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DIGITIZING HEALTHCARE – RISKS AND OPPORTUNITIES OF BLOCKCHAIN IN THE HEALTHCARE SYSTEM

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ABSTRACT

New emerging technologies such as artificial intelligence, big data, or blockchain technology have seen increased interest throughout many different sectors in recent years. Especially in the light of digitalization, the healthcare sector is one of the prime use cases for new technological innovation. In countries like Germany for example, where current the degree of digitalization is comparably low and the health-related expenses are high, much hope is placed into new emerging technologies and automatization. But despite every potential, increased digitalization, and the implementation of new technologies could provide, there are still limitations. Particularly from an ethical perspective, serious concerns and questions need to be considered.

This paper explores the risks and opportunities of blockchain technology in the healthcare system. Specifically, it focuses on current (technical and non-technical) limitations of the implementation of blockchain technology in current systems, possible use cases, and ethical concerns arising due to an increased level of digitalization and the use of blockchain technology. In this context, blockchain technology refers to a distributed ledger, where certain data (e.g., transactions) is stored in blocks, that are cryptographically secured and chained together. In comparison to traditional databases, there is no central form of storage. Participants of the blockchain network (e.g., nodes) all store an exact copy of the ledger, containing the whole data history, eliminating a single point of failure. Before an additional block containing new data can be added to the chain, the participants of the network have to reach consensus. As soon as the new block is validated by the majority of participants, it is added to the chain permanently.

To address the key research questions focusing on possible limitations, use cases, and ethical considerations due to an implementation of blockchain technology in the healthcare system, extensive literature research was conducted. Due to the more transparent, decentralized, and trustless architecture, the results identified promising use cases and significant advantages of blockchain technology in the healthcare system. But despite every potential, there are still limitations. The results indicate a clear lack of ethical guidelines and frameworks, as well as important

ethical considerations and questions, related to the digitalization and the implementation of new technological innovations in the healthcare system.

The results suggest that the implementation of blockchain technology in the healthcare system could provide significant advantages over current solutions. Even today, it could provide major benefits for every participant of the system and especially the patients. Still, there are a couple of technical and non-technical limitations that need to be addressed in the near future to benefit from new technology innovations like blockchain technology. Besides extensive user education, a change of mind needs to happen in society and especially on a governmental level. Especially from an ethical perspective, new guidelines and frameworks need to be established to provide the necessary environment to implement and use blockchain technology as well as other innovations successfully.

Keywords: blockchain, healthcare, medicine, digitalization, technology, ethics

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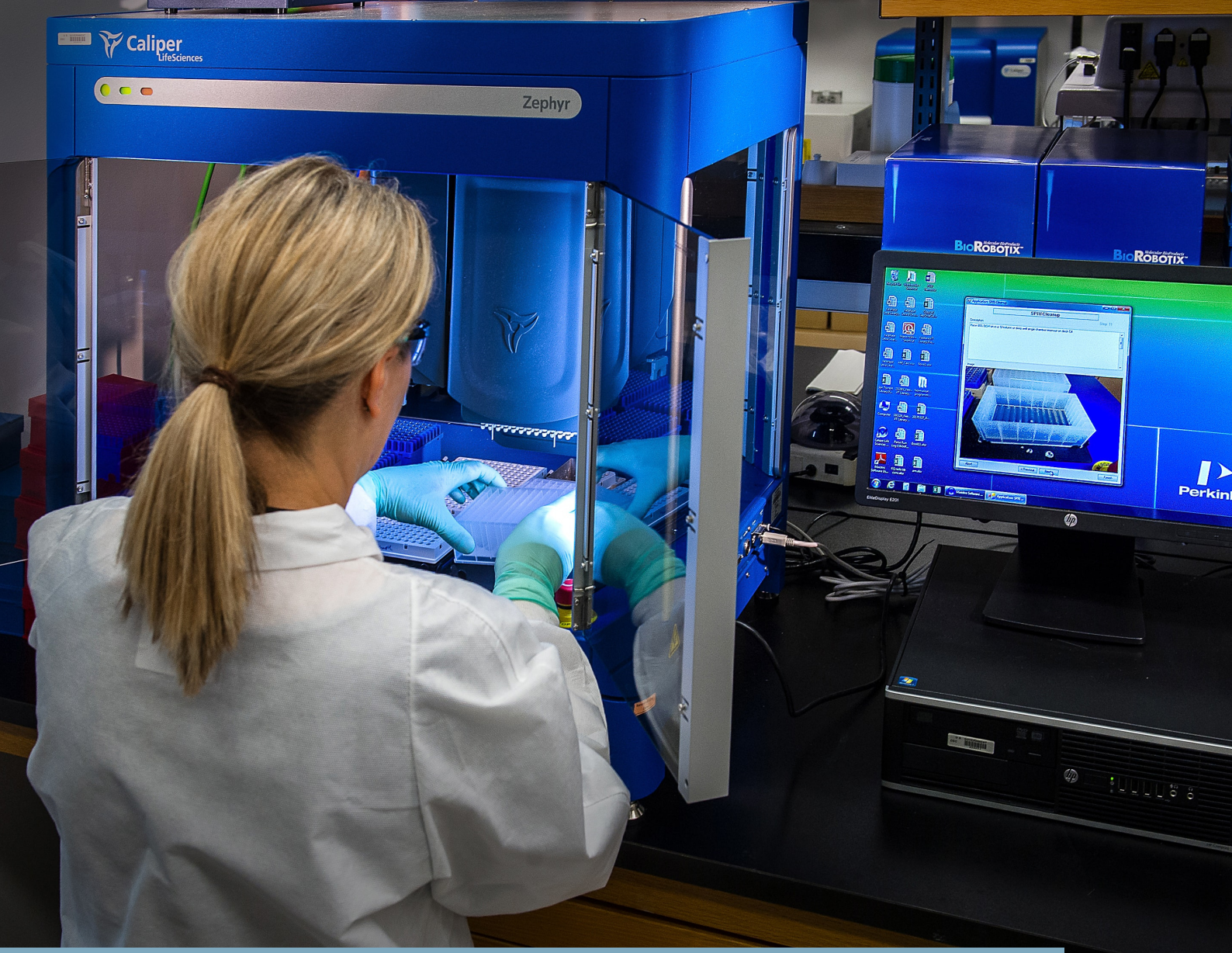

1. INTRODUCTION

Healthcare systems and especially medicine have come a long way since the Hippocratic oath. Dating back over 2000 years, it is referred to as one of the oldest texts available, still being relevant today [1]. It is referred to as the core ethical framework for physicians and medical staff around the world. But since the days of Hippocrates, the world has changed significantly. Especially in the last decades, inventions like the internet or smartphone have changed the world we live in dramatically. It therefore isn´t surprising, that some of the ethical or economic frameworks that worked well for hundreds or thousands of years, might not be applicable to our increasingly online-centric world [2]. A new technical invention, in line with the invention of the internet for many people around the world, is blockchain technology. Independent from all the hype around bitcoin and cryptocurrencies, blockchain technology has the potential to change the world we live in significantly. This is especially true for the healthcare sector, where trust, immutability or privacy are crucial to protect the rights and lives of patients.

In the following chapters of this paper, we will therefore focus on the basics of blockchain technology and other emerging new technologies, such as Artificial Intelligence (AI) or big data. Besides, we will evaluate possible economic and ethical impacts, an integration of blockchain technology could have on our currently existing healthcare systems.

1.1. BLOCKCHAIN TECHNOLOGY

Before we start talking about any economic or ethical impact, blockchain technology might have upon implementation in healthcare systems, we need to understand how blockchain technology works. For the majority of people, blockchain technology is tightly connected to bitcoin. Although there´s nothing wrong with this connection, most people don´t know, that blockchain technology is much more than “just” bitcoin. Blockchain technology was first introduced in October 2008, with the publication of the bitcoin whitepaper [3]. The bitcoin protocol, which was launched in early 2009, was the first implementation utilizing blockchain technology. Although the bitcoin whitepaper was published by the pseudonymous creator Satoshi Nakamoto, the underlying idea to create decentralized networks

started many years before the bitcoin whitepaper was published.

At its core, blockchain technology refers to a distributed ledger, where data of any form (e.g. transactions) is stored in blocks, that are cryptographically secured and chained together. One of the key advantages of blockchain technology is, that there is no central form of storage, rather than the ledger is stored, maintained, and validated by participants (nodes) of the network. As a result, there is no single point of failure as in traditional systems, where a major hack or accident could lead to a complete loss of data. Also, blockchain technology enables direct access of data or interactions between its users, without the need of any third party. This is not only highly efficient, rather than allows a network to be permissionless, where nobody can prevent others from participation. At this point, it´s important to note, that not every blockchain-based network is permissionless, which is not necessarily a bad thing. Besides public open blockchain networks like bitcoin or Ethereum for example, there are private (corporate) permissioned blockchain networks, which can provide significant advantages. Especially in comparison to the blockchain networks named above (bitcoin and Ethereum), private blockchain networks can offer a significantly increased speed (e.g. processing transactions), network capacity, and scalability. In addition, by only allowing selected participants to access and use the network, security can be increased. This is important if we think about highly sensitive data like genomic information for example.

Another attribute, that is often used in reference to blockchain technology, is immutability. In regard to blockchain technology, the term immutability is used to describe the property of being resistant to change. This is one of the key advantages over traditional databases, where if we think about an excel spreadsheet for example, entries can be changed easily. In blockchain based networks, ledger entries of any form (e.g. transactions) cannot be changed easily, without breaking the chain. Due to the architecture of blockchain technology, changing or editing entries in a single block would not only require changing the block itself, rather than any block, that was added on top of the block afterwards. Depending on the underlying consensus mechanism, which refers to the algorithm that is used to find consensus between the participants of the network in the process of validating new

blocks, excessive amounts of energy or resources would be needed in the attempt of changing blocks. Although not completely impossible, the chances of someone challenging the immutability of well adopted and thought-out blockchain networks are often diminishingly low. Due to the ability of direct interactions with participants of the network (e.g. sending transactions, exchanging information or data) without the need of any central authority or third party involved, blockchain networks are often considered trustless. Without the need of trusting others to store certain information or handling money for example, networks utilizing blockchain technologies can provide significant advantages over existing technological systems in many different sectors.

In summary, due to the attributes named above, it shouldn´t be surprising, that people as well as companies are increasingly interested in utilizing blockchain technology. Besides the financial industry, largely affected by bitcoin and cryptocurrencies as a new form of storing and transmitting money, especially the healthcare industry is focusing on utilizing blockchain technology in various different ways.

