Addressing Counterfeiting and Fraud Concerns in Healthcare Packaging and Labeling with Blockchain: Opportunities and Challenges

ANTONIO PESQUEIRA[1], MARIA JOSÉ SOUSA[1], ANDREIA DE BEM MACHADO[2]
[1]ISCTE - University Institute of Lisbon,
Av. das Forças Armadas, 1649-026 Lisbon,
PORTUGAL

[2]Universidade Federal de Santa Catarina,
Florianopolis,
BRAZIL

Abstract: - Blockchain technology (BT), originally developed to facilitate secure digital monetary transactions, has recently gained significant traction in various healthcare sectors. Characterized by the exponential growth of sensitive data, the healthcare sector is poised to witness the emergence of BT. This emergence is primarily driven by the pressing need to globally expose, protect against threats, ensure confidentiality, and establish traceability for the plethora of sensitive data continuously generated by the healthcare industry. The healthcare supply chain focuses on traceability due to the prevalence of counterfeit and recalled drugs. Managing operational constraints such as temperature, humidity, and air quality within specified parameters is paramount. The various processes involved in international trade transactions contribute to the creation of numerous records, each of which is meticulously entered into the systems of the companies involved. Therefore, the problem set for this study was: What are the challenges and prospects for BT in the healthcare sector? To answer this question, the following objective was set: describe and examine the challenges and prospects of BT in the healthcare sector. In addition, a key research objective was to identify specific applications and use cases that can benefit the most from this technological advancement. In line with the research objective, a systematic review of all studies BT for traceability, anti-counterfeiting, and fraud detection was conducted from January 2023 to September 2023. Using robust tools such as VosViewer, we used bibliometric metrics from the renowned medical repository PubMed to construct and visually represent data analysis networks. BT shows remarkable potential to improve traceability and optimize supply chain management within healthcare organizations. The study includes a deep analysis of blockchain capabilities, including smart contracts, identity management, access control, and zero-knowledge proofing.

Key-Words: - Blockchain, Healthcare, Traceability, Supply Chain, Pharmaceuticals, Innovation.

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1 Introduction

The pharmaceutical industry and global public health face several challenges, such as counterfeit medicines in circulation, which pose an enormous threat to patient safety but also undermine the legitimate therapeutic pathway. The current challenges posed by counterfeit medicines have been exacerbated by several factors, including the complexity of supply chains, lack of transparency, and inefficiencies in security measures. New solutions must be developed that require more serialization, traceability, and authenticity control mechanisms. Protecting the quality, safety, and efficacy profiles of available medicines is critical to the quality of care and treatment for millions and is a vital component of the global healthcare system. The overall economic cost losses and indirect cost burden associated with counterfeit drugs, and fraudulent products are enormous, but then also the associated risks for patients, including treatment failure, disease progression, and adverse drug reactions, [1], [2], [3].

Then, the ability for patients to track and verify the authenticity of medicines can also be a challenging task, as system connections and harmonized supply chain mechanisms in data and information exchange are still an area for improvement, especially when the product moves from different healthcare organizations to others (e.g., from manufacturing companies to pharmacies or hospitals). However, more advanced counterfeiters can also introduce counterfeit products by completely bypassing regulations and procedures, sometimes due to a lack of preventive and control measures by governments. In addition, the increase of e-commerce and online pharmacies then poses several different challenges due to the availability of digital channels that might exist without control or regulation and make more easily and freely available for counterfeit drugs to reach consumers directly, [4], [5].

Recently, Blockchain Technology (BT) has emerged as a promising solution in various healthcare and pharmaceutical use cases due to its ability to provide security measures, decentralized identity management, and traceability of transactions along with protection, [4], [5], [6].

BT, as a distributed ledger that enables transactions to be secured and with cryptography as a key pillar, enables different opportunities in terms of activating capabilities as a decentralized distributed ledger. However, BT's capabilities in terms of decentralization, transparency of operations, and immutability are also key components in preventing the circulation and spread of counterfeit drugs. Recognizing the importance of today's pharmaceutical supply chain challenges and bringing some BT considerations to improve the security and traceability of these supply chains is a growing need among today's executives, [5], [6], [7]

Overall, the healthcare industry is experiencing a large and even exponential increase in the volume and complexity of connected data. Compared to centralized and still very traditional data management systems, the likelihood of cyber-attacks is higher compared to decentralized solutions where BT provides a more secure platform through cryptographic security measures. These are seen as qualities to address the supply chain challenges faced by the pharmaceutical industry. By providing a transparent and immutable platform for transactions, BT offers a method to create a record of every step in the drug supply chain process from manufacturing to distribution, effectively preventing counterfeit drugs, [2], [3], [7].

In the following sections, BT is analyzed in more detail, highlighting its potential applications in the pharmaceutical industry and providing a balanced analysis of its advantages and disadvantages. The healthcare supply chain management (SCM) issues related to counterfeiting and fraud will be key points discussed throughout the research paper, with the main objective of assessing how BT can improve supply chain security and efficiency. Some of the most highlighted benefits of BT in terms of SCM have been around its ability to change and also in terms of preventive mechanisms around tampering and avoidance of false product and manufacturing identification information. However, recent research on BT clearly shows that securely managing healthcare-related data, which can be extremely sensitive when it comes to pharmacovigilance or patient-related data, still requires further assessment and a better understanding of its confidentiality and integrity. Some of the available literature strengthens the supporting arguments that BT can offer various advantages in terms of overcoming barriers in the areas of SCM such as serialization, packaging, and labeling in terms of product identification, traceability, and many other areas. BT capabilities around traceability offer several different advantages in terms of traceability options and also according to some of the highlighted literature reviews, [1], [3].

In line with the key concepts described above, this study examines the impact of technology on the pharmaceutical sector, with a particular focus on packaging and labeling practices. In addition, the paper examines how BT can be used to improve traceability and security within the supply chain, combat counterfeiting and fraudulent activities, and improve medication adherence and patient safety. It also explores the opportunities created by blockchain to simplify operations and promote data sharing among participants in the healthcare network.

As a result, the purpose of this paper is to foster a deeper understanding of the role blockchain can play in healthcare and to catalyze further research and development in this area of growing interest.

Also, this research paper will examine the related regulatory concerns, and the ethical and compliant use of BT in healthcare, but then also provide considerations in terms of standards and frameworks to facilitate the integration of BT into specific areas addressing counterfeiting and fraud concerns.

The scope of this paper includes a systematic literature review in terms of the application of BT in healthcare with a critical analysis of the key benefits and challenges in terms of BT adoption, but also with an overview of current BT implementations within the industry.

Intending to provide key considerations for the future development of BT in specific SCM areas, another key supporting objective is to provide policymakers, industry leaders, and healthcare professionals with insights and perspectives on the strategic implementation of BT in healthcare.

The research objectives guided a review of studies on technologies to improve traceability, combat counterfeiting, and detect fraud between January 2023 and September 2023. Using tools such as VosViewer, we analyzed data from the renowned medical database PubMed to visualize data analysis networks. Overall, this research will show that BT can have a significant impact and depends on the context proposed. Some of the conclusions highlighted present differences in terms of what was the applied context, but also accordingly the impact on the industry.

