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The Role of Big Data in Smart Healthcare

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Abstract Health has become a significant issue for people globally, both in terms of its impact on economies and societies. The recent pandemic has highlighted the limitations of conventional healthcare systems, such as hospitals and clinics, in effectively dealing with the situation. It has become evident that relying solely on these traditional healthcare facilities is not adequate for handling large-scale public health crises. A key technology that is aiding modern healthcare solutions is Big Data and IoT. Through the use of wearable devices, telemedicine, and connected medical devices, IoT is helping to improve the delivery of healthcare and make it more accessible to people around the world. Big data has revolutionized the way industries handle, analyze, and utilize non-standard, non-uniform, incomplete, and unstructured healthcare data, making it a powerful tool for industries. Big Data with IoT has the ability to lower treatment expenses, anticipate epidemics, prevent diseases, and enhance overall well-being and helps healthcare providers to make informed decisions. This article discusses what is Big data, source of Big data in healthcare and how utilizing big data with IoT has revolutionized the healthcare field, creating new opportunities for diagnosis, prevention, personalized treatment, research, and reducing costs which we cannot achieve through traditional healthcare. In this article I have also highlighted data privacy, security, ethical & management challenges which are slowing down the progress of big data in healthcare if they are not properly addressed and mitigated. Finally, the aim of this study is to highlight the influential and effective role of Big Data with IoT for fulfilling advancement in healthcare by providing the data and insights necessary to deliver more effective, efficient and personalized care.

Keywords Internet of things, Big Data, Big data analytics, Healthcare, Smart Healthcare

1. Introduction

The combination of the Internet of Things (IoT) and big data has significantly improved companies' ability to gather and analyze data for informed decision-making. While both technologies have developed independently, they often work together in modern business settings. However, there are also distinct differences between the two [1]. Now the big question is what IoT, and big data are.

The Internet of Things (IoT) refers to a network of physical objects, including devices with computing capabilities, which are connected to the internet and can communicate with one another. This interconnected ecosystem allows various components, such as hardware, software, and even animals or people, to interact and exchange data with each other. The IoT is constantly expanding and evolving for enriching and make our lives easier. In recent years, the Internet of Things (IoT) has been implemented in a variety of sectors, including industry and smart healthcare. In the healthcare field, the IoT allows for the delivery of healthcare in new ways and enables the collection and real-time analysis of health data from sensors to inform decision-making [2]. Sensors used in IoT systems generate billions of data and this data is analyzed for the monitoring of important vital signs such as blood pressure, heart rate, oxygen level, and blood temperature without the need for assistance from healthcare professionals [3].

Having more information enables better organization and progress. With more data, we can arrange ourselves in a way that leads to the most favorable results. "Big data" refers to extremely substantial amounts of information that have the potential to be extremely useful. It has gained significant attention over the past two decades due to its potential to be transformative [4]. Big data in healthcare refers to the use of large, diverse data sets to identify patterns, trends, and associations that can help healthcare professionals improve patient outcomes, reduce costs, and advance medical research. The data used in healthcare can come from a variety of IoT sources, including electronic health records, wearable devices, clinical trials, and claims data from insurance companies. By analyzing this data, healthcare professionals can gain insights that can help them make more informed decisions about patient care, predict, and prevent disease outbreaks, and develop new treatments and therapies.

Based on the research of Global newswire, The market for big data in the healthcare industry was valued at around USD 32.9 billion in 2021 and is expected to grow to USD 105.73 billion by 2030, growing at a compound annual growth rate

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of 13.85% from 2022 to 2030. The North American region holds the largest share of the global market due to the growing use of the internet of things and an increasing need for analytical models that use patient data to improve service delivery and compliance with regulations [14].