1.1.1. SMART CONTRACTS

If we talk about blockchain technology and its possible implementation in the healthcare sector, we need to focus on the term “smart contracts”, which allows a completely new level of autonomy. The term smart contract was first introduced by Nick Szabo in the early 90s [4]. Interestingly, although the term smart contracts implies a somewhat intelligent technological feature or function, the actions executed by smart contracts are predefined through a specific ruleset. Smart contracts found widespread adoption and usage after the launch of the Ethereum protocol in 2015. Ethereum was the first protocol to enable native support of smart contracts which enables completely new ways of functionality and automatization. One of the prime use cases of smart contracts, demonstrating how smart contracts can be used, was the distribution of tokens on the Ethereum protocol during a so-called “Initial Coin Offering (ICO)”. During the process of an ICO, where projects were seeking funding in exchange for the distribution of tokens related to the project, people were sending Ether (the native currency on the Ethereum protocol) to a certain smart contract address, triggering the predefined ruleset, leading

to the automatic distribution of the equivalent amount of tokens to the sender [5]. Today, smart contracts found widespread adoption and are basically omnipresent, if we think about the blockchain industry. Since the launch of the Ethereum protocol, many other blockchain networks like EOS, NEO or Tezos feature smart contracts functionality.

In regard to using blockchain technology in healthcare systems, smart contracts will enable completely new ways of automatization. This will become especially evident if we think about sharing patient data with institutions or rewarding certain actions (e.g. physical exercise) automatically [6]. In addition, smart contracts will enable completely new ways of using data if we think about a combination of blockchain technology with other new technologies like AI, IoT, or big data.

1.1.2. ARTIFICIAL INTELLIGENCE (AI)

Besides blockchain technology, another new technology said to change our current world significantly, is Artificial Intelligence. Although the idea of creating artificial intelligence is nothing completely new, as some studies suggest that the idea for AI dates back more than 60 years, the development of AI has grown significantly over recent years, due to the increased amount of data and digital information available [7]. As the name Artificial Intelligence implies, the underlying idea behind the technology is, to create artificial or non-natural intelligence for electronic devices (e.g. computers or robots). As such, AI technology is used to describe software applications that enable intelligent behavior and the ability to learn for non-living objects. Similar to natural intelligence, which is used for humans and animals, AI is able to learn and evolve, given the availability of data.

Following years of development, AI is already used in various ways in the healthcare sector. Besides being used in the process of drug development, where AI can help to find suitable new substances worth investigating, a prime use case for AI is to assist

radiologists in the process of evaluating X-rays or computer-tomographic data. This isn´t surprising, as radiology was one of the first medical fields to start using digital data for diagnostic purposes. Depending on the hospital for example, all X-rays are executed and saved fully digital. Due to the availability of huge amounts of digital data, especially X-rays are used to create AI, helping physicians to find more accurate diagnoses. This is already used in various ways, one example is the evaluation of mammographic X-rays (radiologic pictures of the human breast) to spot early forms of breast cancer [8].

Although AI medicine has already been used in the field of radiology successfully, there are other medical fields, that are currently testing AI to assist in spotting potentially fatal diseases earlier or finding the right diagnosis. If we think about the relevance of blockchain technology in regard to AI, it becomes clear, that the availability of completely new dimensions of digital data available through the implementation of blockchain technology, will enable the development of AI-based solutions in a way, never been possible before [9, 10].

1.1.3. INTERNET OF THINGS (IOT)

The term Internet of Things, which is commonly referred to as IoT, is used to describe the connection of various electronic devices through the internet, to exchange information or data of any form. IoT is most known for its implementation in our homes, where interoperability and connection between different devices is used to create “smart homes”. With the right set of devices for example, a weather sensor would be able to register rain, communicating the blinds to go up and the heating to start. This is only one simple example and the possibilities in our increasingly connected world are basically endless.

In regard to the healthcare system, the usage of IoT is still in its infancy. Still, studies suggest, that IoT will play an increasing role in the upcoming years due to the availability of wearables and electronic medical devices [11]. Especially in sectors, where data security plays a crucial role, the implementation of blockchain technology will help to increase the interoperability of devices and facilitate the adoption of IoT [12].

1.1.4. BIG DATA

As the name implies, the term “big data” is used to describe very large amounts of data. In our increasingly connected and online-centric world, huge amounts of data are created every second. It is estimated, that more than 2000 exabytes of healthcare data will be available till the end of 2020, increasing at exponential speed [13, 14]. Data is often referred to as the currency of the 21st century and the interest in collecting data is constantly on the rise. Although many companies and even governments try to collect data, one of the key challenges in regard to big data currently is not the availability of data itself, rather the ability to process and use it. In many cases, the available data is not standardized, making it hard to process. In addition, although huge amounts of data are already created every second, sensible data is currently often unavailable for the development of new software (e.g. IoT or AI) due to privacy reasons.

If we think about blockchain technology and big data, it becomes evident, that the integration of blockchain technology will allow new ways of data creation, collection, and processing. Especially if we think about highly sensitive medical data for example, blockchain technology will enable real-time data to be collected and used in completely new ways [15].

1.2. HEALTHCARE SYSTEM

In nearly every country of our current world, a working healthcare system is a necessary backbone to every society and economy. It therefore isn´t surprising, that incredible sums are spent to sustain a properly working healthcare system. Studies estimate, that in the last few years, several countries in the world spend more than 10% of their gross domestic product (GDP) on healthcare [16]. The increasing amount of funds spent on healthcare becomes especially important for countries like Germany, where the average age of the society is constantly rising. Governments are therefore seeking new ways to reduce the general healthcare expenses. In our age of digitalization, new inventions like blockchain technology, AI, or big data could reduce the amount of money spent in the healthcare sector dramatically.

But before we can focus on the possible cost reduction by new technological innovations, we need to analyze the main constituents of most healthcare systems, to identify structures that can be improved by digitalization. As such, the healthcare system is mostly divided into three main parts. The first part of the healthcare system is made of providers of medical care services, like physicians, nurses or hospitals in general. The second part is made of patients or recipients of medical services. This of course also accounts for the general public [17]. The last parts of most healthcare systems are medical health insurances or research institutions. As the structure of the healthcare system is highly complex and the degree of interoperability is comparably low, the possibilities for improvement by technological progress is high.

Different studies estimate, that more than 34 billion euro per year could have been saved in regard to general health expenses, by the digitalization of the healthcare system in Germany [16]. As blockchain technology will play a crucial role in the digitalization process, it therefore isn´t surprising, that governments and especially companies around the world are starting to explore blockchain-based solutions in the healthcare sector. Fields of interest include electronic health records, telemedicine, or pharmaceutical supply chain management. Despite the huge possible economic benefits, integration of blockchain technology could lead to significant benefits for the patient and the general public. Due to the increased amount of available data,

the trustless and immutable architecture, blockchain technology can directly improve the lives of many people around the world, due to better research, traceability, and healthcare in general [18].

2. RESEARCH QUESTIONS & METHODOLOGY

2.1. KEY RESEARCH QUESTIONS

New technical innovations, like blockchain technology for example, are often propagated to be the solution to every problem in existence, due to the huge amount of hype in the media. Although blockchain technology definitely has the potential to change different sectors significantly, including the healthcare sector, it won´t be the solution to every problem or challenge we currently face. To understand, where the implementation of blockchain technology in the healthcare sector makes sense and where possible limitations are, I will focus on the following key research questions throughout the next pages:

RESEARCH QUESTION 1:

Why does it make sense to implement blockchain technology in the healthcare system?

RESEARCH QUESTION 2:

What are the possible use cases of blockchain technology in our current healthcare system?

RESEARCH QUESTION 3:

What are the ethical questions that arise due to the implementation of new technologies in the healthcare system?

2.2. METHODOLOGY

To answer the key research questions raised in the previous chapter, extensive literature research, as well as knowledge from both, current healthcare systems and blockchain technology, is required. As such, I conducted a keyword search in major IT and bio-medical related databases (e.g. NCBI, PubMed, Elsevier, Springer, Google Scholar), general search engines (e.g. Google), as well as blockchain technology related forums (e.g. bitcointalk.org) and webpages. The keywords used included the following:

- “blockchain technology”
- “blockchain”
- “healthcare”
- “healthcare systems”
- “medicine”
- “healthcare economics”
- “IoT”
- “Big data”
- “Artificial Intelligence”
- “AI”
- “ethics”
- “emerging technologies”

3. RESEARCH RESULTS

In the following chapter, I will try to answer the key research questions raised previously. Starting with an extensive examination of possible implementations and use cases of blockchain technology in the healthcare system throughout RQ1 & RQ2, we will focus on ethical aspects and consequences for RQ3.

3.1. IMPLEMENTATION OF BLOCKCHAIN TECHNOLOGY IN THE HEALTHCARE SYSTEM

Since the publication of the bitcoin whitepaper, followed by the launch of the network in early 2009, blockchain technology has come a long way. But even today, for the broad public, the term blockchain technology is tightly connected to bitcoin and cryptocurrencies. It therefore isn´t surprising, that the vast majority of people don´t know what blockchain technology is, rather than which benefits an implementation could have on a broad range of sectors and companies. New technologies always take time to reach adoption and are heavily influenced by the opinion of mainstream media in the early years. Various research suggests, that blockchain technology is still at a very early stage in terms of adoption.

But that´s why I am personally more than happy to see, that companies and startups are increasingly interested in the technology itself, rather than focusing on bitcoin and cryptocurrencies alone. Market analysis and research suggest, that around 49 percent of companies in the healthcare sector are already working on blockchain projects or have increased interest in implementation [16]. Although early companies only focused on the implementation in the financial sector, the healthcare sector is surely one of the key sectors to profit from the integration of blockchain technology.

To answer the first key research question of this research paper, we will need to focus on the general advantages of blockchain technology and how it compares to traditional solutions. Although blockchain technology is often propagated to be the solution to every modern-day problem, especially by the general media, there are still many use cases, where traditional solutions like databases, are more efficient. In the past, the term blockchain technology was commonly used to attract investors or create the impression of being a modern

technological company. Most proposed projects and of course startups focusing on blockchain projects failed, mostly due to a lack of knowledge. It´s therefore really hard to define for the majority of people, where implementation of blockchain technology makes sense. This is especially harder for projects targeting the healthcare sector, as medicine and healthcare is often quite complex and existing structures are hard to define. The first research question of this paper is therefore actually closely related to the second one, where we will focus on some selected meaningful blockchain technology based use cases in the healthcare system.

As already mentioned previously, to answer the first question, we need to focus on the core values of blockchain technology and the comparison to traditional databases. In traditional databases, which are often client-server based, there is one central entity controlling the database. The user can access the database stored on a central server and only execute certain actions, that were predefined by the administrator. Depending on the user rights, the end-user as well as the administrator has the ability to change, delete or create existing entries. In blockchain technology-based networks, there is no central authority to have full control over the network, as well as there is no central form of record keeping. A full copy of the database is stored by the participating nodes of the network [19]. To confirm actions or add new entries to the database, the majority of participating nodes will need to reach consensus. In addition, one of the main differences to existing databases is, that only entries can be added, old entries will still remain intact. This feature originates in the key architecture of blockchain technology, where new transactions are added in the form of blocks, cryptographically chained together with existing entries to create a chain. Blockchain technology is therefore often considered to be immutable, which is one of the key differences to traditional databases. Blockchain technology is therefore the technology of choice for use cases in the healthcare sector, where immutability plays a crucial role to enable more trust and transparency. If we for example focus on supply chain management in the pharmaceutical industry very briefly, which is the very first use case presented in the following section, the use of blockchain technology can lead to significantly more transparency and especially security for pharmaceutical drugs and medical

products of all kinds. Without only one single central authority in control of the database, saving the records or entries throughout the supply chain, every step becomes tamper-proof and accessible for every participant in the process [20]. Everybody ran rely on the blockchain based entries, which will build trust and enable transparency.

