Blockchain Technology and Internet of Things (Iot) in Medical and Healthcare Sector: Applications, Challenges, and Future Perspectives

Dr. Rekha Jain[1], Dr. Manoj Kumar Sadual[2], Dr Sushma Patil[3], Dr. Manjunatha D[4], Dr Poonam Agrawal[5]

[1]Department of Computer Applications, Manipal University Jaipur
[2]Associate Professor, PG Department of Law, Utkal University, Bhubaneswar, Odisha
mksadual@yahoo.co.in
[3]Associate Professor, Department of Management, VES's Vivekanand Business School, Mumbai
[4]Assistant Professor, Department of Electronics, University College of Science, Tumkur University, Tumkur, Karnataka -572103
[5]Professor, School of Dental Sciences, Department of Orthodontics and Dentofacial Orthopedics, Sharda University

The Internet of Things (IoT) is a groundbreaking innovation in Information Technology that bridges the gap between the physical and digital worlds. It allows for smart communication between objects and humans through the internet, making it applicable in various sectors like Smart Health, Smart Transportation, and Smart Cities. However, using IoT in healthcare systems can lead to privacy violations of patients. To address this issue, Blockchain technology can be applied due to its features of decentralization, immutability, security and privacy, and transparency. Blockchain is a trending research topic that has the potential to enhance the functionality of healthcare systems by ensuring higher levels of security and privacy. This paper explores the applicability of IoT and Blockchain in drug traceability, remote patient monitoring, and medical record management. By identifying the challenges associated with deploying IoT and Blockchain in healthcare systems, this research highlights the need for further research and development in this field. Overall, the integration of innovative computer technologies like IoT and Blockchain can revolutionize the healthcare industry.

Keywords: Blockchain Technology, Internet of Things (IoT), Healthcare, Medical Record Management.

1. Introduction

The combination of blockchain technology and the Internet of Things (IoT) is transforming the healthcare sector, bringing innovation, security, and interoperability. With healthcare systems facing complex challenges in data management, patient privacy, and connectivity, the integration of blockchain and IoT offers a promising solution. The clinical healthcare environment is a centre of mass data that is created, accessed and distributed regularly. Storing and distributing this large amount of data is an urgent and fundamentally difficult task due to the sensitivity of the data and the limitations of components such as security and protection (Griebel et al., 2015). Safe, secure, and scalable (SSS) data sharing is fundamental to unifying and directing care across healthcare industries and contexts. Data-sharing practices are essential to enable clinical professionals to transfer patient clinical data to appropriate professionals for rapid development. To ensure that the two participants had comprehensive and up-to-date information on medical topics, the hypothetical caregiver and the lay professional had a highly confidential and complete procedure to collect the patient's clinical data. However, telemedicine and e-wellness are two widely used platforms where clinical data is transmitted over distance to competent professionals (at remote locations) for further evaluation. Patient data is transmitted in both of these web-based clinical settings using “store-and-forward technology” or online continuous clinical observation technology (telecheck, telemetry, etc.) (Houston et al., 1999; 2, Bhatti et al., 2018). Patients are assessed and treated remotely by clinical experts using these internet-based clinical environments via clinical data exchange. Security, recognition, and retention of clinical data are some of the biggest challenges that can arise in such a clinical game plan, as patient data is case-sensitive. Therefore, the ability to share data securely, reliably, and flexibly is critical to enabling effective clinical sharing of remote patient situations. With safe and useful information exchange, clinical communication is supported by group recommendations or endorsements by a group of clinical experts, resulting in improved symptom accuracy and effective treatment (Castaneda et al., 2015; Berman et al., 2005). Additionally, various interoperability issues remain in this area. For example, it is very difficult to do legitimate business when clinical data must be transmitted between medical and research institutions securely and efficiently. Sharing such clinical data requires an important, authoritative, and well-coordinated effort among the substances involved. Concepts of clinical data, responsiveness, data-sharing agreements, tactics, calculation of complex patient attributes, moral methods, and supervisory law are some of the potential needs explored in this cycle. These are, in most cases, some of the key questions that need to be resolved before clinical data exchange is complete (Downing et al., 2017). Researchers and medical practitioners have worked together in recent years to create computer vision, artificial intelligence (AI), and Web of Things applications for the detection and treatment of several chronic illnesses. Applications of blockchain technology have received a lot of attention lately for risk-free health data transfer (Azaria et al., 2016; Zhang et al., 2016), biological data sharing (Kuo et al., 2017), e-wellness data exchange (Angraal et al., 2017), mental enjoyment, and thinking. There is significant use of computational networks to segment characteristics, extract crucial information, and classify diseases in plants, animals, and fishes (AlZubi, 2023; Cho et al., 2024; Wasik and Pattinson, 2024). In addition to this, ML also has a wide range of uses in the industrial sector (Porwal, 2024). In essence, it is a multidisciplinary distributed network structure that leverages computing, numerical representation, and encryption to get beyond the drawbacks of conventional circular database synchronization using distributed consensus computation. This is the format for the remainder of the essay