The shift towards digitizing records and the rapid advancement of medical technology have made it possible for big data to have a significant impact on the healthcare industry. In healthcare, big data can be sourced from patient medical records, hospital records, medical exam results, and information collected by healthcare testing machines, such as EKGs. Biomedical research on public health also contributes a large amount of big data that, when properly managed and analyzed, can be useful for patients, doctors, administrators, and researchers. For example, public health researchers can use big data to predict and prepare for future pandemics. The collection and analysis of big data allows doctors and healthcare administrators to make more informed decisions about treatment and services. For instance, doctors who have access to large data samples may be able to identify early warning signs of a serious illness, which can make treatment simpler and more cost-effective. In other areas of healthcare, administrators can use key performance indicators and data analytics to make funding and resource allocation decisions. For example, big data collected from health records and Google maps can be used to create critical health maps that highlight underserved areas and inform the deployment of mobile health clinics and other resources. In healthcare facilities, proper use of big data, can capture a comprehensive view of the patient experience and allow for rapid and accurate communication between patients and providers by consolidating patient data from various clinics, hospitals, and specialist offices [11]. In this way, Healthcare organizations can use data effectively to assist in making clinical decisions, monitoring diseases, and managing public health. The challenge with processing clinical data is not only a large amount of data but also the complexity of processing it [13]. Big data has the ability to efficiently store and organize large amounts of information. However, this data acquired from the IoT devices requires proper management, security & analysis to derive meaningful information [4]. There are many challenges that arise at various stages of managing large amounts of healthcare data. In this article, we provide a review of all these challenges and their proposed solutions.

The rest of the article is organized in the following way. **Section 1** Provides a “Big Data” overview, **Section 2** describes the relationship between IoT and Big data, **Section 3** presents various applications of Big Data in healthcare, and Challenges in implementing big data analytics in healthcare applications are presented in **Section 4**. Finally, we conclude the article in **Section 5**.

2. What is “Big Data”?

The concept of big data has its roots in the field of "business intelligence," which was first defined by IBM in 1958 as “The ability to apprehend the interrelationships of presented facts in such a way as to guide action towards a desired goal.” In other words, the use of data, technology, and analytics to make informed business decisions. Business intelligence involves the collection, storage, and analysis of data to help organizations understand their operations, customers, and markets, and make informed decisions that drive growth and success. The rise of digital technologies in the 21st century has led to the growth of big data, as organizations are now able to collect and process enormous amounts of data from a variety of sources, including social media, sensors, and the Internet of Things. Big data in healthcare refers to large and complex sets of patient medical records, hospital records, test results, and information generated by healthcare equipment, such as electrocardiograms. Additionally, biomedical research on public health also provides a significant amount of big data, that are difficult to process with traditional software, hardware, and data management tools and techniques. These data sets are challenging to manage not only due to their size but also because of the diverse types of data they contain and the need to process them quickly [6].

Figure 1. indicates various source of Big Data in healthcare [18].

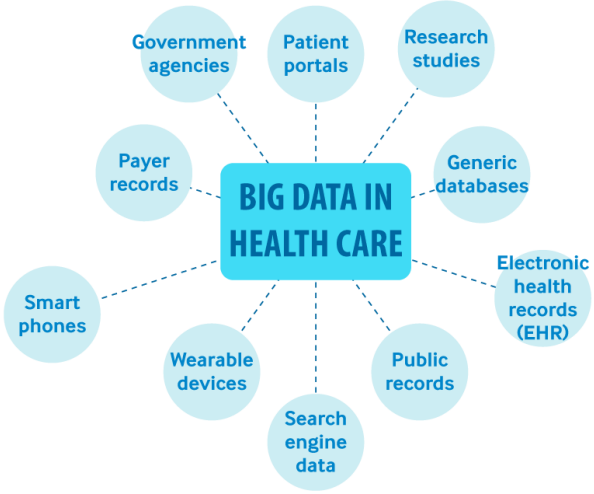

Figure 1. Sources of Big Data in Smart Healthcare

Based on Oracle “Big Data” defined as “Data that contains greater variety, arriving in increasing volumes and with more velocity. This is also known as the three Vs.” [5]. The concept of big data originally included three characteristics, referred to as the "3 V's": Volume, Velocity, and Variety. Later, two more characteristics were added, Veracity and Value, making a total of five important elements that are often referred to as the "5 V's." Some other variation of the V's exists such as 8Vs, 10Vs, and so on, but in this discussion, we will focus on these five main V's: Volume, Velocity, Variety, Veracity, and Value.