Immutability provided by the use of blockchain technology is one of the key advantages for medical use cases. If you think about the need for tamperproof record-keeping, preventing any participant from cheating or abusing the system, blockchain technology might be a suitable implementation. This is for example especially important if we think about the process of distributing organs for transplantation purposes. In the past, many participants were abusing the system, which is heavily relying on trust. By the use of blockchain technology, entries cannot be changed without breaking the chain completely, which might be able to restore some of the much-needed trust in the system over time.

Transparency is one of the additional core attributes of blockchain technology. Stepping away from the healthcare sector for a moment, transparency is one of the key advantages of bitcoin and cryptocurrencies. In a public permissionless network like bitcoin for example, no one is able to stop you from accessing the network. From a network's perspective, everyone is the same, having the same rights to participate. As a result, anyone has the ability to access the ledger and every recorded transaction at every time. This is one of the main advantages over traditional ways of being able to transfer value. If we think about the financial sector and banks for example, the vast majority of people are not able to access information, other than their own bank account. Even the amount of money shown in the bank account is not verifiable, as there is no way to prove, that the bank really owns the money. In addition, the whole process of transacting money is completely non-transparent. Coming back to the healthcare system and possible use cases of blockchain technology, the availability of transparency has been one of the most important challenges in our existing system. If we focus on the "hot-topic" of blockchain technology-based applications, which is digital patient record keeping, features like transparency and immutability have the ability to change our understanding of modern-day medicine completely. Although I personally think a well-adopted blockchain

technology based digital patient record-keeping solution is still several years away in the majority of countries, it definitely will be one of the prime use cases of blockchain technology in the future. In our current healthcare system, there are countless several participants like hospitals, physicians, specialists, health insurances, the government, pharmaceutical companies, or research institutions. As this list is far off from being exhaustive, it only shows how distributed the current healthcare landscape in most countries currently is. Especially in most western countries like Germany, the general healthcare system is very conservative, slow to adopt new technologies, or any form of change [17].

Due to the distributed nature of the healthcare system, patient-related data is currently not stored in any central form and therefore not easily accessible in the majority of cases. In addition, the current system is largely paper-based, which makes it even harder to access all available data. As a result, the current healthcare system is very inefficient, leading to an incredible waste of resources, countless disadvantages for every participant in the system and especially the patient. Patients are often under- or over-diagnosed, due to the lack of available patient data. Whereas the problem of overdiagnosis might not have a severe impact on the health of the patient if we think about additional physical examination or blood samples, it can lead to serious consequences in terms of additional X-rays or computer tomography. The availability of a digital patient record, where all patient data is stored in a secure way, would therefore be a huge improvement for every participant in our current traditional healthcare system. Moreover, this will lead to some serious changes in our understanding of ownership of data and the role of patients in our healthcare system. The patient will be the sole owner of its data, able to decide, with whom the data should be shared. This will change the role of our current understanding of the patient completely, as in the current system, the patient is more like a spectator to its own health. Transparency will be established, as the patient can clearly see who accessed the data and which entries are being made. But blockchain technology will not only enable immutability and transparency, which are prerequisites for digital patient records to be successful, it will also offer integrity. The term integrity is used to describe the ability for users to be sure, that the data is genuine. This is

especially important in the medical field, as everyone needs to be sure, that the data they receive is in the original form and has not been tampered with. Only if integrity is ensured, the necessary level of trust can be established, to rely on the available data to make important decisions. In addition to being decentralized, attributed like integrity, immutability or transparency, will facilitate the adoption of blockchain technology in the healthcare sector and will provide significant improvements over existing solutions. Due to a higher level of automatization (e.g. smart contracts), in addition to the more efficient availability of data, administrative costs can be cut extensively.

Another major advantage of blockchain technology for patients and participants in the current healthcare system, is the ability to reduce the need for third parties or intermediaries. In our current health system, there are several intermediaries interacting with patient data. One of the possible use cases, that reduces the need for intermediaries and greatly benefitting the patients, will be presented as use case number three in the next section. With the help of digital patient records, patients can directly share their medical data for research purposes, without the need of relying on third parties to share and use the data exactly as agreed. Without the need for intermediaries and a central institution in sole control of all data, blockchain technology provides a completely new way for patients to be in control of their own data and revolutionize the healthcare sector in a way, never been possible before.

In addition to the benefits presented above, blockchain technology will provide additional advantages, if combined with other emerging technologies like AI, IoT, or big data. Blockchain technology provides the necessary framework to enable large amounts of (real-time) data to become available and be used. As such, blockchain technology might be the necessary next step in the digitalization of medicine and the healthcare sector. Especially, where attributes native to blockchain architecture, like immutability or transparency, can lead to significant improvements over existing systems, integration should be considered. Although some implementations of blockchain technology in the healthcare system, like digital health records, might still be years away, some of the use cases could still be realized in the near future. Some of the most promising blockchain

technology based use cases are presented in the following chapter.

4.2. SELECTED USE CASES OF BLOCKCHAIN TECHNOLOGY IN THE HEALTHCARE SYSTEM

To answer the second key research question of this paper, I will provide selected use cases of blockchain technology in the healthcare sector. The following four selected use cases were selected based on personal preference, the significance of the underlying problem, and their feasibility. Other examples of blockchain technology in the healthcare system include the following [16, 18-20]:

- Secure storage and transfer of medical data
- Monitoring diseases and report outbreaks in real-time
- Securing genetic data and improve research
- Democratization and acceleration of clinical trials
- Medical supply chain management and drug traceability/safety
- Blockchain-based vaccination certification (COVID-19)

- Medical record management
- Smart contracts for insurance and supply chain settlements
- Increasing IoT security in healthcare
- Medical staff credential verification
- Rabies vaccine tracking with blockchain in Mali and Ivory Coast
- Patient-centric healthcare and personalized medicine

It is worth noting that the provided list is far off from being exhaustive, as the current interest in blockchain-based use cases in the healthcare sector is high. As already mentioned previously, the need for innovation in the healthcare sector is accelerating due to the high costs for governments and health insurances. It therefore isn´t surprising that many reputable organizations and companies are working on new ways to digitalize the healthcare system and implement blockchain technology. Some of the most popular and promising initiatives and companies working on blockchain technology for the healthcare system and medicine are shown below:

- IBM
- SAP
- ConsenSys Health
- Centers for disease control and prevention (CDC)
- HIT Foundation (to be renamed into dHealth Foundation)
- Patientory
- Nebula Genomics
- Doc.Ai
- Chronicled
- Factom
- Akiri

Especially in the light of the ongoing pandemic, the relevance of blockchain technology and the interest of an implementation in the healthcare sector are constantly on the rise. Due to the limited quantity of vaccination available worldwide and inefficient as well as non-transparent distribution, blockchain could offer significant benefits over existing solutions. To reduce the possibility of fraud in the distribution process and to minimize the possibility of counterfeit vaccinations, the first selected use case focuses on the implementation of blockchain technology in drug supply chain management.

4. USE CASES

4.1. USE CASE 1: BLOCKCHAIN TECHNOLOGY FOR PHARMACEUTICAL DRUG SUPPLY CHAIN MANAGEMENT

BACKGROUND AND SIGNIFICANCE:

The first blockchain technology based use case in the healthcare system targets the global problem of counterfeit pharmaceutical drugs and medical products.

Counterfeit drugs have a significant impact on healthcare systems and especially patients all around the world, due to the potentially lethal consequences. Studies suggest, that around 15% of all pharmaceutical drugs in circulation could be counterfeit [20]. As the amount of non-genuine drugs greatly varies between countries and societies, the percentage is even higher in developing countries. As such, studies estimate, that in some countries, even up to one-third of the circulating drugs could be counterfeit. With some pharmaceutical drugs costing more than several thousands of USD (e.g. chemotherapeutics, antibodies, genetic treatments), the market for counterfeit drugs is incredibly huge. Besides any economic impact, the consequences for patients all around the world are potentially lethal on every “treatment”. Not only do counterfeit drugs prevent the patient from receiving adequate medication, which leads to life-threatening conditions in the case of chemotherapeutics, antibiotics, or several other classes of drugs, but the products sold also are often of minor quality and even contain harmful substances themselves [21]. This is especially important if we think about situations, where only minutes or hours will have a significant impact on the life of the patient (e.g. snake bites). In addition, most of the counterfeit drugs are non-sterile, which can lead to serious infections, if administered through injection. Still, despite the significant consequences on millions of people worldwide, the economic impact shouldn´t be neglected. The development process for new pharmaceutical drugs normally takes several years and requires more than the equivalent of one billion USD in funding. If the economic impact on pharmaceutical companies is too high, they could focus on easier methods of producing pharmaceutical drugs, neglecting the costly and complex process of conducting excessive research, needed to identify

completely new classes of pharmaceutical drugs. Although this might not seem too important at first glance, the consequences can be fatal for millions of people around the world. With the growing antibiotic resistance of bacteria, new ways of treatment are needed more than ever. Overall, the impact of counterfeit drugs worldwide is highly important and current security measurements are far off from being protective in the vast majority of cases. End-users currently don´t have the possibility to prove the authenticity of their medication for example, which is highly important even in western countries, due to the rise of online pharmacies and drug distributors. In addition, many different companies and people are involved in the process of distributing the pharmaceutical drugs or products from the manufacturer to the patient. All these steps could be highly improved through the implementation of blockchain technology. One possible solution for the implementation will be presented below.

BLOCKCHAIN TECHNOLOGY SOLUTION:

Since the inception of blockchain technology in early 2009, supply chain management has been one of the prime use cases for the revolutionary technology. The integration of blockchain technology in the supply chain management of pharmaceutical drugs has the potential to decrease the number of counterfeit drugs in circulation significantly, as it introduces the possibility for companies, governments, and patients to check, whether their medical product is genuine. Although especially western countries have identified the problem of counterfeit drugs and their potentially fatal consequences on the population, the solutions in place often lack the possibility of end-user/patient validation. In addition, as most introduced solutions are costly and only introduced in western countries, developing countries, where the number of counterfeit drugs is even higher, often lack additional security measurements.

By implementing blockchain technology, the manufacturer of the pharmaceutical drug would use a newly developed interface (e.g. smartphone/scanner app or web client) to interact with the underlying blockchain and create unique QR-codes (unique identification number). With the creation of the QR-code, which is directly printed on the package containing the pharmaceutical drug or medical drug for

better safety, the underlying blockchain is updated, creating an immutable timestamp and tamperproof record entry. On a side note, to increase the security even further, every package should be sealed to provide the possibility to check, whether the package has been opened or not.