The opening section paves the way for an in-depth exploration of the impact of BT on the pharmaceutical sector. It highlights the issue of drugs in supply chains as an obstacle that requires innovative remedies, introduces blockchain as a plausible solution to this problem, and outlines the objectives, scope, and importance of the research paper.

2 Theoretical Background

2.1 Drugs Traceability

The concept of drug traceability involves the concept of explaining the ability to track and trace the movement of any pharmaceutical drugs through the entire supply chain from manufacturing to distribution to any specific healthcare organization like hospitals pharmacies or others. Overall, this process involves documenting and monitoring the ability of each step the drug takes to ensure the authenticity, quality, and safety of the designated product. The drug traceability process is crucial from the perspective of five key concepts. The first is related to counterfeit prevention, where tracking the movement of drugs makes it easier to identify and prevent the introduction of counterfeit products into the supply chain, where several of the concerns associated with counterfeit drugs are risks of harmful use and, fatal conditions associated with patients, [2], [7].

Then the ability of recall efficiency if a drug needs to be recalled due to safety concerns, and traceability allows for a quick and efficient removal of the affected product from the market, minimizing potential harm to patients. The third key area is related to supply chain security, where traceability enhances the security of the pharmaceutical supply chain by providing detailed information on the movement of medicines, helping to prevent theft, diversion, and other fraudulent activities, [8], [9], [10].

The fourth key component is related to regulatory compliance, where different countries have regulations that require the traceability of drugs, most of the time also related to the serialization of national regulations and procedures. The last major step is related to transparency and trust, where traceability contributes to transparency in the supply chain and builds trust among consumers, healthcare providers, and regulators regarding the quality and safety of pharmaceutical products. To implement drug traceability, stakeholders in the pharmaceutical supply chain use a variety of technologies and systems, including serial numbers, which are unique identifiers for each drug package and enable individual tracking. Barcodes and QR codes can be scanned at various points in the supply chain to track the movement of medicines. But also, RFID tags, which provide another way to track drugs without the need for direct line-of-sight scanning. BT provides a secure, immutable ledger for recording transactions, making it ideal for improving the traceability and security of the drug supply chain, [9], [10], [11].

In the context of SCM, and particularly in the context of healthcare, the need for robust trust and transparency requirements for medicines is fundamental. The drug traceability component assumes a relevant journey as a critical process to ensure that all steps are taken to achieve visibility of the product lifecycle and transportation details.

The overall vigilance is also related to compliance and product quality control, also in terms of increasing preventive control mechanisms in case of a necessary product recall. And here the use of data analytics and data reporting assumes a very relevant role in terms of improvement areas and defining strategies around supply chain management excellence. Traceability is also a key component in terms of order and financial control, but also in terms of inventory management, and other relevant SCM reporting areas, [12], [13], [14].

The entire pharmaceutical industry involves complex tasks in terms of SCM, starting from the distribution of raw materials, through the production of samples and the final drug substance for clinical trials, to the packaging, labeling, and distribution processes. Overall, the entire lifecycle of the process not only starts from the creation and distribution of drugs but also covers the final path of patient access to these drugs. In terms of access, it can go from the investigational or approved final product through clinical trials and regulatory assessments to a pre-marketing or commercialization phase. Where in between all the processes the supply chain management processes in terms of overall cycles can involve several different stakeholders. However, throughout the process some of the major challenges are related to the lack of data transparency and even mismatches or inconsistencies as several process steps are connected, [13], [14], [15].

The literature points in the direction that several pharmaceutical manufacturers invest different resources in terms of regulatory functions, but very few resources are invested in terms of transparency or data management governance protocols to ensure transparency and traceability, and sensitive areas such as side effect tracking, and adverse event monitoring are ignored along with effective product traceability. The literature also highlights the importance of having harmonized and standardized data protocols in terms of having different stakeholders involved in the various traceability processes under the same common understandings and procedures, [14], [15], [16].

Future improvements aim to integrate all process steps into a common layer that provides comprehensive data access at each step and across networks, reducing the time and effort required to retrieve information. However, initiating these advancements and expanding data ownership in healthcare product traceability remains a daunting task for many companies. The healthcare traceability process involves a wide range of stakeholders, including clinical supply chains, medical device manufacturers, and support services such as contract manufacturing organizations and regulatory agencies. For manufacturers, ensuring that clinical shipments are tracked and monitored from production to distribution and linked to healthcare providers and patients requires rigorous quality assurance, cold chain, and inventory management. Real-time access to the full scope of supply chain processes remains elusive for regulatory and compliance organizations, making it difficult to define the product lifecycle on a single platform and monitor activity in real-time, [16], [17].

Future areas of improvement may focus on increasing process efficiency by digitizing manual or paper-based processes that are currently tracked across multiple document repositories, leading to reconciliation difficulties. Various technology solutions, in particular BT, are being explored to link these document repositories or digitize their content for improved accessibility and analysis. Such technology integration can facilitate better decision-making among stakeholders and contribute significantly to the success of supply chain initiatives, [7], [18].

2.2 Counterfeit Drugs

The proliferation of counterfeit medicines poses a serious threat to the health and lives of millions of people who rely on the authenticity and efficacy of their prescribed medicines. The spread of counterfeit drugs including biological products highlights the pressing importance in terms of having preventive tactics and measures to prevent several different risks and overall placing the lives of several different patients in dangerous conditions. Counterfeit or falsified drugs present several different devasting effects and outcomes consequences in terms of having patients who are not aware of what kind of drugs are accessible and available, [18], [19], [20].

In terms of the overall SCM, some of the most important and responsible players are the manufacturing companies, but also wholesalers, public health authorities, and retailers. These players have different responsibilities in terms of understanding the whole landscape and how production, transportation, and distribution can enable effective countermeasures against the spread of counterfeit drugs. The entire network has received different attention from academia in terms of having different procedures, and technologies in tackling the overall challenges in terms of tracking the identification and movement of drugs from production to the final prescription or dispensing point and having throughout the process mechanisms for verification, authentication and validation of identification and traceability areas. But not only Public health implications are at the core of the concerns, but also in terms of impact on the reputation and financial stability of various companies. But also, the need for different protective measures that can work across spectrums of action and areas of intervention, [21], [22].

Some of the major concerns are in terms of quality standards, where counterfeit drugs don't have active ingredients and even look like genuine products, they don't have any therapeutic value. In several developed drugs, these counterfeit drugs may be associated with sensitive areas such as opioids or antibiotics, or even substances that may have abuse potentials such as morphine or its analogs. The overall safety and efficacy risks of counterfeit drugs can range from undisclosed ingredients to the presence of substances that can harm the health of a specific patient or large groups of patients, such as immunosuppressants, or vulnerable groups, such as the elderly, [11], [17], [23].

2.3 Blockchain

BT's establishment with Bitcoin in 2009 as a sophisticated database is careful to the exceptional detail of the transaction history's international picture. As a component of the database, the block's continuous evolution designates them as the means of instantly checking whether an asset is owned. The blockchains' public access and worldwide presence as an infinite number of nodes and lacking administration make BT valid only when objectively, there is a confirmation method. Bitcoin blockchains, the most renowned in terms of dependability and security, trust complex mathematics and expenses for their consensus arrangements of any use, such as Proof of Work (PoW) and Proof of Stake (PoS) is different, predominantly due to alternative cinematographic or arbitrary validator selections, but since the PoW replaces computational technology use. The fact that blockchain allows automated contracts whose processes are based on various trigger circumstances illustrates the above illustration of the network's characteristics as a facet of openness, lawlessness, and censorship contrasting the network's grey face. Nonetheless, reconstruction is complex and time-consuming compared to current practices based on trusted intermediaries, such as digital crawler remuneration, lease follow-up, and upstream tracking of products, [17], [19], [24].

