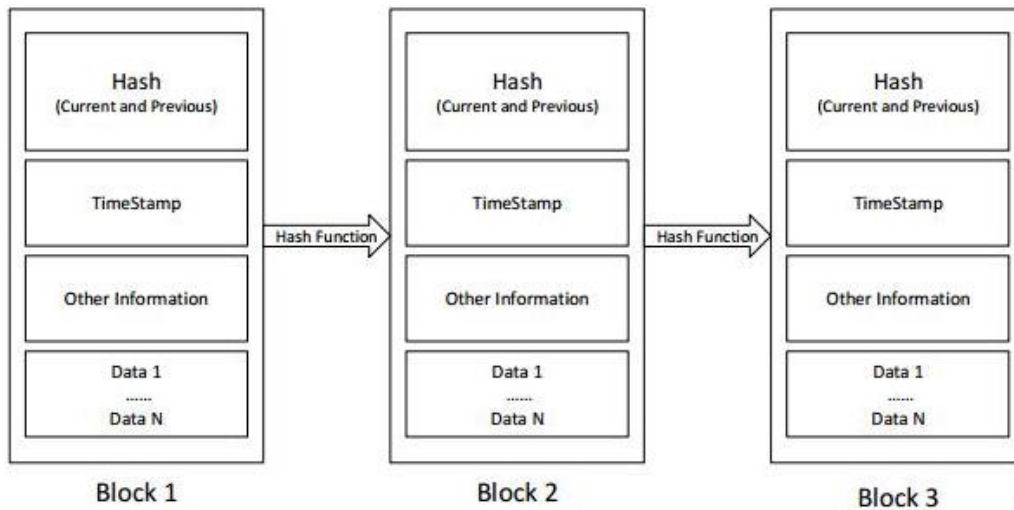
### 3. Methodology

Current approaches for healthcare record management, paper-based systems, decentralized Hospital Information System (HIS) and Electronic Health Records have problems of data security control it is under the public health system authority. In this work, the study explores a system capable of surmounting these barriers by integrating a robust and decentralized blockchain-based electronic medical records (EMR) system.

Ultimately what motivated us to choose blockchain was its underlying properties, that lent itself well for the problems faced by traditional healthcare record keeping methods. The blockchain data is immutable and tamper-proof, which means medical records are reliable to access without a breach or manipulation. Distributed ledger technology: data is held throughout the network of computers ensuring that no access point will break the system and dispersing risk in case a part of the blockchain infrastructure fails. In addition, the transparency of blockchain builds trust and accountability between patients, health care services users and entities as each transaction can be publicly verified. Finally, this means securing automated smart contracts that limit who can retrieve certain data to only those which allow otherwise predetermined patient permissions, giving patients the right to manage their own information.

#### 3.1 Blockchain Architecture

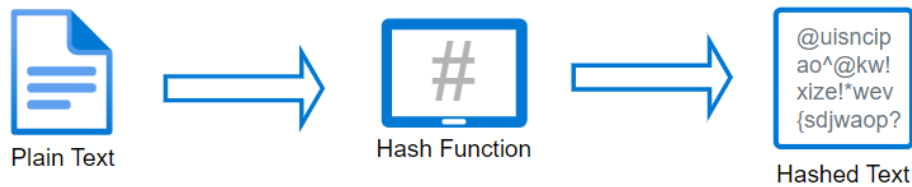
The Health Chain project is built upon a resilient blockchain framework, where patient data is not merely stored, but intricately integrated into a complex system of security and immutability. Conceptually, the blockchain can be visualized as a chain composed of information blocks, rather than metallic links. Each block contains not only patient data, but also timestamps and a unique identifier known as a hash. This hash serves as a distinctive fingerprint, ensuring that any modification to the data within the block is instantly detectable. This structure, referred to as a linked list, establishes an immutable chain, where every block is linked to the preceding one, making it nearly impossible to tamper with the data without affecting the entire chain (Figure 4) [40].



**Fig. 4.** Blockchain architecture

As illustrated in Figure 5, the heightened security of the Health Chain project is derived from the power of cryptographic hashing [41]. This complex mathematical function generates a unique hash for each block of data within the blockchain. Any modification to the data, no matter how minor, would result in an entirely different hash, immediately triggering alerts. So, this is a critical mechanism to ensure data integrity and provenance of the patient throughout healthcare ecosystem.