As in the vast majority of cases, the packages will be packed together and aggregated, a new QR-code for every bigger package should be created too. This will allow any step of the shipment process to be tracked, providing proof on the blockchain. At every step in the supply chain, from the manufacturer to the patient, the QR-codes would be scanned and the blockchain would be updated. As soon as the product reaches a pharmacy, authenticity can be checked before handing the pharmaceutical drug to the patient. But even if the product is purchased over the internet or distributed through intermediaries, the patient or end-user can prove the authenticity of the product on their own. Every step of the supply chain could be retraced, enabling completely new levels of trust. A visualization of the process is shown in Figure 1.

To reduce the number of counterfeit drugs in circulation, each manufacturer labels the newly produced

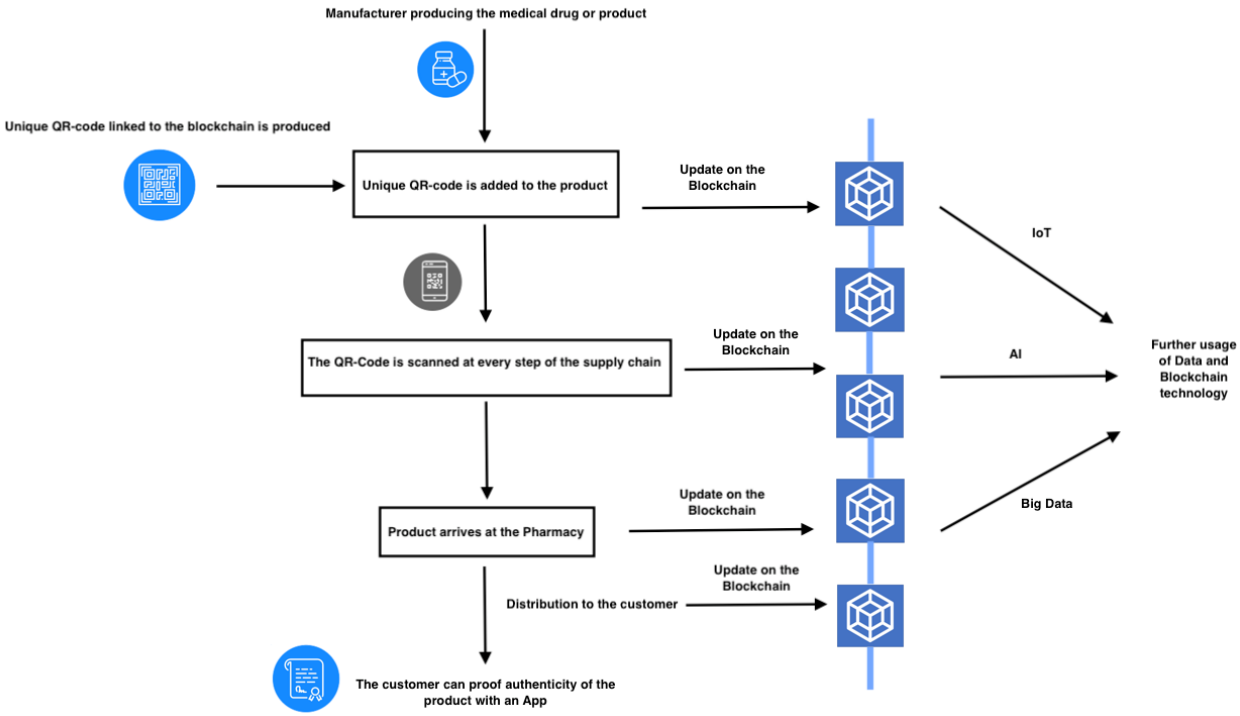

Figure 1: Schematic overview of the implementation of blockchain technology for the supply chain management of pharmaceutical drugs and medical products

pharmaceutical drug with a unique blockchain based QR-code. During each step of the distribution, the blockchain is updated, providing tamperproof timestamps. The end-user or patient is able to self-verify the origin of the medication by using an app to interact with the blockchain.

Besides the significant impact on the security of pharmaceutical drugs worldwide, providing completely new ways of traceability and trust, the integration of blockchain technology into the supply chain of pharmaceutical drugs and medical products will enable even more possibilities in combination with other new emerging technologies like IoT, big data or AI.

In combination with AI and big data for example, by providing reliable real-time data, blockchain technology could be used to predict possible disease outbreak in a certain region of the world, by tracking the sales process of a certain pharmaceutical drug. This might enable significant advantages over existing solutions if we keep the possibility of new pandemics in mind. In addition, the tracking process could identify possible shortages very early, providing necessary information to suppliers or the manufacturer. Thinking about IoT, the integration of blockchain technology would enable a higher level of automatization, as Logistic companies participating in the distribution of the pharmaceutical drugs could be paid automatically, after fulfilling the shipment. The whole process will largely benefit from other features such as smart contracts, providing multiple different significant benefits over existing solutions.

TECHNICAL SPECIFICATIONS:

At the core of the implementation described above, is of course the blockchain. I would personally propose a hybrid blockchain, where interoperability between a public permissionless and a private permissioned blockchain is assured. The blockchain would be run and governed by a consortium, made of every participating member in the use case solution (e.g. pharmaceutical company, logistic companies, pharmacies), in addition to the government (e.g. EU) and pro-patient related organizations (e.g. the WHO). The different distributed validators committed to the network will allow important features, such as scalability, governance, and the protection of user rights. To be more precise, I would propose the blockchain to utilize Proof-of-Stake as an underlaying consensus mechanism, where the

stakeholders are the respective participants/validators of the use case. Using a hybrid blockchain solution has the advantage, that the private network will allow better scalability, faster finalization and blocktime as well as higher throughput. At the same time, the public blockchain would allow third-party developments and increased security and trust. On a general level, the stakeholder/validators of the network would run full nodes, to allow light client functionality on the end-user side, without the need of downloading the whole blockchain. This is crucial to facilitate adoption, as downloading the whole blockchain would reduce usability greatly.

In general, the application or web-client has to be as user-friendly as possible to allow easy and intuitive usage and facilitate adoption. In addition, extensive user education needs to happen, to provide further trust and adoption. One of the main advantages of the proposed use case is, that the necessary technological framework for a successful implementation is already existing. The participating companies could use their existing server infrastructure to run the blockchain. Although the hardware or server requirements should be sufficient in most countries, the lack of knowledge in the area of blockchain solution could slow down the implementation. As such, either internal training or external contracting should be conducted. Besides the points mentioned above, sufficient internet coverage is needed to implement and run the use case as proposed. This might not be a significant problem in most western countries, it could reduce the benefits of the solution in some developing countries. This of course also applies for smartphones or electronic devices connected to the internet, enabling the possibility to use the provided app or web client.

In summary, the technical requirements to implement the solution are comparably low, if we think about the possible huge benefits for every participant and especially the patients worldwide.

LIMITATIONS:

Although the implementation of blockchain technology in the described use case could provide significant benefits over currently existing solutions, there are still limitations. One of the key points of successful integration and usage is, that the QR-code is scanned at every possible step during the distribution process. While

many steps could be automatized in the future, the integration currently relies on the people working in the logistic companies. Although the implementation would still lead to an increase in security and trust, even if the package was never scanned during the whole distribution process and the recipient could only see, that the drug was produced by a certain manufacturer, further proof of authenticity and trust is still lacking. To prevent criminal organizations to sell their counterfeit drugs and products, by creating their own app and mimicking the whole distribution process, extensive public education is needed. To increase the overall level of trust and adoption in the society, participating companies, countries, health insurances, and governments should coordinate their efforts by creating a consortium. This consortium would not only be able to govern and run the blockchain, it would make it even harder for counterfeit drugs to be sold, due to the uniform framework (e.g. app and web client) established.

4.2. USE CASE 2: A BLOCKCHAIN TECHNOLOGY-BASED TOKEN REWARD SYSTEM FOR MEDICAL SERVICE PROVIDERS AND THE GENERAL PUBLIC

BACKGROUND AND SIGNIFICANCE:

The second use case for blockchain technology in the healthcare system focuses on a token-based reward system for medical service providers such as health insurance companies. In many countries around the world, the average age of the society is increasing rapidly. At the same time, so-called "western world" diseases like being heavily overweight (adipositas) are getting more and more popular in the general population. As such, not only the incidence of chronic diseases is constantly on the rise, rather than the overall health-related expenses. Countries like Germany for example are currently spending more than ten percent of their GDP on their healthcare system [16]. It´s therefore not surprising, that governments and health insurance providers all around the world are looking for ways to reduce their costs.

One of the possible solutions is, to promote a healthy lifestyle, physical activity, and undergoing preventive medical checkups to prevent diseases and related costs. Although many people are increasingly interested in their health and living a healthy lifestyle, the vast majority of people in western countries still suffer from diseases associated with adipositas and the lack of physical exercise. This has some serious consequences on the physical and psychological life of millions of people around the world. Due to our fast-changing and online-centric world, diseases like depressions are constantly on the rise [22]. In addition, the oversupply of unhealthy food leads to severe diseases like cancer or heart attacks. In well-developed countries, the healthcare insurances will allow the treatment of most current diseases. While good from a patient's perspective, the overall costs have a direct impact on the economies worldwide [23]. Although health insurances and governments already try to motivate their residents to live healthier by implementing rewards, current programs still lack availability and significant adoption.

BLOCKCHAIN TECHNOLOGY SOLUTION:

Besides the general lack of availability and adoption of current reward-based programs, they also require a lot of administration, are inefficient, and lack transparency as well as trust. This is why I personally think, the integration of blockchain would provide a significant improvement over existing solutions. At first, a blockchain would need to be established. The insurance companies, government, or a consortium of participants will provide the necessary infrastructure to implement the solution and interact with the blockchain (e.g. smartphone app or/and web-client). Insured users or people generally interested in their health would use the app or web client to see possible achievement and claim their rewards. Due to the integration of blockchain technology and smart contracts, most processes could be automatized. Upon completion of a certain task (e.g. achieving a certain exercise goal), the reward (in form of tokens) could be credited automatically. To facilitate adoption and prevent people to abuse the system, the applications should be able to run on wearables and use different sensors (e.g. GPS and gyro-sensors). By the implementation of special physician interfaces, some tasks like undergoing preventive checkups could also be credited directly to the account of the user. With a higher level of automatization, administrative costs can be reduced significantly in addition to faster processing and usability. Besides to reduced costs, the implementation of blockchain technology offers several benefits for the insurance companies. They could for example track, which task finds low adoption, increasing the number of tokens rewarded. In general, the chosen blockchain should of course feature native token support to enable more features and provide better usability in general. By the implementation of a well-adopted reward system, insurance companies could reduce the cost for diseases, at the same time guaranteeing more transparency and efficiency.