Blockchain's decentralized architecture eliminates the central authority, which is essential in addressing issues related to centralized power and ensuring balanced computing resource distribution. Such architecture ensures transparency, as it allows protocols to verify past transactions and record ownership independently, essential in counterfeit detection, ensuring traceability and serialization model validation. Again, integrating blockchain in the packaging and labeling of the healthcare sector is a new dawn in data exchange, including the ability to work on one logical record for all versus separate records and the authenticity and security of documentation. The cryptographic approach will enhance counterfeit drug detection and ensure a framework that backs up data management across different jurisdictions; hence, it will provide fail-safe and confidential data that speeds up the process, increases security levels, and boosts trust and transparency on the traceability and validation of medicine. It is a total shift in the paradigm of the healthcare sector the measures to facilitate the effectiveness of blockchain in healthcare are summarized in. The algorithms and models in this research area have been used to develop smart contract protocols for healthcare applications, [23], [24].

Furthermore, the engineering perspective of anti-tampering mechanisms also involves the development of anti-tampering mechanisms for drug packaging that are linked to BT. For example, newly redesigned packaging that makes it almost impossible or noticeable to replicate or destroy it, and sensors that record and transmit any tampering with the packaging to the blockchain. Although there is a broad range of connections, BT allows patients to independently define the identity of their medicines. It is the ambition of engineering research in that field to create an easy-to-use interface, and system-led guides enabling patients to safely and comfortably access blockchain data. One example is the serialization of drugs utilizing blockchain; the business is presently experimenting with the technology to assign a distinct identifier to each unit of a drug to trace a product through the supply chain. Temperature tracking is also being taken using blockchain-based systems to evaluate and save temperature-sensitive medicines through the supply chain, [24], [25], [26].

3 Methodology

This section delves into the chosen research methodology to validate and address the posed research questions, focusing on assessing various models and use cases for BT applications and processes within the healthcare industry through a systematic literature review.

A systematic review of the existing literature was conducted to cover various models and applications of BT in healthcare thoroughly. This methodical approach was supposed to fill in knowledge about the problems and opportunities of implementing BT in healthcare and demonstrate recent improvements and expectations according to this technology's deployment. This methodology is focused on the meaningful frame of the review process itself; the elements of methodological strength include formulating research questions, choosing filter criteria of relevant studies, selecting analysis methods, and effective execution of data analysis. The primary question was related to identifying the current applications challenges and perspectives for BT in fighting fraud and improving traceability in the healthcare industry. Additionally, the question was purposed to identify the influences of current BT applications on healthcare organizations' antifraud and traceability activities [8], [11].

To achieve a precisely comprehensive review in the timeliest manner, an elaborate software tool, VOS Viewer, was used due to its ability to conduct complex data analysis. This methodology implied using co-occurrence analysis, analysis of the strengths of the association, creation of network graphs, and exploration of the author-level and citation-network levels. The latter aspect allowed for identifying co-authorship relationships through mutual references and a co-link matrix. By applying advanced bibliometric methods, the review selected relevant keywords and points of data, as the importance of the data analysis process cannot be understated. These techniques specifically helped in cross-validating the findings of bibliometric and network analysis. It should be noted that the objective was to map and understand complex data links and structure connections in academic articles based on the articles indexed in the PubMed database. This involved understanding co-occurrence relationships including co-words, co-citations, and co-link matrices, which gave a fuller understanding of the topic, [8], [11].

Second, the bibliometric and network analyses identified the key authors, most important studies, and existing collaboration patterns, as the relationship between these variables had not been analyzed by the author of this paper before. The systematic review in PubMed provided 169 works selected based on the year of publication and research, of which 74 met all validation and quality assessment criteria and were subject to data extraction analysis, providing a good selection of materials for analysis. In turn, these seventy-four works, selected as the basis for methodological research, provided the bibliometric indicators for a qualitative study of the scientific network, the co-authorship, and co-occurrence maps that gave us the primary tools for analysis and research hypotheses outlining.

3.1 Search Terms and Data Selection

In this SLR, the initial phase was focused on the planning stage, where research questions and keywords were aligned, especially with combinations such as "Traceability", "Blockchain Technology", and "healthcare" or "counterfeit drugs".

The methodical effort to explore the diverse applications of BT in the healthcare sector, particularly in addressing the pressing issues of counterfeiting and traceability, was meticulously crafted as a search strategy. This strategy included many synonyms and related terms to ensure comprehensive coverage of the topic. The search terms we used were a) blockchain, to capture the technological aspect; b) healthcare, to focus on the industry of interest; c) counterfeit, to address the specific challenge of fraudulent activity; and d) traceability, to encapsulate the aspect of tracking and verification in the supply chain.

To refine the search and ensure the relevance and quality of the publications, we established a set of strict inclusion and exclusion criteria. These criteria were critical in filtering out publications that did not meet our high standards for academic rigor and relevance. Specifically, we excluded: 1) publications that were not peer-reviewed, such as books, theses, tutorials, keynotes, and similar works, to maintain a focus on scientifically validated studies; 2) articles that were not available in English, to ensure that our analysis was conducted on readily accessible and generally understandable literature; and 3) research published before 2010, to ensure a focus on recent developments and contemporary perspectives in the field.

The above search terms and exclusion criteria were systematically applied within the PubMed database. It used specific search terms tailored to this database to efficiently sift through the vast amount of literature and isolate those studies that were most relevant to the research objectives. The process of implementing these search terms and applying the exclusion criteria is detailed in Figure 1, which provides a clear visual representation of our methodological approach to data collection (see Figure 1 for further illustration).

The systematic review plan, outlined in the visual representation, is a well-structured approach to synthesizing literature relevant to the use of BT to mitigate counterfeiting and fraud in healthcare packaging and labeling.

The reviewed methodology begins with setting rigorous inclusion and exclusion criteria to ensure the relevancy and academic integrity of the reviewed literature. The research itself is conducted on the PubMed digital database, which enables the coverage of a broad range of research. The identified literature is closely reviewed and analyzed on the background of a research question that concerns the primary issues of counterfeit deterrence and traceability improvement in the healthcare industry. The third, the scrutinizing phase, aims to explore the syntax of the studies in the review. Using bibliometric tools and literature coupling, the phase uncovers the complex connections between the publications.

