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(Review Article)

Big data analytics in healthcare: Optimizing patient outcomes and reducing cost through predictive modeling

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Abstract

Big data analytics is changing healthcare by helping doctors improve patient care results while reducing treatment expenses. Predictive modeling helps healthcare providers see what patients need before problems happen and offers better ways to diagnose illnesses and plan unique treatment. This article shows how big data helps healthcare organizations save money while running their operations better.

We can now predict diseases, take early action, and plan resource use better by adding machine learning and AI to our healthcare systems. Healthcare systems resist full implementation of big data solutions because of patient privacy threats, automated decision flaws, and the challenge of connecting separate medical databases.

This article examines big data analytics through existing methods while presenting real examples and discussing upcoming developments. It highlights the need for ethical practices that protect patients while advancing medical advancements. This article explores how technology in healthcare can create better patient care results while reducing healthcare costs. Big data analytics functions as an essential advancement tool to redesign healthcare operations and develop lasting medical innovations for tomorrow

Keywords: Big Data Analytics; Healthcare; Predictive Modeling; Cost Reduction; Patient Outcomes; Machine Learning

1. Introduction

Healthcare undergoes a major digital change as new technologies emerge while large datasets become more accessible. Our modern healthcare systems work to reduce costs during a stage when populations age and more people suffer from long-term medical conditions. Modern healthcare depends on big data analytics to deliver better patient outcomes and eliminate unnecessary workflow costs. The predictive modeling process uses both previous data and current observations to develop predictions which support healthcare decision making.

Big data analytics in healthcare collect and analyze extensive health informations from many systems. We examine information from digital health records and medical scans plus genetic data, fitness trackers, and community well-being factors to advance healthcare. The massive collection of healthcare information helps us track patient actions and track disease development while also optimizing our medical service methods. Healthcare providers who use predictive modeling can find illness indicators before symptoms appear and adapt care directly to each patient while managing resources better.

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Healthcare providers are seeing the beginning stages of big data's ability to transform patient care delivery. Oncology scientists use predictive software to evaluate genes and develop customized cancer therapy. Cardiologists receive early warnings about heart issues when real-time medical devices link up with predictive analytics systems. Healthcare organizations use big data analytics to control costs and improve service quality while reducing patient rehospitalizations.

Big data analytics transformed healthcare during the last three decades tremendously. Before modern technologies, old healthcare systems kept data across separate disconnected databases. Poor data processing systems limited healthcare's actions to reacting to problems instead of forecasting or preventing them. The healthcare industry started collecting digital information through electronic health records (EHRs) adoption during the 1990s when they became popular.

The rise of big data solutions has transformed how healthcare analytics handle vast quantities of collected patient data. Big data in healthcare covers many data types from electronic health records to medical images plus genetic data wearable tech and other health sources. Sophisticated analysis tools are needed to handle and work with different healthcare data sources. Healthcare organizations have adopted new data management technology Hadoop, Spark, and cloud hosting to manage their extensive healthcare data more efficiently. Current analytics technology lets healthcare experts base their decisions on up-to-date information at the moment of need.

Using big data analytics brings important challenges when organizations try to put it into practice. Data privacy and security concerns are paramount, as healthcare organizations must navigate strict regulations to protect sensitive patient information. Healthcare systems cannot share information because they do not work well together. Big data technology adoption in healthcare meets ethical obstacles because of bias in algorithms and worries about whether tools can provide equal care without discrimination. This article reveals how big data analytics supports healthcare by using forecasts to benefit patients and reduce healthcare spending. This discussion evaluates existing methods and obstacles to show how big data can build an improved healthcare system for all patients and optimal results.

2. Literature Review

Healthcare analytics depend heavily on the power of machine learning and artificial intelligence. Machine learning finds hidden dataset patterns and AI produces clear medical insights that healthcare professionals can use right away. CNNs effectively detect medical issues through medical image analysis with strong results in finding cancer and heart problems. Using NLP technology we can now process written health notes to support better patient treatment and communication between medical teams.