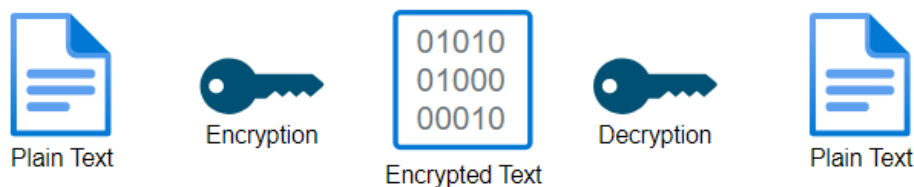
### Hashing Algorithm



**Fig. 5.** Hashing algorithm

Figure 6 gives a process of how encryption works by changing plaintext to ciphertext with an original one-time secret key which can be decrypted back into the simple text using a one-of-a-kind private decryption keyword results that data will always maintain safe during transmission and storage.

### Encryption and Decryption



**Fig. 6.** Encryption and decryption

In addition to the aspect of security, there is a decentralized function, where Health Chain does not reside in any one single location, but its relevant data are with each node. This removes the central system vulnerability by making it tougher for hackers to access the complete chain. Encryption here is like securing each node with a secret key, making sure the data inside is intact. The

information can only be decrypted and accessed by the proper key, thus protecting patient privacy and confidentiality.

### *3.2 Understanding the Health Chain: Data Journey and Security Mechanisms*

The amalgamation of blockchain architecture, cryptographic hashing, decentralization and encryption engenders an impregnable fortress safeguarding patient data. Initially, robust algorithms and the user's private key, concealed within an impenetrable layer of encryption, render the data unreadable to unauthorized parties. Meticulously recorded timestamps chronicle each step, creating an immutable timeline. This encrypted data, combined with other crucial information, constitutes a new block. A unique fingerprint, known as the hash, serves as an indelible identifier for the block. Subsequently, this block undergoes a rigorous validation process, wherein miners solve complex puzzles to earn its place within the ever-expanding chain. Successful completion of this process grants the block a permanent position, forever linked to its predecessors, thus forming an unalterable record. Lastly, the implementation of "smart contracts," self-executing agreements, empowers patients to grant specific access rights. Only individuals possessing the corresponding private keys can unlock the encrypted information.

As illustrated in Figure 7, the aforementioned concepts and methodologies have been effectively executed, serving as a clear indication that the security architecture of the system is both strong and resilient, in line with the prescribed methodologies. Consequently, it ensures the utmost integrity and confidentiality of patient data. The journey of data within The Health Chain epitomizes a powerful symbiosis of technology. Each stage, from encryption through private keys to access authorization via smart contracts, harnesses the advantages of blockchain architecture, cryptographic hashing, decentralization and encryption. This culmination fosters an impregnable fortress that protects patient data, while empowering individuals and fostering trust within the healthcare ecosystem. It serves as a testament to the transformative potential of blockchain, opening the path towards an exceptionally secure, patient-centric and collaborative future for healthcare. The meticulously designed data journey of the Health Chain promotes an "impregnable security," whereas conventional methods like paper records, EHRs and HIS often encounter difficulties in ensuring security.





autonomy. The transparent and verifiable audit trail of all transactions also provides superior auditability compared to the limited traceability of traditional systems. Lastly, the scalable and distributed design of the Health Chain addresses the scalability limitations inherent in centralized data storage and paper-based records.

#### 4. Results

Table 2 showcases the key findings from evaluating Health Chain, a pioneering healthcare system utilizing blockchain technology. The evaluation focused on three main objectives: developing a secure and decentralized system, empowering patients with data control and optimizing processes to reduce duplication.

**Table 2**  
Health chain evaluation results

Objective	Measurement Criteria	User Satisfaction (Health Chain UAT, %)	Health Chain System Results	Previous Work Results
Develop secure and decentralized system	<i>Security</i>			
	User confidence in data security	62% high confidence in data security	N/A	MedRec: High confidence [42] MySejahtera: 38% confidence [43]
	Data discrepancies with traditional records	N/A	98.9% accuracy compared to traditional methods	MedRec: Reduced by 45% [44,45]
	Number of successful data retrievals	N/A	99.9% success rate in simulated user retrieval attempts	MedRec: Agreed possessed more accurate data [46]
	Security in data storage and transmission	N/A	Cryptographic algorithms (AES for encryption and SHA-256 for hashing)	MedRec: Cryptographic algorithms [32] MedicalChain: Cryptographic algorithms MySejahtera: Hyperledger Fabric [47]
	Type of Blockchain	N/A	Public	MedRec: Public MedicalChain: Consortium [48] MySejahtera: Public
Blockchain platform	N/A	Ethereum	MedRec: Ethereum MedicalChain: Hyperledger Fabric, Ethereum (for token) [48] MySejahtera: Hyperledger Fabric	