1. Volume - "What is the amount of data available?"

The size of the data is important in big data analysis. Big

data often involves processing large amounts of low-density, unstructured data, such as Twitter feeds, web or mobile app clickstreams, or sensor data from equipment. This data may not have an immediately apparent value and can range from tens of terabytes to hundreds of petabytes for different organizations [5]. In other words, big data size and value can vary greatly depending on the industry, organization, and advancements in technology over time. As technology evolves, what is considered big data today may not be considered big data in the future. Data volume has been rapidly increasing in recent years, leading to the emergence of big data and the concept of the remaining four V's [15]. In reference [16], the author has demonstrated how the data size and complexity increased exponentially with the increase of computational power.

2. Velocity – "What is the speed of data creation, transfer, or access?"

Velocity refers to the speed at which data is received and acted upon. Typically, data streams with the highest velocity are processed in memory rather than being saved to disk. Some internet-connected smart devices operate in real-time or near real-time and require real-time evaluation and action. For example, A medical device firm that deals with heart pacemakers receives heart rate information, which it needs to process and quickly analyze in order to provide a responsive shock to restore the heart's rhythm and prevent serious injury or death. Daily diabetic glucose measurements, EKGs, and blood pressure readings would increase the velocity of data which represents real-time monitoring of patients.

3. Variety – "What is the variety of data sources available?"

Variety refers to the diverse types of data that are available. In the past, data was typically structured and could be easily stored in a relational database. However, with the rise of big data, data also comes in new, unstructured forms such as text, audio, and video, which require additional preprocessing to extract meaning and create metadata.

4. Veracity – "Is the data reliable or trustworthy?"

Veracity is the degree to which a set of data can be considered truthful or accurate. This includes evaluating the trustworthiness of the source of the data. According to IBM, poor data quality costs the United States approximately $3.1 trillion annually, making veracity an important consideration. Ensuring veracity involves removing duplicates, reducing bias, and properly handling the data for a specific purpose or industry. While artificial intelligence is advancing, it is not yet able to match the judgment of a human analyst. Human analysts and traditional statistical techniques are still essential in this area [8]. Healthcare organizations must utilize strategies like data governance and information governance to ensure the quality of their data by making it clean, accurate, consistent, and accessible [17]. Another example is, A healthcare organization that has found out that there are multiple patients that share the same Patient ID, caused by the consolidation of older data sources into a new and updated data platform [15].

5. Variability – "How Often Does the Data Change?"

The rapid pace of change in healthcare data, sometimes by the second, raises concerns about the relevance and usefulness of the data, what historical data should be included in the analysis, and how long the data should be stored before it is archived or deleted. As the volume of data continues to increase, these decisions will become more critical. The cost of data storage is a significant concern for many healthcare IT departments, and this is further complicated by the fact that HIPAA regulations require healthcare providers to retain certain patient data for at least six years. Datasets that change frequently and have less value for analytical use cases may be more suitable for deletion than those that remain stable and useful for long periods of time, such as the genomic test results of a patient [17].