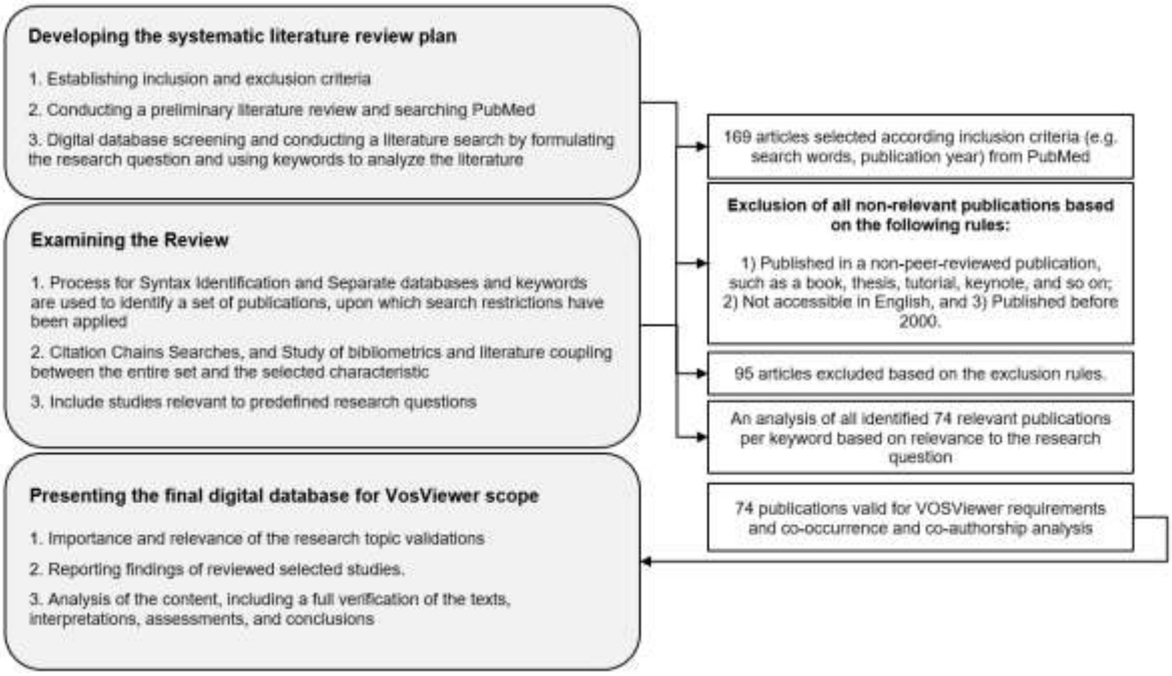

Fig. 1: Overview of the selected methodology steps, database search, and selection criteria

Importantly, the review phase helps identify the works that correspond to the specific, pre-set research questions and align the review focus with the intention, [8], [11].

From the 169 articles initially identified via PubMed, careful exclusion criteria - excluding non-peer-reviewed material, non-English publications, and those published before the year 2000 - resulted in a distilled list of 74 relevant publications. These publications underwent keyword-based analysis to ensure alignment with the research question regarding the impact of blockchain on anti-counterfeiting and traceability in healthcare.

This research reflects the significant relevance of the topic within the academic community, as evidenced by the volume of recent publications. The 74 validated articles represent a rich corpus for VosViewer analysis, facilitating co-occurrence and co-authorship analysis that will undoubtedly contribute to the understanding of blockchain's role in healthcare product security. Through a carefully curated review and analysis process, the study underscores blockchain's potential to serve as a foundational technology in the fight against healthcare counterfeiting and fraud and provides insights into its growing importance and application in this critical area (Figure 1).

4 Data Analysis and Discussions

4.1 Sample Data Analysis

In this section, we summarize our findings from the systematic review and present an in-depth analysis of the bibliographic data extracted from 169 selected articles. Through our analytical procedures, we have uncovered a variety of sub-themes within the designated areas of investigation. The application of statistical methods has allowed us a deeper understanding of the results obtained from the literature review, co-authorship assessments, and co-occurrence investigations, providing us with quantifiable data and indicators from the scientific community network. For the analysis of this particular subsection, we conducted extensive co-authorship and co-occurrence assessments using the 74 articles that were initially selected.

An examination of the distribution of these 74 publications from 2010 to September 2023 revealed that 27 percent were contributed to the year 2023 alone. The following figure is indicative of the escalating importance of our research questions, both in the scientific realm and in the global context, as evidenced by the increase in related publications generated by the identified keywords (Figure 2).

These findings reveal a clear trend and burgeoning interest in the interplay between BT and supply chain management pharmaceutical practices, and the imperative for continued scholarly discourse and investigation in this area (Figure 2).

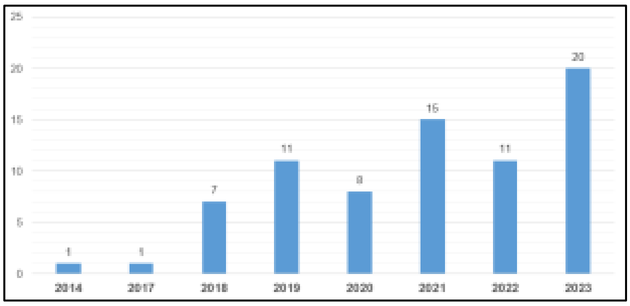

Fig. 2: Overview of the digital database publication years

It systematically applied the full count method to the entire analysis and applied the same weight to the same link results for consistency in the co-authorship analyses.

Forty of the 345 authors in the 74 articles met the quality and criteria, which included at least two papers by an author and two citations.

In addition, to determine the strength of the coauthorship links, the strength of the links between authors was measured, and for this analysis, the authors with the highest overall strength were selected. By using the number of documents and relationships between authors and co-authors, was calculated the relatedness between them. Then, 40 authors per unit were examined and a full count strategy was applied along with a maximum number of documents per author, resulting in all 40 authors meeting both the inclusion criteria and the coauthorship threshold.

To define the data analysis definitions, we required two documents from each author, i.e., we combined authors whose connections and relationships allowed us to understand related graph maps and clustering.

The intricate network shown in the figure illustrates a dense and robust landscape of scholarly collaboration, as evidenced by the myriad of connecting lines and the abundance of names that populate the visual.

The network diagram, presumably generated by bibliometric analysis, could represent the interconnectedness of researchers and academics who are actively contributing to the discourse on BT's role in countering counterfeiting and fraud within healthcare packaging and labeling (Figure 3).

Each node, represented by an author's name, suggests a focal point of contribution to the body of knowledge, while the lines infer collaborative relationships, perhaps through co-authorship or citation.

This rich mosaic of scholarly work underscores the dynamic and extensive nature of research activities, highlighting a thriving community dedicated to inquiry and innovation. Regarding the research nodes clustering, evidenced within the healthcare domain as well, I believe it is due to further exploration of the themes or methodologies concerning blockchain applications. This type of research is undoubtedly of great importance, as it provides the necessary knowledge on how BT can help protect pharmaceuticals from counterfeiting and unauthorized distribution. In addition, there is a tendency for increased collaboration, which is also both evident and predictable.

The pattern shows great urgency and importance in creating strong and reliable strategies to verify the authenticity and traceability of medical products. Collaboration is necessary as the challenges of counterfeit medicine put patients' lives and healthcare systems in jeopardy. The trend is a strong indication of the shared commitment to integration projects using flexible and advanced technologies that not only ensure consumer protection but also increase the industry's ability to defend itself from counterfeits.

The following network diagram is more than just a cluster of names and connections; it is a dynamic representation of the scientific community's response to the challenge of counterfeit pharmaceuticals.

It symbolizes the collaborative spirit that is essential to innovate and develop new standards and governance models for artificial intelligence in pharmaceuticals, ensuring that patients receive safe, authentic medications (Figure 3).