<i>Performance</i>				
	Average system response time	N/A	Average 2 seconds	MedRec: Average 30 to 60 seconds [46]
	Transaction processing speed (e.g., data inserted, data updated)	N/A	Average 12 seconds	MedicalChain: Average 11.6 seconds [49]
<i>Interoperability</i>				
	Successful data exchange attempts with different devices	N/A	High success rate in data exchange attempts between devices used for testing	MedRec: Limited data exchange with other hospitals and community pharmacies [45]
<i>Privacy</i>				
	User satisfaction with data privacy controls	98.9% of users reported feeling comfortable and in control of their data access settings	N/A	MedRec: Positive feedback and satisfying for managing patient medication data [50] MySejahtera: Likely negative satisfied due to data leakage [39]
	Number of user-initiated data access requests (granted/denied)	N/A	Data access requests are frequent, averaging 5 per user in a day	N/A
<i>Data control</i>				
Empower patients with data control	User satisfaction with ease of data management	85% of users found data management tasks (viewing, sharing) easy and intuitive	N/A	MedRec: 64 % of users agreed MedRec improves patient care [46] MySejahtera: 77% perceived ease of use
	Completion rate of data management tasks (e.g., viewing, sharing)	N/A	98.9% completion rate for common data management tasks (e.g., viewing medical records, sharing with providers)	
<i>Data auditability</i>				
	User satisfaction with data audit log functionality	98.9% of users reported using the audit log to track their data access	N/A	N/A
	Access attempts logged and categorized (authorized/unauthorized)	N/A	All access attempts logged and categorized as authorized or unauthorized based on user permissions	N/A

Streamline processes and reduce duplication	<i>Administrative efficiency</i>			
	Number of administrative tasks streamlined	N/A	5 administrative tasks streamlined, including registration and other data entry	MedRec: Pharmacists acknowledge improved accuracy and safety [45]
	Reduction in time spent on manual data entry/record management	N/A	75% reduction in time spent on manual data entry by healthcare providers	MedRec: 69% reported ease of use shortens the time [46]
<i>Reduced Errors</i>				
	Data accuracy and consistency	98.9% data accuracy	N/A	MedRec: 95% accuracy rate [46]

#### 4.1 Objective 1: To Develop a Secure and Decentralized System

Health Chain users exhibited a high degree of confidence in data security, with 62% expressing high confidence levels, surpassing MedRec (45%) and MySejahtera (38%). An impressive 98.9% of users felt comfortable managing their data access settings, demonstrating strong user empowerment. Utilizing cryptographic algorithms and a public blockchain architecture, Health Chain ensures robust security compared to traditional systems. It achieved an average response time of 2 seconds, significantly outpacing MedRec (30-60 seconds) and MedicalChain (11.6 seconds). Additionally, while data on transaction processing speed is limited, Health Chain achieved high success rates in data exchange between various devices, outperforming the limited interoperability of MedRec.

#### 4.2 Objective 2: To Empower Patients with Data Control

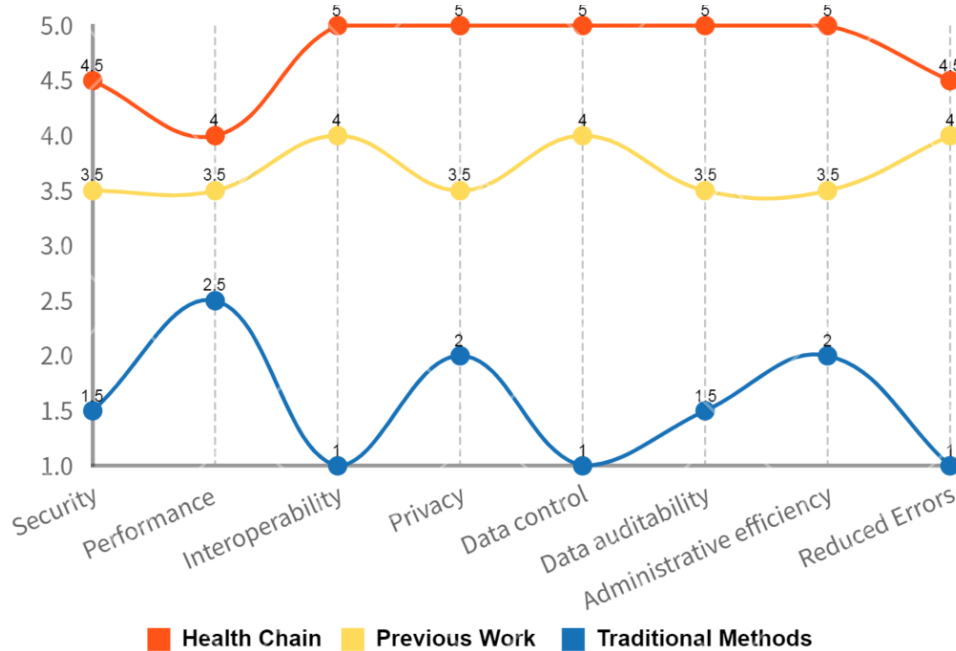
User satisfaction with data management ease reached 85%, with 98.9% successfully completing common tasks like viewing and sharing records. A notable 98.9% of users utilized the data audit log, indicating high user engagement in data tracking. Unfortunately, there is no comparable data from previous work, emphasizing Health Chain’s focus on user control and transparency.