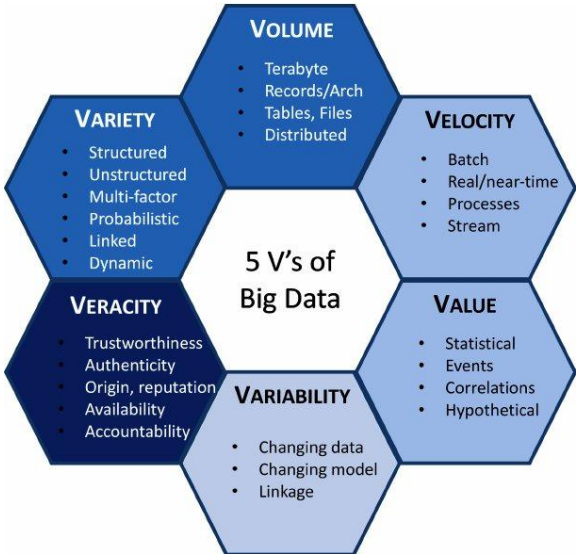

Figure 2. The five V's of Big Data (Adapted from ("IBM big data platform - Bringing big data to the Enterprise," 2014)) [12]

The process of big data analytics in healthcare typically involves the following steps:

1. Data collection: The first step is to collect data from various sources such as electronic health records, claims data, patient-generated data, and data from wearable devices.
2. Data cleaning and preprocessing: The collected data is then cleaned and preprocessed to remove errors, outliers, and inconsistencies. This step also involves formatting the data so that it can be used for analysis.
3. Data integration: The data from various sources are then integrated to create a comprehensive data set for analysis. This step involves mapping and merging data from different sources, such as combining patient demographics with clinical data and claims data.
4. Data analysis: Once the data is prepared, various analytics techniques such as descriptive, predictive, and prescriptive analytics are applied to extract insights and generate reports.
5. Data visualization: The results of the analysis are then

presented in an easy-to-understand format, such as charts and graphs, to facilitate decision-making.

6. Data action: The final step is to take action based on the insights gained from the data analysis. This step may involve changing clinical protocols, developing new treatment plans, or implementing preventive measures.

It is important to note that this process is iterative, and feedback from the data analysis is used to improve the data collection, cleaning, integration, and analysis steps [19]. Figure 3 represents various stages of big data analysis in healthcare applications.

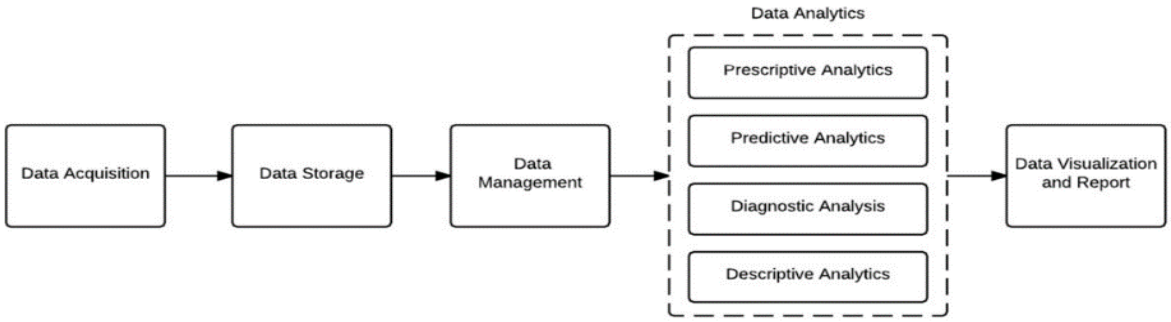

Figure 3. Stages in Big Data analytics for healthcare applications

3. Relationship between IoT and Big Data in Healthcare

IoT and Big Data are closely interconnected, as IoT provides the data that is analyzed by Big Data. Big Data processes and analyzes large amounts of data in real time, and also stores the information using various technologies. While Big Data gathers data on human behavior to create predictions or identify patterns, IoT's data is generated by sensors. In reference [9], author has explained how IoT and big data beneficial to each other