2. IMPLEMENTATION OF BLOCKCHAIN IN HEALTHCARE

Blockchain technology (BCT) was originally intended to be used primarily in finance and cryptocurrency but is now finding increasing applicability in many other areas, including the biomedical industry. In the fields of medicine, genomics, telemedicine, telemonitoring, e-wellness, neuroscience, and custom healthcare applications, the potential of blockchain technology has become apparent thanks to systems of record balancing and storage, with a wide variety of customers can be connected through any type of exchange (as shown in the model in Figure 1).

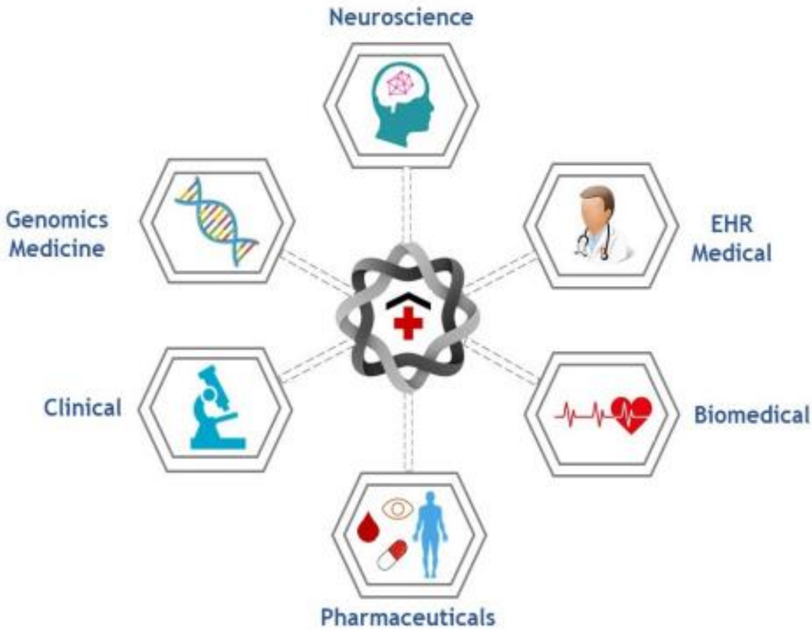

Figure 1: Block Chain in Health care

Below are some examples of the amazing potential of blockchain technology in the medical and healthcare sector:

2.1. Blockchains in Electronic Health Records (EHR)

Clinical professionals, medical institutions, and medical technology have all contributed to the need for significant advances in the digitization of clinical patient records over the past decade. Digitizing this data makes it easier to access and share, and also serves as the basis for better and faster adjustments. Currently, the most prominent area of blockchain innovation in medical services is electronic medical records (EHR). EHR stores patient data in a digital format that is securely exchanged and only accessible by authorized personnel, according to the International Organization for Standardization. EHRs contain private information about a person's health issues and aim to provide efficient service to the patient (Häyrinen, Saranto, & Nykänen, 2008). There are several EHR systems based on blockchain technology.

(a). Medrec: It is a Blockchain-based decentralized record management model that uses smart contracts for authentication, confidentiality, and data sharing. It employs the concept of decentralized data to ensure secure and transparent record-keeping (Azaria et al., 2016).

(b) Data sharing through Gem Health Network: Gem Health Network is a decentralized framework that ensures the secure transfer of user data. It eliminates the issue of centralization of data and offers transparent records. Any changes made to a record are visible to all users across the network (Jamil et al., 2020).

(c) Health bank: A health startup has created a secure platform for managing health data. Patients can earn incentives by contributing to the platform (Mettler, 2016).

(d). OmniPHR: The platform offers a public health record feature called OmniPHR, allowing patients to access and update their records. It differentiates between Electronic Health Records (EHR) and Personal Health Records (PHR). (McGhin et al., 2019).