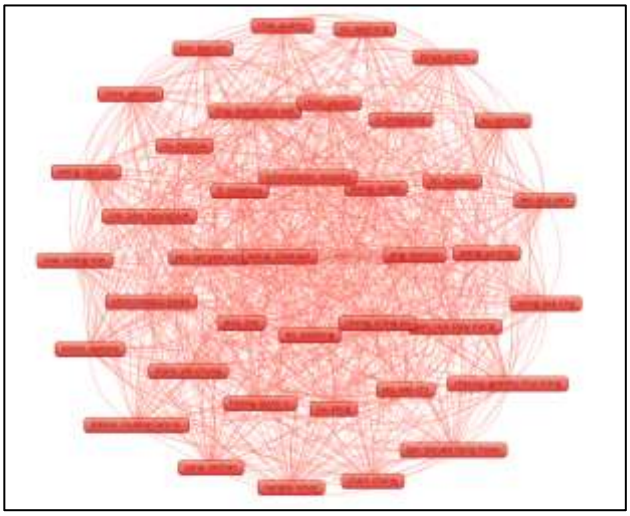
Fig. 3: Network visualization for all 40 authors of the co-authorship analysis

All analyzed papers that were relevant to both topics of healthcare products traceability and anti-counterfeiting presented this cluster of authors that presented high levels of correlations and linkage between all of them, in terms of the presented research work and relevant from all 74 analyzed papers.

For our study, we also used fractionally counting as an analytical technique to calculate co-occurrence. It refers to the fact that author weights are fractionalized so that, if they co-authored a document, their link weights will be fractionalized too. 30 out of 285 keywords matched the threshold, meaning that they were found at least three times.

VosViewer clustering was used to cluster publications within our 285-citation network. Then the co-occurrence analysis measures how many documents, search terms, and keywords are related between presented items and selections based on relationships between items and selections.

To determine whether all authorship links receive the same degree of weight, the co-occurrences of all terms and keywords were accounted for in whole numbers instead of fractionally.

In the following graphs (Figure 4 and Figure 5), it's presented the strongest co-occurrence relationships between terms, which is primarily seen as relatedness in the context of occurrence relationships, such as when the number of linked items is calculated from the number of documents.

Having a large term means that it has appeared in numerous publications, whereas the distance between two terms indicates the degree to which they are related. So, the graphs would display the strongest relationships between the terms after comparing the numbers of publications for each term in addition, the graphs should be understood because all the colors signify groups of terms that are comparatively close in relationship.

As a result, curved lines are used in the visualization to identify the strongest relationships (Figure 4).

The network map vividly depicts blockchain as the nucleus of a diverse constellation of terms, reflecting its multidisciplinary impact and the breadth of its applications. The map's color-coded pathways suggest blockchain's interconnectedness with various sectors, particularly in healthcare, where it intersects with electronic health records, privacy, and telemedicine.

In the red cluster, terms such as 'counterfeit drugs', 'supply chain', and 'IoT' converge around 'blockchain', highlighting its central role in improving traceability and combating fraud. The analysis seems to be compatible with the innovative ways to protect pharmaceuticals from counterfeiting considering that the terms "smart contract" and "proof of concept study" are closely related to the concept of "blockchain." Moreover, the definition of "IoT," or Internet of Things, may indicate the possibility of developing a technological alliance where blockchain would be an eager component of a secured ecosystem of personal medical devices and services. Consequently, the analysis facilitates the intensive development of new ways to improve security and performance in the delivery and monitoring of healthcare products.

Second, the blue cluster, which consists of 'telemedicine' and 'smart contracts,' highlights a new technological trend in the delivery of medical services; it can be presumed in light of the COVID-19 pandemic that this trend has become more popular. Thus, BT can substantially enhance the provision of patient care and management of pertinent health data, enabling those data to be processed free of any central intermediaries and allowing for the provision of medical care at a distance. Third, the green cluster contains the most critical abilities: data 'privacy', 'algorithms,' and 'computer security.'

The fact that blockchain is linked to 'electronic health records' and 'health information exchange' in this cluster reemphasizes the importance of this technology to the safeguarding of health data confidentiality and integrity. In this cluster, blockchain's use is depicted as a strong barrier to the existing health data protection and privacy issues, particularly regarding ensuring that personal health information is kept secure and private. Nevertheless, such information is still accessible in a regulated, transparent way. The general conclusion is then that blockchain's corner is technology, healthcare, and data security. Its central position in the network map underscores its fundamental role in addressing the key concerns of authenticity, privacy, and efficient data management in the healthcare sector. The map underscores the need for continued research and development in this area to fully leverage blockchain's capabilities in creating a safer, more transparent healthcare system (Figure 4).

The keywords of blockchain (53 occurrences with a total strength link of 149), electronic health records (29 occurrences with a total strength link of 118), and privacy (10 occurrences with a total strength link of 47) illustrate the most relevant co-occurrences between terms in particular terms relatedness, occurrence relationships, and associated numbers of documents.

Each term was measured by the number of occurrences, and its distance from another term represents the degree of relatedness between them. A large number of publications indicates a stronger link between terms, so relatedness becomes more dependent on co-occurrences.

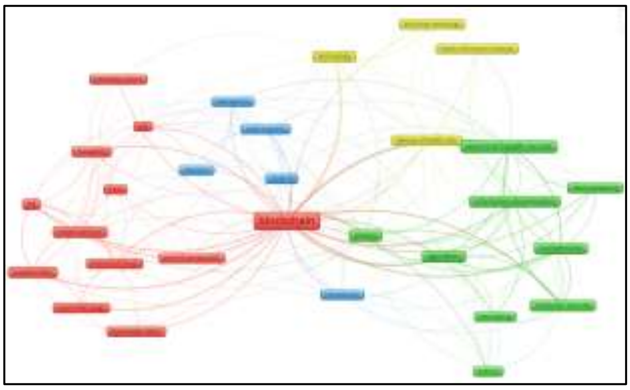

Fig. 4: Network visualization for all 30 selected keywords with 4 cluster parts of the co-occurrence analysis

According to the co-occurrence map creation based on text data, we selected all fields with the terms extracted from the titles and abstract fields from all 74 publications and ignored structured abstract labels or copyright statements from the publication's published data. Figure 5 and Figure 6 illustrate the distribution of publications by binary counting which means that only the presence in a document matters and instead of counting all occurrences of a term in a document.

The graphical depiction showcases blockchain's extensive reach and its interconnectedness with various domains, emphasizing its multifaceted implications for the healthcare sector. In the visualization, blockchain sits at the confluence of several critical themes, each represented by a distinct color and demonstrating the technology's broad spectrum of influence.

The blue cluster emphasizes "patient," "privacy," and "data," highlighting the role of blockchain in handling patient information securely and confidentially.

Therefore, blockchain has the potential to revolutionize how patient data is handled, providing a safer and more private environment for healthcare systems. The inherent characteristics of blockchain – decentralization, encryption, and immutability – ensure that patient data is stored and accessed in a way that maintains confidentiality while still meeting the needs of healthcare providers who require access to identifiable patient records to perform their duties effectively.

The green cluster represents 'transparency,' 'supply chain,' and 'smart contracts,' indicating the use of smart contracts to improve transparency in the healthcare supply chain.

Thus, blockchain can be a new promising way to enhance the efficiency of various operations from drug tracking to the confirmation of drug authenticity. Smart contracts can be used to automate and secure transactions and agreements at all stages of the supply chain. Every party involved will have no other option but to comply with predetermined contractual conditions and rules.