1. IoT Generates a variety of data: The amount of healthcare data that already exists is vast, IoT sensors can generate a wide range of data from various sources, including connected devices in industries beyond consumer electronics. It includes personal medical records, radiology images, clinical trial data, FDA submissions, human genetics and population data, and genomic sequences, among others. The addition of newer forms of big data, such as 3D imaging, genomics, and biometric sensor readings, is contributing to this rapid growth [7]. Having access to diverse types of data helps analysts gain a more comprehensive understanding of a situation and leads to deeper insights.
2. Increase volume of data: IoT sensors also generate large amounts of data, which can be overwhelming for companies that are not prepared to handle it. To effectively utilize this data, companies need to have systems in place to store and process it, ideally in real-time. The proliferation of IoT devices is driving the need for fast edge processors and flexible, cloud-based storage systems.
3. Real-time analytics: The rapid data collection enabled by IoT allows for real-time analytics using tools such as artificial intelligence, machine learning, and deep learning. These tools can provide insights that can be immediately used by healthcare providers to provide guidance to patients to encourage the development and continuation of healthy habits, rather than just monitoring their behavior.

4. Application of Big Data in Smart Healthcare

The utilization of large amounts of data, or "Big Data," holds significant potential for revolutionizing the healthcare sector and can assist in various areas such as diagnosis, prevention, personalized medicine, research, and cost reduction.

1. Diagnostics

The utilization of large amounts of data, or "Big Data," through analytics techniques, can provide a deeper understanding of clinical information, enabling more informed decisions to be made regarding the diagnosis, that is the cause of disease [13].

2. Preventative medicine

The current upward trend in healthcare costs has made early disease prevention more crucial than ever, particularly as new disease variants and bio-terrorism threats have emerged. Additionally, advancements in data collection and computing technology have led to an increase in available healthcare data, which in turn has increased the need for efficient, sensitive, and cost-effective solutions for preventing illnesses [20].

3. Precision medicine

Precision Medicine is defined as tailored care for individual patients - Personalized medicine. The inadequacy of the traditional approach to medical decision-making, which treats all patients the same, has led to a shift in the healthcare industry towards utilizing big data and analytics to personalize treatments according to each patient's unique genetic, environmental, and lifestyle factors [21].

4. Medical research

In clinical research, big data refers to the information collected through electronic databases, which comes from everyday clinical practice without any manipulation or screening and retains its natural characteristics. These data are not subject to strict inclusion and exclusion criteria [22].

5. Reduction of adverse medication events

Big Data advantages are exploited to prevent adverse drug reactions caused by the interaction between medications, under or overdosing, & medication errors due to the overprescribing or prescribing of contraindicated medications.

6. Cost Reduction

Big data analytics can be used to lower healthcare costs by identifying high-risk patients, detecting fraud, optimizing the supply chain, improving population health management, providing clinical decision support, and optimizing resource allocation. It can help healthcare providers to make more informed decisions that lead to cost savings in the healthcare system.

7. Population Health

Big data analytics can be used to improve population health by identifying patterns and trends in patient populations, such as clustering of certain conditions or high utilization of certain services. This information can then be used to develop targeted interventions and preventive measures to improve the health outcomes of the population as a whole. It allows identifying key health issues, and at-risk populations and the design of effective strategies to improve the health status of a community.

8. Telemedicine

Big data can be used in telemedicine to gather and analyze data from remote monitoring devices and wearables, to support remote diagnosis, treatment, and monitoring of patients, enabling healthcare providers to make more informed decisions and provide better care to patients remotely.