2.2 Blockchain Technology and Medical Studies

Preliminary clinical investigations may raise various concerns, like cost justification, accurate reproduction of data, efficient data sharing (Ullah et al., 2020), etc. Blockchain, the ensuing web age (Alsumidaie, 2018), can provide a solution to these problems. Using blockchain technology, medical professionals are working to solve these problems (Nugent et al., 2016; Buterin, 2014). Blockchain applications will soon flood the healthcare sector, along with artificial intelligence (AI) and other forms of human-made consciousness. In a study by Nugent, et al., 2016, which focused on finding the solutions to patient recruitment problems, it was observed that Ethereum will lead to faster exchanges compared to Bitcoin, and as a result, the firm conclusion is that Ethereum smart contracts will be used to simplify data management frameworks in preliminary clinical studies.

2.2. Blockchains for Identifying Medical Fraud

Supply management is an important issue to protect in all sectors, but it is even more important in healthcare given the complexity of the industry. This is because every disruption to the supply chain of the healthcare system hurts patient health (Clauson et al., 2018). Due to the many moving parts and people that make them up, supply chains are fragile and have gaps that can be exploited by unscrupulous attackers. Blockchain eliminates this problem by providing a completely secure platform, and may even eliminate misrepresentation by improving data transparency and item identification. Blockchains are difficult to control, as records on the blockchain must be approved and updated by sophisticated consensus (Siyal et al., 2019).

2.3. Neuroscience and Blockchains

The discipline of neurology is likely involved in the burgeoning blockchain applications news and research (Swan, 2015). The goal of modern brain research is to develop novel perspectives that remove the need for mechanical engagement with the surrounding substrate and instead permit the mental control of devices and data. Instances of brain activity may be scanned by these sensors, and the data thus gathered can be translated into commands for other machines. A person's present mental state may also be determined by analysing their mental activity. Brain interface devices are equipped with several high-tech sensors, registration chips, and long-range communications to manage the complex process of deciphering mental input. They read the brain's electrical activity, which is then translated and sent to tracking gadgets. All of this technology is contained in a single device worn on the person's head. Such mental signals are recorded in brain interfaces utilising blockchain logic, which involves sophisticated computations and enormous volumes of data. As previously mentioned, Neurogress is planning to use blockchain technology. The firm, which was established in 2017 and has its headquarters in Geneva, is a brain-controlled frame that gives its users command over robots, drones, smart medical devices, and AR/VR (augmented reality/virtual reality) devices. Pharmaceutical Industry and Research Blockchain

When it comes to healthcare, the pharmaceutical industry is one of the most dynamic and rapidly expanding fields. The pharmaceutical sector plays an important role in ensuring the quality and legality of medical supplies and medications given to patients, and in shaping public opinion about highly awaited new treatments. Drugs that are shown to be safe and effective in reducing symptoms and speeding up recovery are another area of focus for the pharmacy. As a result, there is a major danger that counterfeiters may be hesitant to produce legitimate drugs or attack systems, and pharmaceutical businesses typically struggle to make their goods available. Therefore, the production and sale of fake pharmaceuticals pose a serious risk to public health across the world, particularly in underdeveloped regions. The research and development (R&D) of these drugs, as well as the predicted therapeutic development cycle, may be best assessed, monitored, and guaranteed using blockchain technology. Hyperledger (Taylor, 2016), a research group, has just initiated a project to combat the production of fake medications by using blockchain technology for authentication and prevention. To efficiently supply genuine and authentic medications to patients, the whole process of producing and delivering pharmacological medicines utilising computer-assisted innovation must be evaluated, assessed, and assured globally, particularly in non-industrial nations. In this way, the Digital Drug Control Framework (Plotnikov & Kuznetsova, 2018) may develop into a reliable strategy to prevent the sale of fake pharmaceuticals. Big pharma companies (Sanofi, Pfizer, and Amgen) have started working together on a pilot project to test out this blockchain-based DDCS to review and assess novel medications. By using blockchain technology, it is possible to track the manufacturing and storage of pharmaceuticals at any given time before they are delivered to the final consumer, which helps ensure the quality of pharmaceuticals, the security of the pharmaceutical supply system, and the identification of tainted pharmaceuticals (Sylim et al., 2018).