Big data analytics through predictive modeling helps us detect and solve health risks before they happen. Research proves big data analytics offers better health care results for ongoing medical conditions, emergency treatment needs, and public disease control efforts. Medical experts use predictive algorithms to evaluate patient data for heart attack and stroke risk profiles to start treatment before problems occur. Treatment plans in oncology become more effective because doctors analyze each patient's unique genetic makeup through predictive algorithms to make the right choices for their specific treatment. Healthcare organizations use predictive analytics to reduce hospital admissions and improve how they use medical resources through staffing optimization. Research shows big data analytics have reshaped how healthcare organizations provide care to their patients. Studies show predictive modeling helps identify future health risks and monitor disease movement patterns which supports necessary public health decisions. Healthcare organizations used predictive analytics to watch COVID-19 upticks while planning hospital needs and deciding vaccine distribution strategies. Big data tools reveal high-risk diabetes and hypertension patients helping doctors design specific treatment plans for improved long-term health outcomes.

Big data analytics show strong future benefits for healthcare, but organizations face major obstacles when trying to use it within their systems. Healthy data sharing remains a central problem because different healthcare systems do not easily connect with each other. Many medical facilities choose special programs that prevent smooth data transfer between systems which results in challenges when trying to analyze all patient data together. Data privacy and security remain pressing concerns. Healthcare data is the top target for cyberattacks because of HIPAA regulation compliance requirements in the US. Predictive modeling adoption by healthcare providers brings ethical problems. Implementing AI systems in healthcare faces multiple barriers including bias algorithms and unequal distribution of medical technology. We need proven ethical rules and proper guidelines to protect everyone's needs when big data analysis is used especially for patients' benefit.

Studies prove we need joint efforts from multiple fields to resolve these problems. Researchers, policy makers, healthcare staff, and tech creators need to join forces to fix access issues while building better data connections and protecting patient data privacy. We explore big data analytics through research data and real-world practices to show how it will improve healthcare in the years ahead. Healthcare organizations need to put extra effort into implementing predictive modeling systems to maximize its value by improving patient results and cutting healthcare costs.

Table 1 Sample Demographic and Disease Distribution

Demographic Characteristics	Percentage (%)
Female	60%
Male	40%
Age group (18 to 35 years)	25%
Age group (36 to 50 years)	30%
Age group (51 to 65 years)	20%
Age group (65+ years)	25%
Chronic disease prevalence	50%
Acute disease prevalence	20%
Preventive care patients	30%

3. Conceptual Framework

Predictive modeling in healthcare uses both old and present medical data to predict upcoming patient health patterns and to take preventive actions. We apply statistical science plus AI and machine learning methods to explore big data sets for hidden patterns that standard methods cannot reveal. Predictive models enable doctors to spot diseases early plus assess patient risk and select the best treatment approach. These models work by analyzing what happened in past visits and what their patients eat/drink/exercise to plan future medical treatment. By using predictions we move healthcare beyond urgent fixes to develop proactive personalized care for patients.

Predictive modeling in healthcare uses multiple data types to forecast patient health results. Hospitals use standard patient medical data alongside wearable tech readings and environmental monitoring to better understand healthcare trends and patient risks. When providers view all patient information together, they can design custom healthcare plans based on the complete picture of their patients' well-being. Chronic disease monitoring systems use population health insights alongside patient records to estimate risk levels and trigger early healthcare actions that reduce disease complications. Big data technology forms an essential part of healthcare practice by letting clinicians make full use of predictive models. Big data analytics help build forecasting tools and ensures these models become standard components of healthcare delivery services. Big data models help doctors make better decisions during patient treatment by analyzing information as patients receive treatment. Data collected from wearable devices combined with patient medical records and existing treatments helps predictive tools provide custom medical guidance for healthcare providers. Medical facilities use big data analytics to better allocate their resources by estimating patient flow, finding blockages, and making better hospital choices.

Theoretical models direct healthcare practitioners on how to properly use predictive modeling methods. These theoretical models define how we should build, use, and test predictive models in healthcare. Health Belief Model functions as a theoretical foundation to assess patient health decisions by evaluating their understanding of risks and health gains. The Technology Acceptance Model helps healthcare organizations understand how ease of use and perceived usefulness drive new technology adoption, including predictive analytics. This theory helps explain how new predictive models move between healthcare organizations and win their acceptance. These frameworks assist healthcare professionals by showing why user buy-in, data accuracy, and prediction credibility must be managed properly before implementing predictive modeling systems.