Table 1. Big Data Applications in Smart healthcare – Overview

Ref	Description	Applications
[23]	Offer a comprehensive overview of the current state of the art as well as insights on how big data analytics can be applied in the management of healthcare organizations, how to efficiently & effectively address the increasing demand for healthcare services	Better health services and management
[24]	Propeller's technology involves placing a sensor on the Enerzair® Breezhaler® or Atectura® Breezhaler® inhaler, this sensor sends data on medication usage to the Propeller app on the patient's smartphone. The app can also send reminders to the patient to take their medication and keep track of adherence over time. The patient can share this information with their clinician to aid in the treatment plan. Research has demonstrated that the Propeller platform can lead to a significant improvement in asthma control by up to 63%, enhance medication adherence by up to 58%, and decrease asthma-related emergency department visits and hospitalizations by as much as 57%.	Medical research
[25]	A hospital in France has implemented the use of a reliable analytics platform to predict and forecast emergency department visits and hospital admissions. "In addition to helping specific hospitals organize and allocate resources to avoid overcrowding and other emergency room challenges, I see a number of other uses for this solution," said Dr. Saïk URIENS, Unité de Recherche Clinique et CIC Paris Descartes Necker Cochin, APHP, Research Director at Inserm. "Moving forward, our hospital administrators and medical staff should be able to use this predictive analysis, on retrospective big data, not only to estimate the number of emergency department visits (including admissions rate) but also to categorize these visits. For instance, it would be very helpful to have predictive data that showed the proportion of children, adults, and elderly persons or men and women, as well as the type of medical causes (infection, cardiology, surgery, traumatology, etc.)."	Predict disease Diagnostics, Better health services and management
[26]	China exploited the use of information technologies to tackle the COVID-19 pandemic in 2020. They used Big Data analytics for epidemic prevention and control to predict potential outbreaks, using predictive modeling and forecast methodologies. Additionally, supercomputing was utilized to accelerate the development of vaccines and drugs. They harnessed AI-assisted radiology for image interpretation and intervention recommendations. China's use of innovative technology in fighting COVID-19 was unprecedented.	Population health
[27]	Author Yu et al. proposed a research model which was based on the organizational information processing theory (OIPT) and aims to study the impact of big data analytics capability (BDAC) on the advancement of supply chain integration (SCI) and operational flexibility in hospitals.	Efficient health management
[28]	Mahima Agarwal et al. have proposed an integrative analytic approach for cancer genomics. This approach takes multi-scale biological interactions as key considerations for model development. They applied our approach to a public lung cancer dataset from an 18-year clinical study of 109 individuals and found new disease markers and drug targets that were confirmed using scientific literature. These findings showcase the potential of big data analytics in uncovering useful information for disease management.	Medical research, Disease management
[29]	Big Data is used to Our research aims to investigate the initial stages of common neurodegenerative conditions like Parkinson's disease, monitor their progression and evaluate the effectiveness of different treatment options using big data analytics.	Medical research
[30]	By utilizing emerging wearable clothing technology, the author has proposed a new healthcare system that combines low-power wireless communication, cloud computing, big data, and machine learning techniques to	Diagnostics, Predict disease,

	provide personalized healthcare services through the monitoring of basic physiological information. Furthermore, in this case, Big Data analysis on large historical data can predict disease trends and provide personalized health services by forecasting users' health status.	Better health services
[31]	Liu et al. have presented e-health systems that are used for continuous monitoring and diagnosis. Prediction and treatment. It helps to reduce healthcare costs and increases the quality of life for long-term chronic disease care.	Diagnostics, Better health services, Intelligent health care
[32]	Priyan et al. have proposed three-tier architecture to store a large amount of sensor data for the early detection of heart diseases. The first layer is responsible for gathering data, the second layer is for storing large volumes of sensor data in the cloud, and the third layer develops a prediction model for heart disease using Receiver Operating Characteristic (ROC) analysis to identify potential symptoms before the onset of the disease.	Predict disease
[33]	A low-cost remote monitoring system was proposed to detect various fatal diseases such as cardiovascular diseases, diabetes, hypertension, and chronic degenerative medical conditions using Heart Rate Variability (HRV) measurements.	Cost Reduction, Predict disease
[34]	Smartphone-based healthcare system using AI and big data analytics is used to identify anomalies by analyzing various data collected from IoT devices.	Predict disease, Diagnostics
[35]	Beck et al. applied a computational pathology model on big data using AI to breast cancer samples and discovered previously unknown morphologic characteristics that were able to predict negative outcomes.	Medical research
[36-37]	Data mining with AI is believed to be more precise and accurate than traditional methods. Big data is used to visualize Adverse drug events and interactions between medications.	Reduction of adverse medication events
[13]	Predictive analytics uses past performance to anticipate future events by analyzing historical or summarized health data, identifying patterns, and extrapolating those patterns. It can be used to predict patient response to drugs or reactions during clinical trials, anticipate risk and discover relationships in health data, predict the spread of epidemics, plan healthcare resources and anticipate service contracts. Predictive analytics is useful in making accurate diagnoses and providing appropriate treatment for patients with specific diseases.	Predictive Medicine