IoT and Related Concepts

The TCP/IP architecture is similar to the underlying technology of IoT. Versatility, interoperability, reliability, and quality of service are just a few of the many components of IoT engineering that need to be considered. The fundamental engineering of IoT and the many layers that form the overall IoT architecture:

Figure 2: Applications of IoT

In addition to the common IoT architectures listed above, several unique constructs have been incorporated into IoT and written by experts in various fields to meet the needs of various applications. Jacobson et al., 2009 and Amadeo, 2014 proposed a main NDN (Named Data Network) approach. At an organizational level, NDN is responsible for multiple IoT functions including data collection, security and more. IoT is a collection of various applications. NDN can meet multiple requirements of IoT applications by serving data to another customer with low-power activity at the NDN hub. NDN supports the continuous improvement of an organization's energy capabilities. Several NDN features help address key IoT needs. In addition, it also contains energy productivity reservations within the network. In-network reservations and multipath steering are also used for reliability. For IoT security reasons, NDN also includes data integrity.

In another study (Duan et al., 2011), the authors address the overall IoT design and discuss the need and importance of how to manage the IoT. There are some requirements to support a test project. Management awareness is one of the most important requirements of QoS (Quality of Services). The Application Layer, Organization Layer, and Insight Layer are the three divisions of QoS design. Interoperability is a priority factor (Figure 2). Connections between devices are called interoperability. Major IoT applications are covered by this concept, with each of the three layers (data model, communication, and organization) expecting connectivity (Desai et al., 2015). The principles of messaging are present in the existing design from start to finish, but this is how the engineering changes as it incorporates online improvements into the existing engineering to achieve clever deployments. Software-specific systems management engineering used for a more secure organization is the next design on the list. IoT engineering with SDN is flexible and offers different SDN spaces (Olivier et al., 2015). In addition, compatibility that has been emphasized in engineering so far is realized.

2.4. Communication Technologies in IoT

In the Internet of Things, many organisations and devices have accumulated. Reliable communication between the door and items is essential to explore centralised options for IoT (Atzori et al., 2010). The IoT tunnel serves as a link between the organisation area and the detecting space (Chen et al., 2011).

IoT entry points are anticipated in two scenarios: when associations occur between different detecting spaces, such as Zigbee and Bluetooth, and when associations occur between detecting and organisation spaces, such as Zigbee and 3G. The following list includes the most common communication standards and technological breakthroughs used in IoT correspondence:

2.4.1. NFC (Near Field Communication)

It is a technology for long-distance communication over short distances. Radio waves can be used for communication between two NFC-enabled devices that are quite close to one another (often within 4 cm). The three different NFC activity modes are User/Author, Distributed, and Card Impersonation. Record sharing, portable installations, and data exchange with clever banners and business cards are some useful NFC applications. Additionally, it can be used in healthcare, library construction, and home automation (Madakam et al., 2015). NFC technology can be used in your home to automate turning off lights, door locks and air recirculation systems.

2.4.2. RFID (Radio Frequency Identification)

A technique known as radiofrequency ID uses radio waves or radio recurrence. Using this technique, items are automatically recognised. There is nothing that the objects in this place cannot be. Articles may be anything, including books from the library, purchases you make at the mall, your car, and so on. They may be used not only to observe demonstrations but also to observe people, animals, and birds. It is essentially identical to the technology used in scanning tags. The fact that uniform identification is a view technology while RFID is not is what counts. RFID tag and RFID per user are the two components that make up the RFID framework. Particularly, there are two types of RFID labels: detached and dynamic labels. RFID applications include tracking people, managing supply chains, managing school transportation, halting choices, and assembling.

2.4.3. V2V (vehicle-to-vehicle)

Short-range dedicated communication such as WIFI is a long-distance communication standard used in V2V. Combining DSRC and GPS creates the lowest-cost technology. Rear cameras, routes, web access, rights management, and other cutting-edge innovations are not included in V2V. V2V provides important information when drivers need it. This secure framework does not track your vehicle and keeps your personal information anonymous. The driver perceives warnings to avoid impending danger via the display. Precautions such as "stop impact caution", "intersection development support", "application failure", and "vulnerable side caution" are prepared.

2.4.4. Bluetooth

In the past, Bluetooth was generally a great communication tool. It served as an unconditional benchmark for regional organizations to measure progress. Short range, low cost and low power consumption are the features of this technology. A device with Bluetooth capability can exchange data with its other Bluetooth-enabled devices over the air. Bluetooth makes it easy to organize nearby devices in small spaces.