The user of the solution would benefit from a possible reduction of general health insurance costs as well as the possibility to spend their token on certain health-related products (e.g. wearables or sport-clothing) as well as health-related services (e.g. massages). By utilizing blockchain technology, further features and functionalities would be able to be implemented if combined with other new technologies like AI, big data, or IoT. For

example, if multiple electronic devices would be able to interact and communicate, certain rewards could be adjusted automatically (e.g. a smart scale will detect weight loss/increase and adjust the daily exercise goal). By using blockchain technology, research institutions could benefit from the increased availability of secure real-time data to develop new treatments or services, which could help to improve the lives of people even further. Overall, the presented use case would be highly efficient and feature significant benefits for its users and providers, compared to mostly non-existent or adopted current solutions. A schematic visualization of the concept can be seen Figure 2.

To reduce the incidence of diseases related to an unhealthy lifestyle and the lack of physical exercise, a blockchain based reward system is implemented to motivate patients and the general public. Patients can interact with the blockchain by using a mobile application or wearables to claim their reward for certain tasks. The rewarded

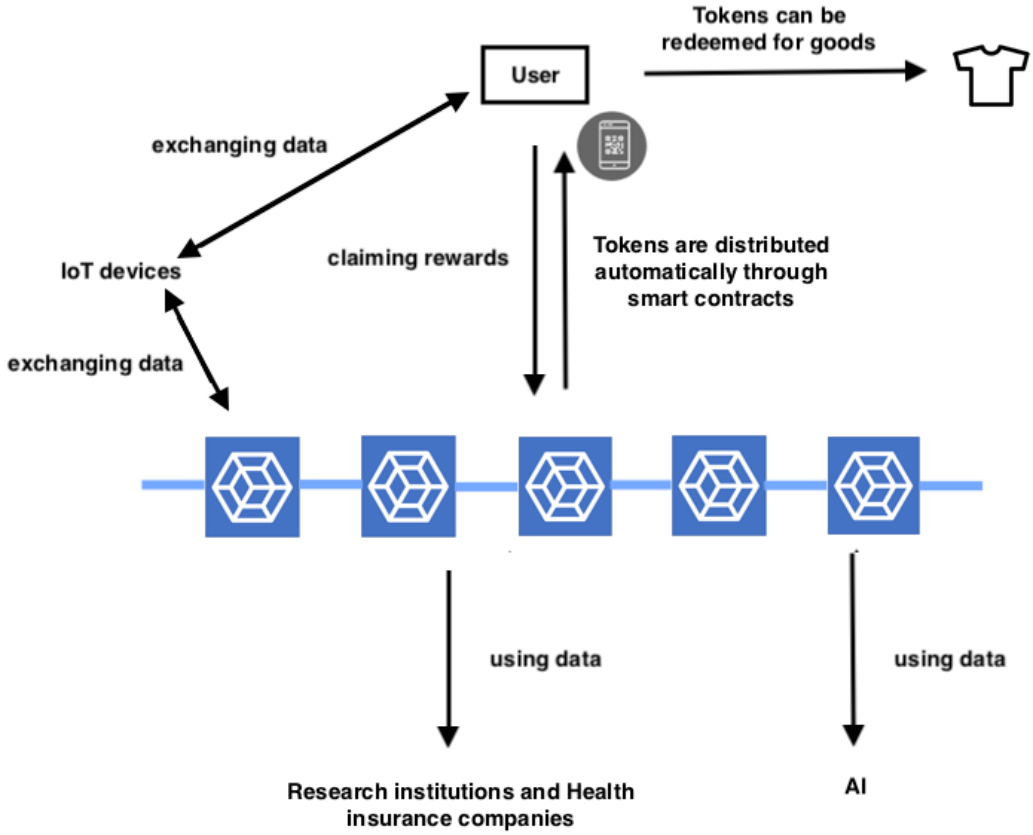

Figure 2: Visualization of a blockchain technology based token reward system for health insurances and other medical service providers

tokens can be distributed automatically by smart contracts and could be redeemed for several different goods (e.g. sportive clothing).

TECHNICAL SPECIFICATIONS:

To implement the proposed use case from a technical perspective, existing server architecture and IT- infrastructure could be used. At its core, a blockchain would need to be implemented to allow token transfers, smart contract functionality, and the integration of other technologies and applications. For the necessary blockchain, I would propose either a private permissioned blockchain or a hybrid solution between a private and a public blockchain to allow full functionality, protect user rights, and guarantee privacy for patients or participants.

Proof-of-Stake would be the most suitable consensus mechanism for the proposed use case solution, with the stakeholder or validators being the participants of the healthcare system. As such, I would propose the formation of a consortium, made of health insurance companies, governments, pro-patient non-profit organizations. The consortium would not only run the blockchain, but also be validators, run full nodes, rather than introduce governance to allow the introduction of new features. In addition, the introduction of a private permissioned blockchain technology network will allow scalability, sufficient transactions per second, and a necessary high throughput, to allow full functionality and facilitate adoption. In general, the application or web-client to access the blockchain and allow full functionality should be developed as user-friendly as possible. The application and web-client would enable the user of the application to function as a traditional blockchain wallet at its core. To further increase adoption, the integration with wearables (e.g. Fitbit, apple watch) should be facilitated. Besides, extensive effort should be put into establishing partnerships to provide use cases and value to the reward token. Depending on proposed functionalities, an interface for physicians would need to be implemented, to allow confirmed entries. To allow even better functionality, the integration with other possible solutions like digital IDs or electronic health records should be established as soon as they are available. If possible, the development of such applications should be funded by the participants of the consortium, allowing extensive interoperability. On a general level, for the

proposed use case to find adoption, a high level of internet availability as well as mobile devices (e.g. smartphones) would be necessary.

LIMITATIONS:

Similar to any new technology, there are several limitations to blockchain technology-based solutions in the healthcare system. Although the solution would offer various benefits over existing solutions, partnerships would still be crucial for success. Without widespread adoption and usage, the solutions might not be maintained over a long period of time, lack features and usability. As people will need to somehow confirm their identity for being able to track their achievements and be rewarded, the implemented blockchain has to be audited carefully to protect user rights and maintain privacy. This is especially important if we think about the combination of the proposed use case with other features like a digital ID or electronic health record solutions. In either way, the collected sensitive data should never be usable for selective purposes in a way, that people who do not participate, have any sort of disadvantages. In addition, even older wearables and smartphone generations should be supported as good as possible, to make the solution available to a broader amount of people.

4.3. USE CASE 3: BLOCKCHAIN TECHNOLOGY IN THE INCENTIVIZATION PROCESS OF HEALTH DATA

BACKGROUND AND SIGNIFICANCE:

Although I personally think, that blockchain technology based digital health records are many years away, at least in my home country Germany, health-related data is still incredibly valuable. It therefore shouldn't be surprising, that private companies and startups seeking to establish themselves in the healthcare market. One solution, that could be implemented quite easily already and still adds significant value to existing structures, is the presented use case number three, which we will talk about next.

In the vast majority of countries worldwide, the healthcare system is very conservative and non-digitized. Due to missing standards and high regulations, the healthcare market often lacks innovation in terms of new or emerging technologies. In an aging society, where the health expenses are increasing rapidly, the need for new ways of cutting costs and still improving existing structures is higher than ever. As the current degree of digitalization is low, interoperability between systems is very low. Many physicians for example still use paper-based patient records, inaccessible for further usage. The low degree of digitalization is an especially big problem if we think about research and public health. Although more people than ever are interested in maintaining a healthy lifestyle and participating in research to do good and improve the overall health even further, the possibilities are currently very limited [24]. In the majority of cases, people can only participate in trials, where a certain patient collective is formed, and new pharmaceutical medication is tested. Besides, in many cases, people need to have a certain disease for being able to participate in research. The general (healthy) public often does not have the possibility to take part in research and provide valuable data to research institutions. In addition, if people are asked to participate due to some rare diseases, they often cannot be sure, that the collected samples (e.g. blood samples) are solely used for the connected trial. Overall, current conditions lack trust and especially transparency, which is very important in our modern community.

This is why I personally think, a blockchain technology-based solution would be a significant improvement over existing structures and provide people around the world possibility to provide new data, participate in research, and get rewarded for it. This new data would be incredibly valuable to researchers and institutions worldwide, as current research and trial samples often aren´t representative for the general population (e.g. different age, pre-conditions, biological sex, constitutions, genetic information) [25]. In addition, most pharmaceutical trials testing new pharmaceutical drugs or medical drugs, often are quite time-limited. New side-effects and possible drug interactions are often not registered, due to the inability to submit new symptoms easily. In addition, without any reward system, people miss their follow-ups and aren´t sufficiently motivated.

BLOCKCHAIN TECHNOLOGY SOLUTION:

To solve the points above and provide even more features and functionality, the implementation of blockchain technology would provide significant benefits over existing solutions. With a blockchain running at the core of the application, patients and people interested in research could be rewarded through a token-based system. The token could be used in various ways, for example incentivizing the patients to keep their data up to date or participate in surveys. As those rewards can be redeemed for medical goods or services (e.g. better insurance rates, wearables, clothing), people are motivated to supply even more specific data (e.g. blood test results). Patients would be able to interact with the underlying blockchain directly with an app or through a web-based client. The “account” created would allow traditional blockchain wallet functionality and enable the user to save their collected tokens. By using blockchain technology and the help of smart contracts, tokens could be distributed automatically after completion of a certain task or survey. In addition, the user will benefit greatly from more transparency. As the data is only stored locally, always under the control of the patient, and only shared in a cryptographically secured way, trust is created.

From a research institution´s perspective, the implementation of blockchain technology will allow the selective collection of data without the need for

any intermediary. As such, the overall cost of acquiring the data can be reduced greatly. In addition, existing structures will be unified and different processed automatized, reducing administrative costs significantly. With the integration of interfaces for health officials (e.g. physicians), not only their participation can be incentivized, the introduction of a selective reward structure is possible (e.g. official confirmed diagnoses could be worth more). Additionally, the implementation of blockchain technology will allow on-chain governance to protect user rights and decide democratically on new features or changes to the existing protocol. Blockchain technology allows validators from different sectors to interact and communicate on important decisions. Besides, by the use of so-called “oracles”, external data can be integrated and used, allowing even more automatization and functionality if we think about AI or IoT (e.g. using real-time data to predict disease outbreaks by identifying the increasing incidence of new symptoms). This will especially become important in the future and the broader usage and accessibility of wearables. A schematic visualization of the use case can be found in Figure 3.