#### 4.3 Objective 3: To Streamline Processes and Reduce Duplication

Health Chain has streamlined five administrative tasks, reducing manual data entry time for healthcare providers by 75%. Despite previous improvements, Health Chain excels in optimizing processes. Furthermore, Health Chain’s user-reported data accuracy is 98.9%, compared to MedRec’s 95%, potentially reducing errors and improving healthcare quality.

This evaluation, incorporating research data from previous work and results from system testing and user acceptance testing (UAT) of Health Chain, highlights the system’s significant potential. Health Chain exhibits notable enhancements in data accuracy (98.9% vs. MedRec’s 95%), user confidence in data security (62% high confidence vs. MedRec’s 45%) and ease of data management (85% finding tasks easy vs. MedRec’s 64% agreeing on improved care). These findings suggest that Health Chain could enable patients (e.g., with 5 data access requests per user per day), streamline processes (e.g., 75% reduction in manual data entry) and reduce errors. Further research with comparable methodologies is needed for definitive comparisons. Nonetheless, Health Chain’s user-

centric approach and promising initial results indicate its potential for widespread adoption and a positive impact on the healthcare landscape.



**Fig. 8.** User perspective on evaluating healthcare systems

The questionnaire-based evaluations explored user perspectives on various aspects of healthcare systems, including security, performance, interoperability, data control and efficiency. These assessments painted a promising picture for Health Chain, particularly when compared to previous work and traditional methods. Notably, Health Chain received the highest average rating of 5 for security and privacy, significantly outperforming other alternatives. This high level of user confidence can be attributed to the system's decentralized architecture and robust cryptographic protocols for data protection. Furthermore, users highly valued Health Chain's data control and auditability features, as evidenced by ratings exceeding 4.5. This suggests that Health Chain empowers users by granting them clear ownership and oversight over their healthcare data. Additionally, users perceived improvements in process efficiency and error reduction, suggesting the potential for streamlined workflows and enhanced data accuracy.

However, it is important to recognize that user perceptions, though valuable, may not necessarily align with actual performance. Therefore, conducting extensive objective testing is crucial to ensure a comprehensive evaluation. Additionally, detailed comparisons with specific "previous work" systems would provide valuable context. Despite these limitations, the positive user response towards Health Chain, along with its promising initial system testing results, justifies further exploration. While real-world deployment and testing will provide the most accurate data, these preliminary findings tentatively suggest Health Chain could potentially address some of the challenges currently faced in the Malaysian healthcare landscape, particularly in remote areas [51].

## 5. Discussion

The proposed Health Chain system leverages blockchain technology to offer numerous advantages in terms of data security, patient empowerment and healthcare efficiency. The system allows the trust and data privacy of patients to make it impossible for anyone authorized by them their medical records safe from back. In addition, patients have control of their own health data and

are involved in medical decisions helping them lead healthier lives. In turn, users access streamlined processes for managing records and sharing them securely improve the efficiency of healthcare provision in areas such as patient care pathways into hospitals with reduced waiting times and costs leading to an improved end-to-end experience.

However, certain limitations must be addressed for wider adoption and optimal impact. The current system's inability to store various medical documents, such as images and scans, obstructs comprehensive patient care and diagnosis. Integrating the Interplanetary File System (IPFS) would enable secure storage and access to diverse medical files, rectifying this limitation [8]. This research has also been limited to managing medical records and not more extensive healthcare workflows such as appointment scheduling, telemedicine or payment systems. Broadening this to cover more services would create an all-in-one healthcare experience for patients and providers alike.