3. Healthcare-Derived Industrial IoT Blockchain Challenges

In the field of medicine and healthcare, the following are the main challenges to using blockchain technology and IoT:

3.1. Interoperability

Interoperability in healthcare refers to the exchange of data within blockchain organizations. Due to the large and diverse number of providers and their enormous openness, this is a basic test (Boulos et al., 2018). There may be a variety of participants, including emergency medical services, insurance companies, doctors, and private professionals. Ensuring true interoperability can be a challenge in the healthcare industry.

3.2. Safety

The decentralized concept is more secure, but it also has some drawbacks. Data can be lost in protection as it is communicated in a public record, similar to a decentralized blockchain. Blockchain creates an environment where data can be communicated securely because people know or trust each other. However, there are situations in which this can fail. Due to safety concerns, many patients may be uncomfortable disclosing their clinical information (Boulos et al., 2018).

3.3. Scalability and Processing Storage Requirements

Keeping track of individual data is virtually impossible. The majority of clinical records consist of archives, photographs, and laboratory results. Due to the expanded capacity of clinical records of various patients, a large capacity limit is required. Clinically exchanging the same data set stored in multiple locations and everyone stored circularly would require enormous capacity constraints and could impact healthcare systems (Linn et al., 2016).

3.4. Lack of standardization

A developing technology, blockchain has been embraced by several nations. Blockchain is used in fields and companies where security, trust and identifiability are important. Standards, innovations, and other things should be legally standardized. Specific guidelines must be followed when defining the kinds of data that may be exported from and kept on the blockchain (Kumar et al., 2018; Stangren, 2017).

3.5. Lack of Skills among Doctors and Medical Practitioners

The transition from paper to technology-based healthcare can be challenging for doctors and other medical practitioners. Electronic records and prescriptions can be difficult as doctors cannot omit mandatory fields. Similar questions of accuracy and efficiency might arise when employing IoT and Blockchain technology for remote monitoring. The abilities and education of physicians will ultimately determine how well technology-driven healthcare works. Before implementing these technologies, proper training and skills must be imparted to medical practitioners to build their confidence in using these tools. This will ensure that the accuracy, efficiency, and performance of technology-driven healthcare are optimized, allowing doctors to provide better care to their patients.

3.6. Hospitals and Related Institutions are Reluctant to Share Information

As with commercial purposes, many emergency medicine clinics are reluctant to disclose patient-related and other clinical information because of the need to charge different fees to different clients. In the same way, although data may be highly helpful to clinics in tracking their expenses, both insurance companies and clinics may be hesitant to provide information.

Building and persuading people to share data is essential for a better healthcare system (Beck, 2018).

4. CONCLUSION

In conclusion, the medical and healthcare sector has enormous potential for change as a result of the confluence of blockchain technology with the Internet of Things (IoT). Better data integrity, security, and interoperability are anticipated from the cooperative synergy of blockchain's safe, decentralized ledger with the networked capabilities of IoT devices. While there are obvious benefits to applications like supply chain traceability, remote patient monitoring, and patient data management, there are also issues that must be addressed, such as scalability, standardization, and regulatory considerations. In the future, a safe, transparent, and individual-controlled patient data ecosystem will be part of the healthcare system, promoting trust and enhancing overall health outcomes. To overcome obstacles and guarantee the appropriate integration of blockchain and IoT for a robust, patient-centric, and technologically advanced healthcare environment, cooperation between technology entrepreneurs, healthcare practitioners, and regulatory agencies is essential.

Future Directions:

Blockchain technology is predicted to revolutionize the medical and healthcare industries by providing safe, standardized and patient-focused solutions. It offers improved data security, reduces privacy risks and builds stakeholder confidence. Patients will have total control over their medical data, choosing who may access them and actively choosing their course of treatment because of the technology's special features of immutability and decentralization. Blockchain-enabled seamless interoperability will usher in a new era of comprehensive patient care, enabling safe data interchange across various platforms. This technology is expected to enhance clinical trials, supply chain management, and administrative procedures, making them more effective, transparent and compliant. To create a resilient, patient-centred future in healthcare and fully realize the potential of blockchain technology, cooperation between technology developers, medical experts and regulatory agencies is essential, even when faced with ongoing obstacles.