To incentivize the sharing of health-related data for research purposes,

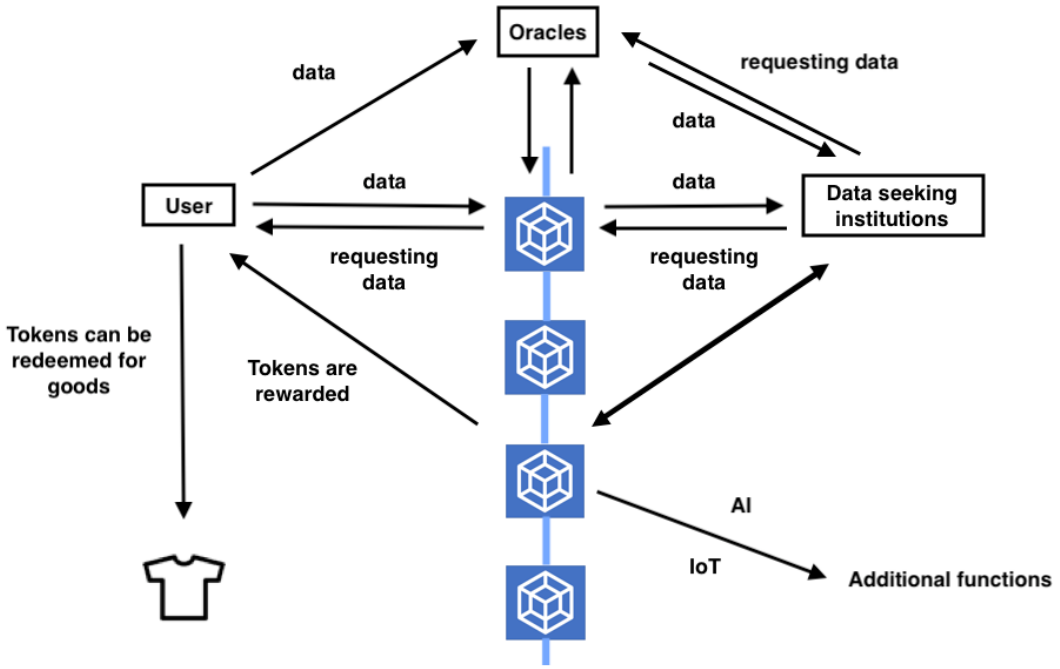

Figure 3: The implementation of blockchain technology in the sharing process of digital healthcare data

blockchain technology is used to provide the cryptographically secured possibility of direct patient and research institution interaction. Data-seeking institutions can directly send requests for selected data (e.g. surveys) to the user in exchange for rewards (e.g. tokens). As the patient is the sole owner of his data, he is free to decide which data he is willing to share and with whom. The rewarded tokens can be redeemed for different kinds of services and goods. The token allocation is fully automatized by the use of smart contracts and even more functionality (e.g. the use of external data) can be provided by the implementation of oracles.

TECHNICAL SPECIFICATIONS:

The central key piece to the presented use case is of course the underlying blockchain. To provide the best functionality and allow external third-party development, I would implement a hybrid blockchain solution for the proposed use case. This has several benefits for both the user or patient for the application and the research institutions seeking health-related data. The private permissioned blockchain network will allow higher throughput, better scalability, and more (trans-) actions to be processed per second. In addition, it will allow further governance function and provide higher security for data. The public blockchain component of the hybrid solution will enable third-party development, direct user verification, easier audits, and establish more trust. In general, due to better efficiency, lesser cost of operation and lower ecological impact, I would choose a variant of Proof-of-Stake as an underlying consensus mechanism. The stakeholders/validators of the blockchain will be the participants involved in the solution. As such, same as with the use cases mentioned previously, it would make sense to form a consortium (e.g. made of pro patient-related organizations, governments, health insurance companies, research institutions) to govern, run and maintain the blockchain. The consortium members would run a sufficient number of distributed full nodes to allow light client interaction of end-user. Additionally, the consortium would develop an app and web-client able to interact with the blockchain. The application should include all major operating systems as well as support older devices to enable usability and participation to a broad base of people. The app should of course be as user-friendly and intuitive as possible to facilitate adoption. The

application will work as a traditional blockchain wallet, providing private and public keys, allowing token transfer and grant access to surveys or tasks. As any data is solely transmitted to research institutions upon confirmation of the user, the application will notify about any possible request immediately. As the app will function as a light client, providing access to the blockchain and related services through the connection to full nodes, there is no need to download the whole blockchain history. This fact is especially important if we think about sufficient adoption.

If a certain task is fulfilled by the user (e.g. completing a survey or providing a certain degree of medical data) the tokens can be distributed automatically with the help of smart contracts. The awarded tokens can be redeemed for goods and services (e.g. wearables) through the app or web-client. To comply with existing laws and regulations (e.g. GDPR), the use case should be developed and maintained under legal and official governmental guidance. At any point, the user should be able to delete the saved data completely. In general, the data will be transmitted cryptographically secured and anonymized, to provide trust and privacy. Oracles can be implemented to use external data and standardize and process available data, enabling the usage of data without any interaction direct interaction between the user and the institutions seeking information.

LIMITATIONS:

One of the main advantages of the proposed use case is, that it could be implemented quite easily from a technical/hardware perspective. One of the limitations could be the availability of sufficient workforce to develop the proposed use case. The lack of knowledge in terms of blockchain technology development could therefore be one of the key limitations. Besides, even though the benefits for all participants are evident, the motivation to change from a governmental, healthcare system related side could be low. In addition, one of the limitations could be the lack of sufficient integration of current mobile devices and wearables. This is especially important, to make the use case as accessible as possible. As general adoption of the use case is the key to success, a lack of integration as well as non-intuitive software applications can lead to a failure of the overall project. Either way, extensive user-

education will be needed to increase participation. This also accounts for health care officials such as physicians and other participants (e.g. government). In general, sufficient internet coverage and education, as well as mobile device availability are needed to improve adoption and the chances of success.

4.4. USE CASE 4: BLOCKCHAIN TECHNOLOGY FOR ORGAN TRANSPLANTATION PROCESSES

BACKGROUND AND SIGNIFICANCE:

We currently live in a world, where due to incredible medical innovation, many deadly diseases of the past can now be treated or even cured. Although this is incredible progress for millions of people, it also holds completely new challenges for societies and economics all around the world.

Besides the discovery of vaccines, which effectively prevents diseases completely and saves millions of lives every year or the development of antibiotics, one of the key innovations of our modern-day medicine was the development of dialysis. During dialysis, a machine equipped with some special membranes mimics the function of our kidneys, washing out toxins or other waste products, otherwise leading to severe damage and successively the death of a human body. For hundreds and thousands of years, there was no sufficient and long-lasting way to replace kidney function. As a result, people with acute or chronic kidney disease, without a sufficient remaining function of the kidney, would die sooner or later. The reason for an acute or chronic kidney insufficiency varies, including infection, kidney stones, or autoimmune processes. In either way, the general renal function steadily decreases with age. It therefore shouldn´t be surprising, that the amount of people needing dialysis is constantly on the rise, due to our aging society. As the process of dialysis can increase the life expectancy significantly, at the same time leading to an increase in health-related costs spent, it bears some ethical challenges and consequences [26].

Even though it might not be highly relevant in well-developed western countries, it definitely is an important topic in countries all around the world. Although dialysis effectively saves the lives of people around the world every day, it still has some limitations. The process is highly time-consuming and always holds the risk of potentially fatal infections. In addition, it cannot replace normal kidney function fully, affecting other organs over time. As a consequence, to improve the overall life expectancy and quality of life, people around the world are waiting for organ transplantation. Currently, the need for organs to be transplanted

exceeds the number of available organs by far. This has some serious consequences for people around the world and is owed to various important factors. The most important factor is of course the willingness to donate organs. One of the main reasons for the decline, is the lack of trust in the distribution process of organs, due to bad practices in the past [27, 28]. Physicians would try to put their patients on top of the list through the manipulation of required parameters. In addition, in some countries around the world, corruption is common, and people would try to influence the decision-making process with money. In other parts of the world, even today there is still a black market for organs (e.g. China or India). It is noteworthy, that this is not only the case for possible kidney transplants, rather than for any transplanted organ (e.g. liver, heart or lungs). Studies suggest, that past malpractices have damaged public opinion and the willingness to donate organs permanently. It will take a significant change in existing structures to establish new trust and transparency.

BLOCKCHAIN TECHNOLOGY SOLUTION:

Due to a lack of transparency and bad practices in the distribution process of organs in the past, the trust in existing structures is very low. At the current state, due to the fact that not every organ can be matched with every possible organ recipient (e.g. because of the size, molecular marker otherwise triggering an organ rejection, failure to meet transplant criteria), central international organizations and institutions are coordinating the organ transplantation process. Although the reputation and trust in these institutions is low due to the organ mismanagement in the past, some sort of central institution will still be needed for coordination. In the future, I have no doubt that the organ matching process can be highly automatized with new emerging technologies like big data and AI. Still, to improve the current situation as soon as possible, the implementation of a “second look” institution would be the most suitable way in my opinion. As such, as soon as a new patient needs to get enlisted for a new organ, the corresponding hospital or physician will initiate all required tests to start the process (e.g. determine molecular patterns to prevent organ rejection and loss of function). At the

same time, additional blood samples are taken and sent to the central organ transplant matching organization. As soon as the first test results are received, a newly established interface is used to interact with the blockchain, and tamperproof entries are created. The blockchain should be run and governed through a consortium that is made of all selected participants in the process, as well as the governments (e.g. EU), pro-patient non-profit organizations to ensure the chances of corruption and mismanagement are significantly decreased. As soon as the second test results are available from the central organ matching organization, which should be controlled independently from the consortium, the blockchain is once again updated, either to confirm the previous test results or to request additional/new testing. The underlying blockchain is of course the key piece to the use case and acts as an immutable, open ledger to provide transparency and tamperproof record keeping. The blockchain should of course be auditable to ensure functionality and identify possible misbehavior of any participant. As many people will have to wait for several years before they´re able to receive a suitable organ, routine checkups in predefined time periods (e.g. 3 to 6 months) are required to stay enlisted. Following each checkup, new blockchain entries should be made to ensure the important variables are still correct.

If a new organ becomes available for transplantation, additional testing is required. This will ensure that the molecular patterns and other variables such as size and anatomic properties are suitable for a possible organ recipient. Once again, all tests should be conducted through at least two independent institutions. Following that, a digital organ twin should be created on the blockchain. At this point, matchmaking between the organ to be transplanted and the possible recipient can be conducted. This process should be as automatized as possible through the use of AI for example. In the transition face, the independent central organ transplant institution will determine possible recipients and coordinate the transportation of the patient or organ. As soon as the patient has successfully received the needed organ, the blockchain will become updated, indicating that the patient and the organ aren´t available anymore and shouldn’t be considered in further processes. An overview of the use case solution is shown in Figure 4.