Finally, such an initiative could decrease the possibility of counterfeit products penetrating the market, making quality control and management of medical supplies more transparent and effective. In other words, the described accident proves that blockchain contributes to the transparency of the pharmaceutical supply chain and can lead to a revolution in the process of how drugs are tracked back to the manufacturer or patient, thus increasing the level of products' authenticity and reducing the possibility of counterfeit medicines to reach the market. The red sector including 'technology', 'research', and 'IoT' also supports the advanced synergy of blockchain, and several technologies and this issue can be utilized to support the constant research needed to utilize these tools for creating high-quality healthcare solutions.

At the heart of the diagram (Figure 5), 'blockchain' forms the nucleus that binds these aspects together, signifying its role as a foundational technology capable of addressing the myriad challenges presented by the modern healthcare landscape.

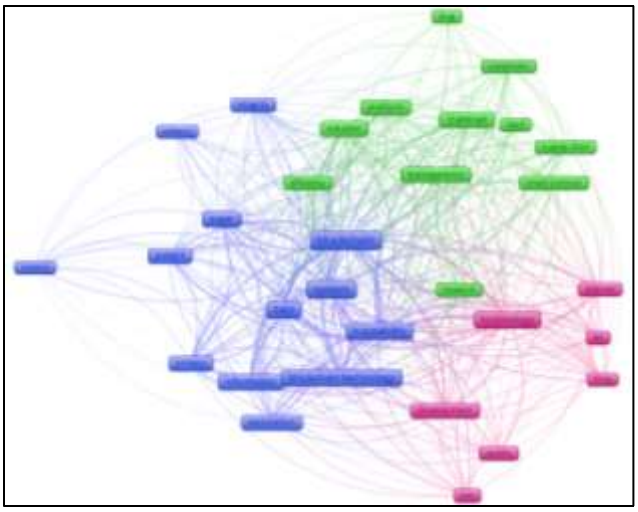

Fig. 5: Network visualization for the most relevant keywords part of the co-occurrence analysis

The chosen threshold in terms of analysis was a minimum number of 8 occurrences of a term where out of 2107 from all 74 publications, only 32 met the threshold.

However, the full counting method was also applied in terms of better understanding the full range of the co-occurrence maps based on the title and abstract textual information from the 74 papers. We, therefore, selected from the 2107 terms, the ones that presented the highest levels of the relevance score and occurrences that were valid to our scope of work and analysis (Figure 6).

The visualization presented offers a complex network of terms related to the healthcare sector, with a pronounced emphasis on the integration of BT. Central to the network are nodes such as 'platform', 'medicine', 'product', and 'architecture', which are intricately linked to 'blockchain', highlighting its central role in the digital transformation of healthcare.

The 'platform' node, which is connected to 'COVID', 'security', and 'scalability', suggests a focus on using blockchain for secure, scalable solutions amid global health challenges. The closeness of “architecture” to “medicine”, and “supply chain” shows that blockchain might help with a more organized and transparent pharmaceutical supply chain, fighting counterfeit drugs.

The connection of the red words or “medicine” and “clinical trials” to blockchain unveils how medical research can be amended and improved in regard to management, storage, and execution through increased data transparency and authenticity. It is possible to suppose that it will deliver a tamper-proof immutable ledger more trustworthy and permanent than those on the current technologies. Moreover, it will be both a secure and transparent way to record, store, and spread data which means any change will be obvious and transparent as well. With these aspects in mind, it is clear that blockchain can enable easier purview of clinical results which mitigates industrial risk of tampering or malicious reports; thus, it can frame a standard of quality that must be satisfied. Additionally, these words even suggest significant alterations in how medical studies will be conducted, emphasizing real ones. The system cluster combines blockchain and the words “medical record” and “data security”. Most likely, it indicates a unique way to protect health data vital for medical compliance. The bright lines running through these words show that it is a multifunctional device with transparent results on multiple industry undertakings, from systematization of data-to-data security and clinical trials, to supply chain integrity.

This network map serves as a graphical abstraction for discussions about how blockchain can be used to address pressing issues in the healthcare industry, including but not limited to securing medical records, improving drug traceability, and streamlining clinical operations. The visual is a testament to blockchain's ability to connect various components of healthcare into a cohesive, secure, and efficient system (Figure 6).

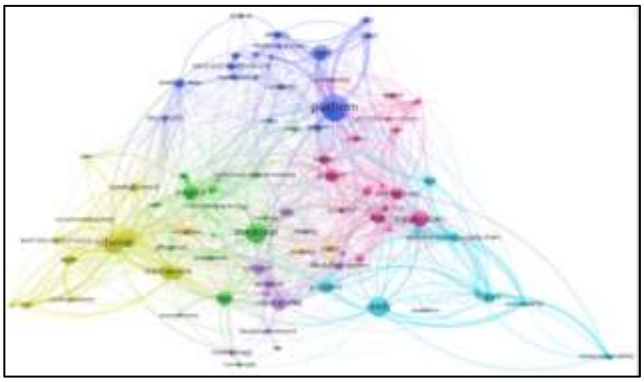

Fig. 6: Levels of relevance and occurrences of all key terms at the highest level

It was found that, based on our search terms that included BT applications in healthcare, medication traceability, and counterfeit prevention, the majority of research relates to consent protocols, routing schemes, authentication processes, and identity systems, among many other topics described in the above figures and analyses.

Overall, this research, compiled with the systematic literature review conclusions presented in Table 1, provided cross-validation of our systematic literature review conclusions and co-occurrences and coauthorship analysis presented in Table 1.

The table provided is a compendium of research that underscores the pivotal role of BT in enhancing various aspects of the pharmaceutical industry.

A key part of the table’s information is the implementation of blockchain to improve the traceability and security of pharmaceutical supply chains. This aspect is paramount for addressing the problem of counterfeit drug distribution, which remains widespread. As underlined by the identified study, BT has the power to “adopt distributive ledger technology to improve drug visibility and related security”. For example, the Med Secure System applies blockchain to trace counterfeit medicine. In this way, it enhances the visibility of the chain by ensuring that all processes can be tracked and recognized. Thus, transparency and process accountability are significantly improved in such a case. Each study collectively reinforces the transformative potential of BT as a bulwark against the challenges posed by counterfeit pharmaceuticals, heralding a new era of secure, transparent, and reliable healthcare delivery systems.