Accessibility limitations present another challenge, as the system's dependence on the MetaMask extension may limit user reach due to browser compatibility issues. Developing a dedicated mobile application compatible with various platforms would significantly enhance accessibility and user experience. Additionally, the system's reliance on patient account creation and login could pose difficulties in emergency situations where immediate access to medical information is essential. Implementing alternative authentication methods, such as biometric verification or granting temporary access to authorized healthcare providers in emergencies would ensure timely access to critical patient data.

Looking ahead, several exciting enhancements hold the potential to further optimize the Health Chain system and revolutionize healthcare management. With the Interplanetary File System (IPFS) integrated, you could safely store and effectively manage different medical documents in one place letting healthcare data find light like this via a consistent depository. Faster and economical handling of documents. This would eliminate the need for physical document storage or retrieval, reducing costs in this process increasing convenience to both patients as well provider. Furthermore, if Health Chain were to scale into a standalone healthcare platform with features like appointment scheduling, telemedicine and payment services it would offer users an added layer of streamlined improvement convenience of user experience in obtaining all health care services as one station which sought to streamline the processes for its consumers and increase access.

A mobile application to ensure medical records could be accessed on the go, anywhere and anytime would extend it into convenience with expanded outreach of users considering patient or user with a smart phone. In conclusion, a biometric authentication implementation on the mobile app would increase security and enable user experience. Finally, implementing solutions like emergency access mechanisms or alternative authentication methods would address the challenge of accessing patient data in critical situations, ensuring prompt medical attention when needed.

The Health Chain proves to have a great promise in boosting performance, securing data and empowering patients as it was designed for. By addressing the limitations identified and incorporating proposed enhancements will make this system more potent, contributing to real patient-centred, efficient healthcare getting at Malaysia.

## 6. Conclusion

The Health Chain project is a novel approach using blockchain technology to support secure management of medical records. The project is pioneering in nature and much needed to address Goal 3 of the Sustainable Development Goals: Good Health and Well Being. The Health Chain system truly sets the stage for a healthier, more sustainable future by providing stronger data protection to empower patients and improve healthcare productivity. The Health Chain stands to revolutionise

medical record management by providing patients with more control and accessibility of their data, giving them a greater say in the health decisions that impact their lives. With uncompromising security and confidentiality levels, any patient data remains private. The global adoption of Health Chain can improve overall quality care by promoting patient-provider trust and collaboration, leading to significant improvements within the industry.

The research question on blockchain technology with a focus to deliver transformative use of medical record management in Malaysia is successfully addressed by using Health Chain system as the ultimate secure, user-friendly and health information transfer able based Blockchain application platform. You can bet that the patient stands to benefit greatly from this paradigm shift, enjoying greater ownership and access of their personal medical records. This means improved health care decision making and treatment plans cater to each need. In addition, healthcare providers especially doctors will save considerable time via efficient Medical Records and Management processes. As described earlier, the Health Chain system runs on top of Ethereum blockchain and then there is a faith in transparent data storage carried out with adequate security measures so that it cannot be modified. In addition, a user-friendly interface can be adapted for patients and medical staff to access records quickly as well as for easy registration and feedback functionality.

The Health Chain system has some praiseworthy accomplishments, although limitations and defects need more inquiry and investigation to be solved. Currently, there is no way to upload all types of medical data, for example photos or videos, which requires the integration with IPFS (Interplanetary File System) in order give support for safe and centralised storage of several kinds of health information. More broadly, the system could add coordinates to key healthcare functionality such as payment systems and appointment scheduling enabling a faster unified user experience. In addition, the MetaMask browser extension is also a serious accessibility limitation of current system version that it should be improved to either make compatible with other web browsers or develop an independent mobile app to reach more users.

In summary, this is one of the most potential projects to deploy blockchain technology in healthcare management and thus enable patients by providing them with better access to overall health care. Nevertheless, more research and development are required to overcome said limitations and gaps before such a healthcare solution could be conducive for all. With diligent work and cooperation, Health Chain can improve lives in a sustainable way, helping us move towards a future where patients have more control over their own health while healthcare is optimised to create maximum net benefit for all.

## Acknowledgement

This project was support and funding from Asia Pacific University of Technology and Innovation. This project received the Best Final Year Project Award from BP (British Petroleum) Business Service Centre Asia SDN BHD.

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