To restore trust in the organ transplantation process, which was shaped by

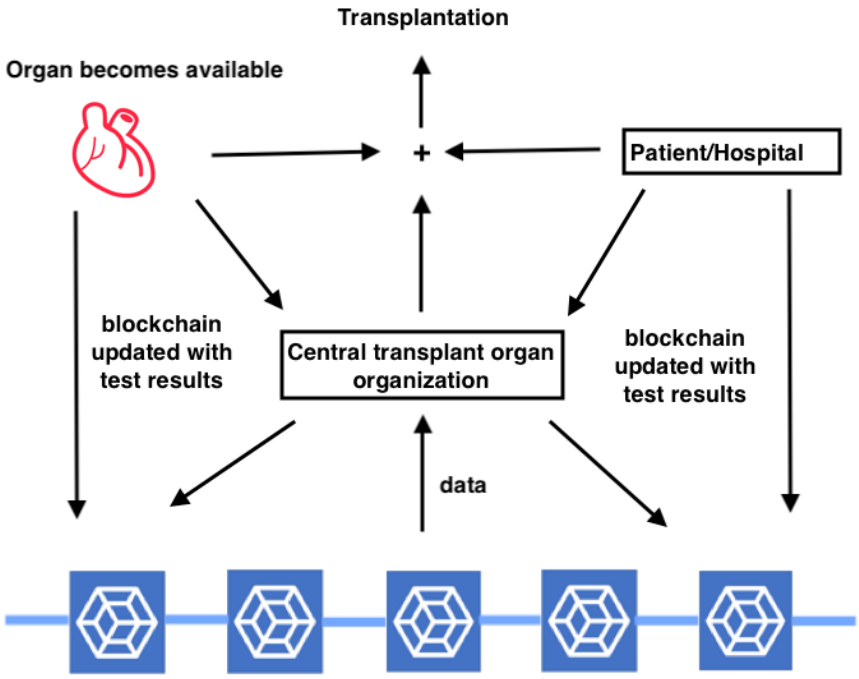

Figure 4: A visualization of implementing blockchain technology in the organ transplantation process

mismanagement and corruption in the past, blockchain technology is implemented to provide transparency and reduce the need for intermediaries. Health data, important for the decision-making process of distributing organs, will be recorded on the blockchain. To provide even more trust, the necessary test results should be evaluated by at least two independent organizations. As soon as a new organ becomes available, a digital twin is created on the blockchain to start the patient-organ matching process and ensure transparency. Although a central transplant organ organization will remain important in the early stages of the implementation, AI could eliminate the need for a central organization to oversee the process completely.

Technical specifications:

The centerpiece of the presented use case is, of course, the blockchain to create completely new levels of transparency, immutability, and trust. For the proposed use case, I would establish a Proof-of-Stake algorithm to find consensus. The stakeholder or validators of the blockchain should be made of the participants involved in the process, as well as the government and other patient-related or independent institutions (e.g. the WHO). This consortium will be able to govern the blockchain to allow changes to the existing protocol as well as run a distributed and significant amount of full-nodes to ensure decentralization and

functionality. As we are dealing with highly sensitive data, the core network would be a permissioned private network. But to ensure transparency, I would choose an underlying blockchain protocol, that allows interoperability with public permissionless blockchains to build a hybrid blockchain solution. If anyone could access the information, which or of course would not contain any personal information that could be used for identification, a completely new level of trust could be established. Although one central blockchain for the global organ transplant process would be preferable, interoperability between related blockchain networks will be highly important, as many solutions are likely to evolve over time. In either way, the chosen blockchain protocol should be able to allow sufficient scalability and high throughput.

The consortium formed to govern and run the blockchain would additionally develop a specific interface for participants in the organ transplantation process to interact and update the blockchain in an intuitive and easy way. The patient as well as the organ to be transplanted could both receive their digital twin on the blockchain to enable save and tamperproof record entries. Each update of the patient data would be fully transparent, as participants like hospitals or physicians would use specific private keys to access their functionality and conduct any change to the patient data. One way to make changes to a certain digital twin record would be the use of specific tokens. A certain patient-specific address could therefore receive certain tokens (e.g. indicating their molecular makers) from an authorized institution, which would be visible to anyone accessing the blockchain. As already mentioned previously, the whole process of matching organs with possible recipients could be highly automatized. With the help of big data and AI, the software could easily identify suitable match partners based on the transparent data available through blockchain technology. Still, as a transition to new technologies always takes time, the implementation of a blockchain based solution with an independent organization to match the organs might be easier to implement in the upcoming years. Nevertheless, the implementation of blockchain technology in the matching process or organs and possible recipients offers incredible advantages over existing solutions and might restore much-needed trust in the system.

LIMITATIONS:

In systems where the availability of an organ has a significant influence on the life expectancy of people, the willingness for fraud and misbehavior is often high. Therefore, it isn´t surprising, that existing systems solely controlled by humans, led to significant mismanagement and corruption in the past. As such, as long as humans participate in the organ transplant distribution process, they will remain the main source of error. Especially in the first phase, where the matchmaking process will not be fully automatized by the use of big data and AI, certain people could still try to trick the system to their own benefit. Still, the implementation of blockchain technology will make it significantly harder to do so and decrease the chances of success. But even if fully automatized, one of the limitations will still be the consortium governing and running the blockchain. If coordinated, consortium members could still try to influence or change the protocol to their own favor. In addition, one of the key limitations is still a possible lack of participation. If not every organ is distributed through the newly established system or framework, the success of the use case will be decreased significantly. As such, extensive user-education needs to happen to increase adoption. Besides, the new solution has to be communicated to the general public to establish a new level of trust and willingness to donate organs, as this will still be the key limitation of the overall problem.

5. ETHICAL QUESTIONS AND CONSIDERATIONS OF NEW TECHNOLOGIES IN THE HEALTHCARE SYSTEM

As already mentioned briefly in the introduction of this paper, the first and best-known ethical framework dates back to the days of Hippocrates, thousands of years ago. Although the oath was updated over the years to fit changing requirements over the years, the key messages stayed the same. As such, medical students all around the world still take the oath of Hippocrates in the first days of their medical studies. Although the majority of statements will eventually even be valid thousands of years from now, most ethical frameworks our current world is based on, date back many years [1, 2].

With the increased technologization of medicine and the healthcare sector, more and more ethical questions and consequences were raised in recent years. One of the key innovations, that at least in western countries like Germany led to the formation of ethical committees, was the development of modern kidney (renal) replacement therapy known as dialysis [26, 29]. Up to that point in time, a loss of renal function due to acute or chronic reasons was very difficult to treat. In the majority of cases, there was no real treatment and people would die sooner or later due to the retention of water, waste products, and toxic molecules in the body. Although you may think, that a loss of kidney function is something rare and without a large impact on the healthcare system, it´s quite the opposite as different studies estimate. Especially as we keep in mind, that the function of our renal system constantly decreases with age. As such, this topic is even more important than ever, as the average age of our society is constantly increasing in many countries around the world. It therefore isn´t surprising, that the invention of dialysis led to some serious ethical questions and discussions. Now, the life expectancy of people with a loss of kidney function can be increased significantly. Although this might sound like a complete success story of modern-day medicine, which it definitely is in my opinion, there are important aspects to keep in mind.

Although medicine shouldn´t be defined by any economic background, it´s often quite the opposite in many countries around the world. Even in well-developed countries like Germany, hospitals are led just like companies, with the need to at least cover the cost of operation. As a result, technical innovations like dialysis led to the question, whether it makes sense to prolong life at all costs.

Although the ecological standpoint might not be the leading consideration in this question, it´s still always present in the mind of physicians with executive roles in hospitals. The question of how long life should be extended is especially important if we keep situations in mind, where there is no realistic chance of receiving a new organ due to severe other diseases or very high age. In the majority of cases, dialysis is used as a so-called “bridge to transplant”, where the dialysis is used until a new organ becomes available. This is important, as we need to keep in mind, that even as good as dialysis is today, it won´t be able to replace every natural function of the kidneys. As such, other organs of the human body still suffer due to the loss of normal kidney function. The best solution is of course the replacement of the organ, which led to even more critical questions itself.

The possibility to transplant organs from one human to another was made possible due to the innovation of new medication, able to suppress the natural function of the immune system. Before that, every attempt to replace an organ would sooner or later result in a rejection of the transplanted organ and a loss of function. From an ethical perspective, the ability to transplant an organ from one human body into another one led to serious discussion [30]. One of the most important questions is of course, who should preferably receive the organ? Does a young adult with many years left to live have a higher priority or right to receive the organ compared to an elderly person, with a lower life-expectancy but in much higher or urgent need for the organ? Those questions are hard to answer absolutely and even lead to important discussions on a regular basis today. But even if there is no absolute answer, an ethical framework or recommendation needs to be established, to provide guidance to deal with new medical or technological innovations.

In my opinion, technological innovations like the internet, artificial intelligence, big data, and blockchain technology will have a comparable impact on society like the development of dialysis years ago. As such, the need for an ethical framework is very high. Especially as the development and usage of new technologies won´t stop until an ethical framework is established. In countries like Germany, where ethical frameworks and guidance has a long tradition, the lack of early decisions could lead to possible life-changing opportunities being missed almost completely. New technologies like AI

will evolve over time, with or without ethical guidance. This is why I personally think, we should start to understand the possible impact of new technologies as soon as possible.

Although I am convinced that the impact of new technologies like AI or blockchain technology will be tremendous and change the way medicine is defined completely in the upcoming years, there are still some crucial ethical and socioeconomic factors to be considered. If we think about the availability of more (real-time) time data to be available due to blockchain technology, big data will lead to a significant improvement of the existing systems in terms of identifying and treating especially rare diseases. Big data could lead to a faster development of new pharmaceutical drugs, help to identify possible side effects and interactions. Still, the broad availability and collection of data will have a serious impact on the lives of millions of people if we think about possible hacks or data breaches [31]. In addition, if the data becomes available to the wrong company, government or institution, the consequences could be fatal. Health insurance companies, for example, could increase the monthly payments based on the available data or even refuse to insure a certain person. Medical data is highly sensitive and security breaches could lead to a transparent society [32]. Companies could stop recruiting certain persons based on their medical history if for example some conditions like depression or burnout are known. The relevance of this topic becomes even more important if we think about the broad testing and availability of genetic data in the not too distant future. Although most scenarios connected to genetic data are currently related to movies, this will definitely change in the upcoming years. Sequencing the whole genome was highly complex and expensive only a few years ago (around 1 million USD). Now, due to the broad technological progress, the price to sequence has dropped to around only 300 USD. It therefore shouldn't be surprising, that the field of personalized medicine, where genetic information is used to create unique treatments, is one of the next big topics in the evolution of modern-day medicine. With more genetic data being available, new technological methods such as blockchain technology are needed to provide better safety, transparency, and trust in the storing and the sharing process of genetic data [33]. Blockchain technology will definitely have a significant impact on the way we store and access data, not only limited to

genetic information. Still, the availability of genomic information in general has to spark some critical ethical discussions. Although the benefits for the patient become clear, the full scope of possible downsides of having genetic information available and potentially exposed, are hard to grasp.

Even today, the possibility to check for genetic disorders before babies are born regularly leads to extensive discussions in our society. The broad availability of data may even lead to some selective processes in our society for the general public. The availability of new technologies, especially in medicine in the healthcare sector is therefore not always absolutely positive. Still, as the benefits clearly overweigh possible downsides, the need for ethical discussion is higher than ever. If we think about AI for example, recent studies suggest, that the impact on especially the medical sector will be huge. This isn´t surprising, that even today, AI can help physicians to treat and diagnose patients in a significant improved way. Due to the increased level of digitalization in the field of radiology, this was one of the first prime use cases of AI in medicine. AI can help to identify possible suspect lesions on thoracal X-rays to identify breast or lung cancer. In addition, used in connection to scans of the skin, AI can help to find possible malicious lesions. But due to the availability of more data even in other medical fields, AI can now for example be used to potentially identify psychological diseases or even early forms of dementia. In every case, the use of AI can significantly improve the performance and life of physicians. Without a doubt, the availability of more data and the combination with other technological innovations such as IoT or especially blockchain technology, AI will significantly transform the field of medicine in the upcoming years [8].