Table 1. Methodologies and overview of selection to appropriate publications

Key Concept	Ref.	Connection
Enhancing Traceability and Security	[1], [3], [21], [27], [28]	Blockchain technology improves traceability, visibility, and security in pharmaceutical supply chains, preventing counterfeit drugs.
Chain DrugTrac Framework	[4], [22], [28], [29], [30]	A blockchain-based framework for drug traceability and counterfeit detection, demonstrating effectiveness through a prototype.
Med Secure System	[5], [6], [21], [30], [31]	Blockchain-based system for tracking and tracing counterfeit medicines in the supply chain.
Mitigating Counterfeit Medications	[5], [6], [10], [30], [31], [32]	Blockchain-based drug traceability improves pharmaceutical supply chain transparency and accountability.
Improving Data Integrity	[1], [9], [20], [32], [33]	Blockchain technology reduces the circulation of counterfeit drugs by enhancing data integrity and traceability.
Smart Contracts for Drug Traceability	[5], [10], [13], [17], [34], [35]	Blockchain approach using smart contracts enhances drug traceability in healthcare supply chains.
Decentralized Health Infrastructure	[9], [10], [36], [37]	Blockchain and smart contracts enhance product traceability in healthcare, reducing counterfeit drug risks.
Identifying Counterfeit Drugs	[1], [3], [13], [28], [32], [33]	Blockchain technology traces and identifies counterfeit drugs in the drug supply chain.
SUPPLYDECK for Supply Chain Management	[6], [13], [14], [32], [33], [34]	Blockchain technology ensures transparency and security in pharmaceutical supply chains with SUPPLYDECK.
Verifying COVID-19 Vaccine Provenance	[4], [13], [14], [28], [35]	Blockchain enables patients to verify COVID-19 vaccine quality, reducing counterfeits in the pharmaceutical supply chain.
Securing Pharmaceutical Supply Chain	[9], [10], [15], [19], [36]	Blockchain technology secures pharmaceutical supply chains by reducing counterfeiting and manual operations.
MedBust for Supply Chain Revolution	[3], [4], [20], [19], [37]	Blockchain revolutionizes the pharmaceutical supply chain by improving efficiency and reducing counterfeit drugs.
Combating Counterfeit Drugs in India	[5], [6], [9], [24], [38]	India implements BT to combat counterfeit drugs in the pharmaceutical industry.
Ineffective Traditional Traceability Methods	[9], [14], [16]	Blockchain and IoT ensure safe and sustainable supply chain operations against counterfeiting.
Blockchain for Drug Supply Chain Transparency	[10], [15], [16]	Blockchain improves drug supply chain transparency, security, and traceability.
Good Distribution Practice Model	[9], [14], [15], [24], [38]	Blockchain enhances transparency, security, and reliability in drug distribution.
End-to-End Traceability Improvement	[13], [14], [15]	Blockchain technology improves traceability and resilience in the pharmaceutical supply chain.
Transparency in Supply Chains	[13], [14], [22]	Blockchain guarantees transparency in supply chains, particularly in pharmaceuticals.
Blockchain-based Traceability Meta Model	[13], [14], [21]	A meta-model for blockchain-based supply chain traceability, connecting actors and events.

It's possible to infer based on the above table and the 14 presented publications that 4 studies represent Finished Goods Traceability, 3 are representative of Counterfeiting and Finished Goods Traceability simultaneously, and supply chain and anti-counterfeiting individually. From the above representation of the table, we have one study related to the tracking of medical information and data.

These 14 publications explain a variety of proposed solutions and we can conclude that the application of BT technology is being examined to improve several different projects, and over the last few years, the implementation of BC-based initiatives has been evolving in a variety of ways.

From the reviewed articles, it is evident that healthcare companies are more responsible than ever before to automate anti-counterfeiting processes, traceability processes for drugs, and data governance and analytics standards to assist in the decision-making process. Furthermore, through our research investigations, we can also understand the importance of BT in providing healthcare organizations with the ability to manage different product lifecycles and provide packaging and labeling solutions to meet public health emergencies across various cultures.

Additionally, the systematic literature review model revealed that different BT benefits could be divided into patient-related benefits, such as products and data security, personalized healthcare, patient-reported health data, and monitoring patients' health states.

Different organizational-related benefits were also mentioned, including healthcare information exchange, pharmaceutical supply chains, and finished goods traceability management. We also determined that some general threats are associated with BTs, such as installation and transaction costs, interoperability issues, and lack of technical skills on the part of organizational teams, however, we also perceived social threats, such as social acceptance and regulation issues slowing down processing.

As a result of the systematic literature review, we also learned that several healthcare organizations are partnering with technology companies to develop a new concept of counterfeit prevention that combines technology and processes to control physical materials protection and the way data is stored on back-end BT platforms that can be authenticated.

A falsified medicine directive requires that all prescription medicines are equipped with an anti-tamper device, which prevents the manipulation of the medicine. Then, it goes one step further by serializing the medicine. Among the selected 14 final papers where deeper analysis was conducted, different conclusions were presented concerning patient safety, brand protection, or regulations that drew a need for anti-counterfeit packaging in the form of temper evidence solutions. Pharmacovigilance is one of these areas that is unique since a falsified product is usually detected only through the package itself, which is designed to alert the patient.

4.2 Discussions

In the realm of healthcare, the convergence of BT, counterfeiting, and fraud concerns, particularly in the context of packaging and labeling, presents a multifaceted and evolving landscape. This systematic literature review synthesizes findings from various academic sources to provide a comprehensive understanding of this intersection. BT emerges as a pivotal innovation in healthcare, offering substantial benefits in enhancing transparency, security, and efficiency. There are various healthcare applications of BT, ranging from safeguarding the identities of patients and providers to traceability of pharmaceutical and medical device distribution and even public and open geolocated data. Possibilities exist for device and patient source tracking, while clinical trials, pharmaceutical experiments, and health insurance also seem to take BT advantages. Nevertheless, the aforementioned scalability, security, and interoperability difficulties pose significant barriers to BT's extensive implementation in the healthcare industry.

In healthcare packaging and labeling, counterfeiters are becoming more sophisticated, complicating the detection and prevention of counterfeited products. There is an urgent need for more effective procedures to combat counterfeiting, given the increasing level of sophistication and the complexities in establishing a sustainable monitoring process to track and authenticate products. Healthcare fraud is prevalent at the global level and is characterized by multifaceted risks brought about by fast-evolving fraud patterns and the compliance of data privacy. Despite the strides made, there are significant gaps in research, primarily the integration of BT in existing healthcare systems to address scalability and interoperability challenges. More sophisticated technologies in the detection of counterfeit products and innovative strategies in fraud prevention, especially emerging technologies and evolving frauds, are necessary.

The dynamic field of security, transparency, and efficiency improvement due to the convergence of BT, counterfeiting, and fraud in healthcare packaging and labeling is extremely opportunity-rich and promising. High-priority areas for research and further development efforts include the challenge of technology integration, counterfeit detection, and fraud prevention. Future research must proactively look for new solutions and serve as the basis to develop a theoretical framework to enable the creation of healthcare systems that are more secure and efficient. Many of the core BT's properties, such as decentralization, transparency, and prevention of data tampering, are both relevant and entirely beneficial for any attempts to battle counterfeiting and fraud in healthcare. Indeed, blockchain technology can be beneficial for all organizations, be it a large hospital or a small pharmaceutical company. In the latter, it provides logs for transactions that are clear and safe, which significantly assists in patients' data protection and guarantees drug authenticity. Blockchain's potential in terms of enhancing healthcare's safety, efficiency, and reliability is simply enormous. However, some of the immediate challenges, such as complexity of implementation, technical expertise requirements, and scalability concerns, remain to be addressed. Once these concerns are addressed, blockchain technology has unparalleled potential to revolutionize patient safety and trust enhancement, fraud and counterfeiting minimization, care quality improvement, and reduction of fake drugs. Thus, a reduction in counterfeiting and fraud will primarily increase the patient's safety and confidence.

This inspires trust in the treatment and health plans, meaning the system must be closely monitored and patient education must be improved.