5. Challenges of Big Data in Smart Healthcare

The adoption of big data analytics by healthcare organizations is expected to yield multiple advantages in the future, such as reducing healthcare expenses, enhancing disease diagnosis and prediction, better patient care, developing protocols to prevent readmissions, optimizing staff and equipment usage, forecasting bed and resource needs, and streamlining the drug supply chain [38]. While big data has the potential to bring many benefits to healthcare, there are also some open issues and challenges associated with its use. Some of these include:

1. Data quality and standardization

One of the biggest challenges in using big data in healthcare is ensuring that the data is accurate and of high quality. Data standardization is also an issue, as data may be collected in different formats and structures, making it difficult to combine and analyze.

2. Data privacy and security

Security and privacy are ongoing concerns in any industry, but especially in healthcare where sensitive patient information is handled daily. This sensitive information is often coming from multiple sources, and it can be difficult for healthcare organizations to ensure that it is properly protected. To mitigate this, it is essential to adhere to legal regulations, perform regular audits, and educate employees on data protection best practices to ensure the security and privacy of patient information [39].

3. Data Governance

With large amounts of data being collected, it is important to have clear policies and procedures in place for how the data will be collected, stored, and used.

4. Data integration

Big data is often collected from a variety of sources and in different formats, and it can be challenging to integrate and make sense of the data.

5. Data analytics and modeling

Analyzing big data can be complex and requires specialized skills and expertise, such as machine learning and data science.

6. Data bias and ethical concerns

Data can be biased, leading to biased predictions, recommendations, and decisions. It's important to consider the ethical implications of big data and ensure that they are aligned with patients' rights and welfare. When using big data, there can be ethical and legal challenges that arise, such as the potential to breach privacy and personal autonomy, or negative impact on public trust, transparency, and fairness. These concerns need to be considered and addressed to ensure that the use of big data is in line with ethical standards and legal regulations [40].

7. Data interpretation and explanation ability

Predictive models and algorithms are used to extract insights from big data, but it can be difficult to interpret and explain how these models arrived at certain predictions or recommendations.

8. Lack of infrastructure and resources

Implementing big data solutions can be expensive, and many healthcare organizations may not have the necessary infrastructure or resources to support them.

9. Management Challenges

To fully take advantage of big data analytics in healthcare, organizations may need to adapt their operations and processes. This may involve hiring data scientists and IT staff with the necessary skills to run the analytics and potentially upgrade their IT infrastructure. Some organizations may find it difficult to replace their existing systems but utilizing cloud service providers can alleviate some of these concerns. Additionally, physicians and administrators may need time to build trust and confidence in the insights and advice provided by big data analytics [41].

6. Conclusions

Big data has the potential to greatly impact healthcare and bring about significant changes in smart healthcare. By utilizing big data, healthcare organizations can improve patient care and increase efficiency and value. In conclusion, Big data is a powerful tool that has the potential to transform healthcare in many ways. By leveraging large amounts of data from various sources, healthcare organizations can gain valuable insights that can help to improve patient care, lower costs, and drive value. optimize resource allocation. Big data can also be used to identify patterns and trends in patient populations, which can help to improve the quality of care for individual patients. Additionally, big data can be used to identify patients at high risk of certain health outcomes and to develop targeted interventions to reduce the risk of these events. However, there are also challenges associated with using big data in healthcare, including data quality and standardization, security, privacy, and ethical concerns. To fully realize the benefits of big data analytics in healthcare, organizations need to be prepared to adapt their operations and processes and address these challenges in a responsible and ethical way.

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