But although the potential benefits of implementing AI in the medical field might be very high, it led to some extensive ethical discussions. Especially early versions of AI had some serious downsides. Without the availability of large amounts of data, early implementations lack accuracy. Although this may “only” lead to some high economic impact or consequences in many fields other than medicine, it can be fatal if physicians rely on the technology. This might have significant consequences, as the lack of accuracy can lead to a loss of trust in potentially life-changing new technologies. Studies suggest, that early AI implementations have to be evaluated critically, as

the availability of data can even lead to the development of biased decision-making. In some cases, the availability of excessive data on the unfiltered internet even led to some form of racism. One of the reasons behind this is, that technology is not neutral. Technology is formed by programmers, whose values are embedded in the code, intentional or non-intentional. As a result of human innovation, the use of any new technology should be evaluated critically. This is especially important, if you think about the significant consequence, biased decision making in the medical field could have (e.g. in the organ transplantation process). In addition, the ethical consequences of new technologies like AI become even more important, as the implementation of AI for example, will eventually start replacing certain functions of physicians over time [34]. More and more processes can and will be automatized in the future, leading to a lower direct human influence on many different sectors. As a result, the implementation of extensive ethical guidance and frameworks is important, to specifically define the actions and limitations of new technologies. This should become evident, as it needs to be defined, who is responsible for actions based on or with the help of technologies like AI. This might not be relevant for the majority of cases, where the use of technology will lead to benefits for the patient, rather than become important for treatments or actions resulting in certain unwanted outcomes. But this will not only be important for implementations of new technologies in the healthcare system if we think about self-driving cars and the possibility of accidents caused by software (e.g. AI and IoT). The relevance of ethical guidance is therefore more important than ever, as the implementation of new technologies will change the world as we know it completely. Especially in the healthcare system, where ethical questions and discussions have a long-lasting tradition, the need for regulation is very much needed to allow new technologies like AI, big data, or AI to be implemented and provide a tremendous impact on the life of people around the world.

6. CRITICAL REFLECTION & CONCLUSION

Following the results presented in the previous chapter, we will now focus on some critical reflection of the findings of this paper. One of the major things to keep in mind, evaluating a technology-focused paper or research in general, is the relative immaturity of the market and the new emerging technologies themselves. If we focus on blockchain technology of example, although roughly 12 years old at the time of writing, it is still incredibly young in terms of technology. This becomes even more evident if we focus on the level of adoption of blockchain technology in our current society. Although many companies increasingly start to look into an implementation of blockchain technology, we are still early in terms of overall adoption. At this point, it is important to distinguish between the adoption of blockchain-based cryptocurrencies, such as bitcoin and Ethereum for example, and blockchain technology itself. The level of adoption or at least recognition of cryptocurrencies is of course several magnitudes higher than the underlying technology. This isn´t very different for other new emerging technologies such as AI, big data, or IoT. Although some of them are around for a couple of years already, the general level of adoption is still comparably low.

As such, the results and conclusions of this paper and every research related to those emerging new technologies have to be evaluated in the context of the publication. Although I tried to present use cases, that should remain important and viable in the upcoming years as well, the presented results should be seen more like a snapshot of the general state of the art at the time of writing. The level of digitalization of our current world is happening at an incredible speed, which of course also accounts for our healthcare systems. As already mentioned briefly before, in my personal opinion, the healthcare system will be one of the prime use cases to implement new technologies such as blockchain technology, AI, or big data.

The healthcare system can greatly benefit from the use of blockchain technology as it will provide more transparency, security, and trust for all participants. But even with all the advantages of blockchain technology named over the course of this paper, we should always keep in mind, that due to the rather new age of the technology, it still has some possible vulnerabilities. Like with every software application, even if audited by several independent entities, there can still be bugs, hacks, or exploits. As a result,

the chosen blockchain for each of the presented use cases in this paper should be tested extensively. This is really important, as severe hacks of one specific blockchain protocol might not only affect the project itself, rather hurt the general reputation of blockchain technology in the public. To prevent this, not only extensive testing is needed, rather than the general public needs to be educated about blockchain technology. Although the vast majority of people won´t be interested in learning about new technologies, the general public should know about the huge benefits implementation of blockchain technology could have on their life. Especially if we think about the development of digital patient records, blockchain technology will enable the patient to be the sole owner of his data, which is a huge change to our current existing system. The implementation of blockchain technology will therefore not only lead to a change in existing structures, rather to completely new ways of interaction and of course ethical discussions and consequences. As blockchain technology will enable large amounts of data to become available in a secure and anonymized way, it will facilitate the adoption of other heavily data-reliant technologies such as AI. Each of the new technologies will of course have its very own advantages and disadvantages, but blockchain technology is likely to remain the necessary backbone for implementation. Although blockchain technology has of course the potential to change our healthcare system permanently, there are still possible limitations. Besides the relative immaturity of the technology in case of adoption and security, blockchain technology will of course not be an answer to every existing problem. If we think about possible technical limitations for example, it would not make much sense to save every available data directly on the blockchain itself. The more information is stored directly “on-chain”, the more storage will be required to download the complete blockchain history. If we think about the size of the bitcoin blockchain for example (around 300 Gb of the time of writing), without storing any sort of storage extensive data, it becomes evident, why it doesn´t make much sense to store every kind of data directly on the blockchain. This becomes even clearer, if we think about the huge amount of medical data produced every day and their need for extensive storage capacity in case of computer tomography (CT) or magnet resonance therapy (MRT). Although there are already blockchain protocols available,

where a huge amount of data can be stored (e.g. Filecoin, Sia), it would neither be efficient nor lead to any sort of cost reduction [35]. As such, hybrid solutions need to be developed, to combine blockchain technology with the storage capacity of traditional databases. Blockchain technology could for example be used to assure the integrity of the data stored in databases. This is only one limitation of current use cases of blockchain technology in the healthcare sector and the reason why I personally think, a holistic and widely adopted blockchain-based digital health record solutions will still need years to reach the market.

Despite the technical limitations, that could prevent or slow down the adoption of blockchain technology, there are of course some non-technical limitations as well. As blockchain technology will have a significant impact on many companies and people currently working in the healthcare system, resistance to change is always important to keep in mind. Especially people that are already working in the healthcare system for many years, maybe about to retire in only a couple of years, won´t be happy to change their way of work [36]. Especially if we keep in mind, that in many countries, existing systems are still largely paper-based. To implement blockchain technology successfully, you would need to further digitize existing structures. This can lead to heavy resistance, as it will change the way many people will need to work completely [37]. In addition, at the current state, especially in more conservative nations like Germany for example, there is a significant lack of knowledge in regard to new emerging technologies. The level of knowledge regarding blockchain technology for example is still very concentrated at an academic level. Although some companies are increasingly interested in blockchain technology, most don't have a distinctive "blockchain team", rather than a single person able to dedicate a few working hours on the topic. Therefore, the lack of knowledge in regard to new emerging technologies such as blockchain technology or AI is a major problem in currently existing systems.

Another major limitation of blockchain technology based use cases in the healthcare system is, that most solutions are developed for people, that are not very tech-savvy. In contrast to younger generations, that grew up with the internet, a huge percentage of people in our current society lack technological knowledge. Although most of the currently proposed use

cases, like the digital patient record solution, could of course benefit the younger generation, the people of older generations are statistically the ones, to have more impact on current healthcare systems. This is a major problem to consider, as the majority of people could be overwhelmed by the implementation of new technologies [38]. As a result, even the best developed technological improvement, possible to provide significant benefits for patients, could still find no major adoption. Especially in healthcare, where existing structures are complex, the lack of adoption from a patient side often results in a step back to previous lesser digitized solutions.

Overall, the implementation of blockchain technology in the healthcare system has the potential to change existing structures permanently, leading to huge benefits for every participant and especially the patients. In my opinion, it is a necessary step in the process of digitalization, able to provide the necessary framework for other new technologies such as AI, IoT, or big data. But despite all the potential benefits or advantages an implementation of blockchain technology could have, there are still several technical and non-technical limitations to keep in mind. Although widespread adoption of blockchain technology might still be years away depending on the use case, it is still definitely worth facilitating, to provide the necessary framework for digitalization of healthcare systems all around the world.

At this point in this paper, I want to recapitulate the research questions very briefly and focus on the main conclusions.

Key research question number one focused on possible advantages of blockchain technology over existing solutions in the healthcare system, challenges, as well as the aspect of feasibility. The main results and conclusions to **Research Queation 1** are summarized below:

Current solutions in the healthcare sector feature a low level of interoperability, which are inefficient and time-consuming.

Blockchain technology can offer significant advantages over existing solutions in the healthcare sector due to its more decentralized, transparent, and immutable architecture.

Blockchain technology can provide the necessary framework for other

emerging technologies like big data or IoT in the healthcare system.

Increased digitalization and the implementation of new emerging technologies such as blockchain or AI can change our understanding of modern-day medicine completely.

With blockchain technology, the need for third parties or intermediaries interacting with sensitive patient data can be minimized.

Following RQ1, the second key research question focused on possible use cases of blockchain technology in our current healthcare system. The identified and presented use cases for **Research Question 2** are outlined as follows:

Blockchain technology for pharmaceutical drug supply chain management

A blockchain technology based token reward system for medical service providers and the general public.

Blockchain technology in the incentivization process of health data.

Blockchain technology for organ transplantation processes.

The possible main limitations for the provided use cases include the lack of blockchain specific knowledge and workforce, the lack of uniform frameworks and guidelines for digitalization in the healthcare system, sufficient motivation to change from a governmental perspective, the development of user-friendly and intuitive applications, as well as sufficient interest and adoption in the society.

Extensive education of every participant in the current healthcare system needs to happen to increase adoption and the success of every blockchain technology based solution.

Ethical questions and considerations of the implementation of new technologies in the healthcare system were addressed as part of **Research Question 3**, and the main results and conclusions are the following:

Most existing key ethical frameworks and guidelines date back many years.

Digitalization and the integration of new emerging technologies, such as blockchain technology or AI, will have a significant socio-economic impact and require new ethical guidelines and frameworks to be established.

Handling of highly sensitive patient data (e.g., genomic data) will require important ethical discussions and data ethics.

Automatization in medicine will require new laws and regulations established to define liability and responsibility for technological innovations (e.g., AI).

As blockchain technology, especially in combination with AI or IoT will have a significant impact on current healthcare systems and our understanding of medicine, ethical guidelines need to be established to facilitate adoption and development.

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