References

1. Alsumidaie, M. (2018). Blockchain Concepts Emerge in Clinical Trials. Applied Clinical Trials, May.
2. Amadeo, M., Campolo, C., Iera, A., & Molinaro, A. (2014, June). Named data networking for IoT: An architectural perspective. In 2014 European Conference on Networks and Communications (EuCNC) (pp. 1-5). IEEE.
3. Angraal, S., Krumholz, H. M., & Schulz, W. L. (2017). Blockchain technology: applications in health care. Circulation: Cardiovascular quality and outcomes, 10(9), e003800.
4. Atzori, L., Iera, A., & Morabito, G. (2010). The internet of things: A survey. Computer networks, 54(15), 2787-2805.
5. Azaria, A., Ekblaw, A., Vieira, T., & Lippman, A. (2016, August). Medrec: Using blockchain for medical data access and permission management. In 2016 2nd international conference on open and big data (OBD) (pp. 25-30). IEEE.

6. AlZubi, A.A. (2023). Artificial Intelligence and its Application in the Prediction and Diagnosis of Animal Diseases: A Review. Indian Journal of Animal Research. 57(10): 1265-1271. https://doi.org/10.18805/IJAR.BF-1684
7. Beck, R. (2018). Beyond bitcoin: The rise of blockchain world. Computer, 51(2), 54-58.
8. Berman, M., & Fenaughty, A. (2005). Technology and managed care: patient benefits of telemedicine in a rural health care network. Health economics, 14(6), 559-573.
9. Bhatti, A., Siyal, A. A., Mehdi, A., Shah, H., Kumar, H., & Bohyo, M. A. (2018, February). Development of cost-effective tele-monitoring system for remote area patients. In 2018 International Conference on Engineering and Emerging Technologies (ICEET) (pp. 1-7). IEEE.
10. Boulos, M. N. K., Wilson, J. T., & Clauson, K. A. (2018). Geospatial blockchain: promises, challenges, and scenarios in health and healthcare. International journal of health geographics, 17.
11. Buterin, V. (2014). A next-generation smart contract and decentralized application platform. white paper, 3(37), 2-1.
12. Castaneda, C., Nalley, K., Mannion, C., Bhattacharyya, P., Blake, P., Pecora, A., ... & Suh, K. S. (2015). Clinical decision support systems for improving diagnostic accuracy and achieving precision medicine. Journal of clinical bioinformatics, 5(1), 1-16.
13. Chen, H., Jia, X., & Li, H. (2011, October). A brief introduction to IoT gateway. In IET international conference on communication technology and application (ICCTA 2011) (pp. 610-613). IET.
14. Clauson, K. A., Breeden, E. A., Davidson, C., & Mackey, T. K. (2018). Leveraging Blockchain Technology to Enhance Supply Chain Management in Healthcare: An exploration of challenges and opportunities in the health supply chain. Blockchain in healthcare today.
15. Cho, O.H., Na, I.S. and Koh, J.G. (2024). Exploring Advanced Machine Learning Techniques for Swift Legume Disease Detection. Legume Research. https://doi.org/10.18805/LRF-789
16. Desai, P., Sheth, A., & Anantharam, P. (2015, June). Semantic gateway as a service architecture for iot interoperability. In 2015 IEEE International Conference on Mobile Services (pp. 313-319). IEEE.
17. Downing, N. L., Adler-Milstein, J., Palma, J. P., Lane, S., Eisenberg, M., Sharp, C., ... & Longhurst, C. A. (2017). Health information exchange policies of 11 diverse health systems and the associated impact on volume of exchange. Journal of the American Medical Informatics Association, 24(1), 113-122.
18. Duan, R., Chen, X., & Xing, T. (2011, October). A QoS architecture for IOT. In 2011 International Conference on Internet of Things and 4th International Conference on Cyber, Physical and Social Computing (pp. 717-720). IEEE.
19. Griebel, L., Prokosch, H. U., Köpcke, F., Toddenroth, D., Christoph, J., Leb, I., ... & Sedlmayr, M. (2015). A scoping review of cloud computing in healthcare. BMC medical informatics and decision making, 15(1), 1-16.
20. Häyrinen, K., Saranto, K., & Nykänen, P. (2008). Definition, structure, content, use and impacts of electronic health records: a review of the research literature. International journal of medical informatics, 77(5), 291-304.
21. Houston, M. S., Myers, J. D., Levens, S. P., McEvoy, M. T., Smith, S. A., Khandheria, B. K., ... & Berry, D. J. (1999, August). Clinical consultations using store-and-forward telemedicine technology. In Mayo Clinic Proceedings (Vol. 74, No. 8, pp. 764-769). Elsevier.
22. Jacobson, V., Smetters, D. K., Thornton, J. D., Plass, M. F., Briggs, N. H., & Braynard, R. L. (2009, December). Networking named content. In Proceedings of the 5th international