Also, regulatory compliance is aided by blockchain in meeting healthcare industry regulations through legal standards, audit trails, and reporting requirements. Simplified compliance processes and transparent and accessible records for audits present opportunities, while keeping up with evolving regulations remains a challenge.

Finally, BT adoption is critical to realizing the benefits of blockchain in healthcare. It drives innovation, user adoption, and the development of technology infrastructure. Staying ahead and gaining an advantage in a competitive environment encourages innovation, but resistance to change, ensuring adequate training, and supporting the adoption of new technologies are significant challenges (Table 2).

Table 2. Summary overview of main use cases, benefits, and applications

Key Terms	Relations	Key Concepts	Opportunities	Challenges
Blockchain	Enables secure, transparent, and immutable transactions	Decentralization, Transparency, Immutability	Enhanced security and traceability in the supply chain, Improved data integrity, Regulatory compliance	Implementation cost, technical expertise required, Scalability concerns
Counterfeiting	Addressed through blockchain's traceability and verification capabilities	Authentication, Verification, Traceability	Reduction in counterfeit products, Enhanced patient safety, Trust in pharmaceuticals	Difficulty in complete eradication of counterfeit products, Dependence on technology adoption
Fraud Concerns	Mitigated by blockchain's immutable and transparent record-keeping	Data Integrity, Security, Auditability	Reduced fraud and errors, Improved regulatory reporting, Enhanced patient trust	Complexity in integrating with existing systems, Ensuring user privacy and data protection
Healthcare Packaging	Utilizes blockchain for tracking and verifying authenticity	Supply Chain Management, Product Lifecycle Tracking, Quality Assurance	Real-time tracking of products, Assurance of drug authenticity, Efficient inventory management	Integration with existing supply chain systems, Ensuring widespread adoption across suppliers
Labeling	Benefits from blockchain's data management for accurate information display	Information Accuracy, Regulatory Compliance, Consumer Information	Accurate and tamper-proof product information, Compliance with labeling regulations, Informed consumer choice	Aligning BT with labeling standards, Training for proper data entry and use
Healthcare Organizations	Different scales of organizations adopt blockchain for varied purposes	Large Hospitals, Medium Clinics, Small Pharmacies	Tailored blockchain solutions for different organizational needs, Competitive advantage	Varying resource availability and technical capacity across organizations
Interoperability	Blockchain facilitates data exchange among diverse healthcare systems	Data Exchange, System Integration, Collaborative Healthcare	Seamless patient data sharing, Enhanced collaboration among providers, Unified patient records	Achieving interoperability among diverse healthcare systems, Data standardization
Patient Safety	Directly impacted by reducing counterfeiting and fraud	Drug Authenticity, Medical Record Accuracy, Treatment Efficacy	Increased confidence in treatment, Reduced medication errors, Improved health outcomes	Continuous monitoring for system effectiveness, Educating patients and providers about technology
Regulatory Compliance	Blockchain aids in meeting healthcare industry regulations	Legal Standards, Audit Trails, Reporting Requirements	Simplified compliance processes, Transparent and accessible records for audits, Reduced legal risks	Keeping up with evolving regulations, Balancing innovation with regulatory constraints
Technology Adoption	Essential for realizing the benefits of blockchain in healthcare	Innovation, User Acceptance, Technological Infrastructure	Staying ahead in technological advancements, gaining a competitive edge, Encouraging innovation	Resistance to change, Ensuring adequate training and support, Cost of new technology adoption

5 Discussions

5.1 Recommendations and Limitations

In contemplation of the transformative potential BT harbors for the healthcare sector, particularly in mitigating the challenges associated with packaging and labeling to thwart counterfeiting and fraud, it is imperative to consider future recommendations that could pave the way for its effective implementation.

Enhanced scalability of blockchain solutions must be prioritized to manage burgeoning data volumes in healthcare systems without impeding performance. The establishment of universal interoperability standards is essential for facilitating efficient data exchange between disparate healthcare systems. Collaborative engagement with regulatory bodies will aid in the development of standards and frameworks that align with blockchain's capabilities, thereby ensuring compliance and fostering trust. Moreover, the investment in technical training and education to address the skills gap will ensure that healthcare professionals are equipped to navigate and maintain blockchain solutions.

Placing users at the heart of blockchain application design is critical, focusing on enhancing usability to boost adoption among healthcare providers and patients alike. As blockchain becomes more integrated into healthcare data management, advancing strong security protocols is paramount to safeguard sensitive patient information from new cyber threats. The healthcare sector stands to gain from conducting pilot programs and sharing detailed case studies, which would shed light on the tangible challenges and benefits of using blockchain in medical settings. This approach would offer valuable insights and serve as a guide for future initiatives.

The complexity of BT in terms of the technology itself is undoubtedly a challenge to its wider application in the healthcare sector because the systems that already function need to incorporate the blockchain, which becomes time and capital-consuming. In this regard, data security may require navigating multiple regulatory policies, which may be especially challenging for systems users that include individuals from different jurisdictions. Lastly, the way various stakeholders behave and have historical experience is hardly predictable. Healthcare providers rarely adopt new tools as they are used to a habit that complicates any change implementation.

To effectively address these challenges, the healthcare industry must adopt a comprehensive strategy. It involves not only simplifying the use of new technologies for integration but also helping to adapt them to existing systems, solve any issues with existing policies and laws, and develop a culture that is open-minded about innovation. Wrestling with these problems will allow the healthcare industry to leverage the full potential of the blockchain and create safer, more streamlined, and transparent systems of healthcare service delivery. It is time to go beyond the theoretical discussions in academic articles and present an initiative based on real-world pilot studies and case studies. The approach in this discussion article will provide a practical roadmap for the next systematic research and development, offering a practical aspect of the use of technology in the real healthcare setting and its potential.

5.2 Conclusion

BT revolutionizes the healthcare sector by offering vast improvements in the administration of pharmaceutical supply chains. While counterfeit drugs and fraudulent activities such as repackaging and rebranding are substantial threats across various fields, blockchain exhibits diverse benefits, such as better traceability, security, and transparency of transactions. These aspects play significant roles in enabling patient-provider trust and ensuring safe products. Designing supply chain systems based on blockchain decentralization creates secure, robust records that cannot be manipulated. It enhances the integrity of healthcare and supply chains, delivery of quality services, data integrity, and regulatory compliance, leading to reduced counterfeit products and improved patient safety. Besides, product packaging and labeling can be trackable in real-time using this technology, ensuring that only authentic, safe, and effective pharmaceuticals reach patients.

Nevertheless, blockchain has several barriers. This includes technical complexity and high costs, the need to integrate blockchain-based systems with existing technologies, and the importance of database safety and privacy protection and ethical data management. Implementation of new systems is hampered by the inertia of some employees and industries that are used to old, but most importantly, labor-intensive methods. Sustainability concerns demand energy-efficiency mechanisms in blockchain systems due to high energy consumption, such as in the Proof of Work model. As a result, no blockchain system can remain effective without constant monitoring and updating. The healthcare sector could benefit from investing in detergent and more user-friendly designs to secure health data. Pilot programs and case studies provide insights. Aggressive global investments in the healthcare supply chain system are likely to have transformative effects and shift the existing tendencies to the new creation of medical product administration and delivery.

Furthermore, extensive pilot studies and real-life trials validating blockchain applications in various health settings are critical for capturing their practical implications and facilitating wider adoption.

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