conference on Emerging networking experiments and technologies (pp. 1-12).
23. Jamil, F., Ahmad, S., Iqbal, N., & Kim, D. H. (2020). Towards a remote monitoring of patient vital signs based on IoT-based blockchain integrity management platforms in smart hospitals. Sensors, 20(8), 2195.
24. Kumar, T., Ramani, V., Ahmad, I., Braeken, A., Harjula, E., & Ylianttila, M. (2018, September). Blockchain utilization in healthcare: Key requirements and challenges. In 2018 IEEE 20th International conference on e-health networking, applications and services (Healthcom) (pp. 1-7). IEEE.
25. Kuo, T. T., Kim, H. E., & Ohno-Machado, L. (2017). Blockchain distributed ledger technologies for biomedical and health care applications. Journal of the American Medical Informatics Association, 24(6), 1211-1220.
26. Linn, L. A., & Koo, M. B. (2016, September). Blockchain for health data and its potential use in health it and health care related research. In ONC/NIST Use of Blockchain for Healthcare and Research Workshop. Gaithersburg, Maryland, United States: ONC/NIST (pp. 1-10).
27. Madakam, S., Lake, V., Lake, V., & Lake, V. (2015). Internet of Things (IoT): A literature review. Journal of Computer and Communications, 3(05), 164.
28. McGhin, T., Choo, K. K. R., Liu, C. Z., & He, D. (2019). Blockchain in healthcare applications: Research challenges and opportunities. Journal of network and computer applications, 135, 62-75.
29. Mettler, M. (2016, September). Blockchain technology in healthcare: The revolution starts here. In 2016 IEEE 18th international conference on e-health networking, applications and services (Healthcom) (pp. 1-3). IEEE.
30. Nugent, T., Upton, D., & Cimpoesu, M. (2016). Improving data transparency in clinical trials using blockchain smart contracts. F1000Research, 5.
31. Olivier, F., Carlos, G., & Florent, N. (2015). New security architecture for IoT network. Procedia Computer Science, 52, 1028-1033.
32. Plotnikov, V., & Kuznetsova, V. (2018). The prospects for the use of digital technology “blockchain” in the pharmaceutical market. In MATEC web of conferences (Vol. 193, p. 02029). EDP Sciences.
33. Porwal, S., Majid, M., Desai, S. C. Vaishnav, J. & Alam, S. (2024). Recent advances, Challenges in Applying Artificial Intelligence and Deep Learning in the Manufacturing Industry. Pacific Business Review (International), 16(7), 143-152.
34. Siyal, A. A., Junejo, A. Z., Zawish, M., Ahmed, K., Khalil, A., & Soursou, G. (2019). Applications of blockchain technology in medicine and healthcare: Challenges and future perspectives. Cryptography, 3(1), 3.
35. Stagnaro, C. (2017). White paper: Innovative blockchain uses in health care. Freed Associates.
36. Swan, M. (2015). Blockchain thinking: The brain as a decentralized autonomous corporation [commentary]. IEEE Technology and Society Magazine, 34(4), 41-52.
37. Sylim, P., Liu, F., Marcelo, A., & Fontelo, P. (2018). Blockchain technology for detecting falsified and substandard drugs in distribution: pharmaceutical supply chain intervention. JMIR research protocols, 7(9), e10163.
38. Taylor, P. (2016). Applying blockchain technology to medicine traceability. Securing Industry.
39. Ullah, H. S., Aslam, S., & Arjomand, N. (2020). Blockchain in healthcare and medicine: A contemporary research of applications, challenges, and future perspectives. arXiv preprint arXiv:2004.06795.
40. Wasik, S. and Pattinson, R. (2024). Artificial Intelligence Applications in Fish Classification and Taxonomy: Advancing Our Understanding of Aquatic Biodiversity.

FishTaxa, 31: 11-21.
41. Zhang, J., Xue, N., & Huang, X. (2016). A secure system for pervasive social network-based healthcare. Ieee Access, 4, 9239-9250.