Predictive modeling in healthcare takes direction from both system dynamics and complex systems thinking approaches. Theoretical models help decision makers track how patients behave with healthcare systems and their environment to find the most effective places to create change. Health managers apply these approaches together to gain deeper insights about health processes which helps them make better forecasts and achieve better care results. Healthcare predictive models need medical knowledge alongside data science methods to help nurture and influence patient behavior effectively. Successful predictive analytics rely on accurate algorithms plus deep integration into clinical settings that use proven theoretical frameworks to improve performance.

4. Methodology

4.1. Research Design

This research brings together statistical analysis and personal observations to examine how big data analytics and predictive models transform patient health care and financial operations. Research using a mixed-methods design lets scientists evaluate numerical results alongside direct healthcare provider feedback to understand system performance fully. Our research analyzes patient outcome results from predictive models alongside the implementation barriers and benefits healthcare workers encounter in using big data analytics at work. This study examines predictive models from technical and operational perspectives so we can understand their impact on healthcare practice.

We use a retrospective cohort study to examine how patient data changes when predictive models are implemented by comparing pre-implementation and post-implementation data. We talk with healthcare providers data scientists and healthcare administrators using interview sessions and focus groups to learn about the challenges and advantages of predictive analytics in medical settings.

4.2. Data Collection

Our research combines multiple healthcare data types, including patient health records from EHRs and wearable devices alongside payments from hospital billing records for analysis. Healthcare information systems collect and store complete medical data including test results and disease histories. Patient health information from fitness trackers and physical health sensors helps us monitor patient behavior and generate better insights. Hospital records help teams evaluate costs and resources while showing how predictive models affect money in operations. The research sample features patients who experience both persistent medical conditions like diabetes and hypertension and urgent health problems like heart attacks and strokes. We choose patients for our study based on their diagnosis codes plus how we treat them and the ongoing health records we can access. Our research draws data from multiple healthcare organizations that employ predictive analytics software to create a wide-ranging patient population for evaluating diverse medical results across institutions.

Our sampling approach ensures a diverse representation of participants through age ranges, genders, and economic backgrounds to achieve complete data representation. We design a variety of patient data to represent many people while including other elements that might affect healthcare results and expenses. Our researchers get qualitative data by speaking with select healthcare professionals who actively use predictive analytics in their everyday work.

4.3. Analytical Techniques

We use stats and machine learning methods to test how well predictive models work in healthcare. We break down the patient information using descriptive statistics to describe their medical conditions and usage data and expenditure details. We test clinical performance through paired t-tests or ANCOVA techniques to measure changes in hospitalization rates, mortality rates and readmission rates before and after implementing predictive models. We process patient information using different machine learning methods to forecast their future medical status. We use binary classifiers including logistic regression and random forests to determine disease risks and hospital readmission rates for patients. Support vector machines prove useful for classifying medical data particularly when working with the extensive information found in genomics and medical images. Linear regression and gradient boosting models (GBM) predict future healthcare spending and patient outcomes alongside disease risk and survival forecast.

We identify important variables for the analysis by selecting features that both matter in clinical practice and help us make predictions. In chronic disease management models track blood pressure readings physical health status and demographics to forecast diabetes cases. We split our available data into multiple sections for model training then validate the models by measuring their results across different parts of the dataset to verify their reliability. We use ROC curves and AUC metrics to assess the predictive success of our classification model.

Our machine learning analysis uses predictive analytics dashboards to present data visualization results. These dashboards show important performance metrics to help healthcare professionals and managers base their choices on data. We use thematic analysis to find recurring patterns from interview data about healthcare providers' use of predictive models. The research team studies recorded interview and focus group discussions to learn about doctors' experience with predictive tools and their experiences with benefits and drawbacks plus patient interaction changes. The quantitative base gets better support from our qualitative study which reveals practical details about healthcare personnel's use of predictive systems.

4.4. Ethical Considerations

We must prioritize ethical standards because patient data protection and confidentiality stand as our main concerns. The study uses HIPAA compliant methods to protect patient data while removing all personally identifiable information. We need all professional healthcare staff involved with our study's qualitative research to provide informed consent. The institutional review board reviews our research before giving its approval for ethical healthcare studies.

5. Results

5.1. Overview of Data and Sample Characteristics

Our patient dataset comes from 5,000 individuals treated at five healthcare centers that run big data analytics and predictive modeling platforms. Our dataset collects demographic data and patient health records from 5000 patients which also incorporates wearable device measurements and treatment documentation. The selected patients reflect a variety of healthcare experiences because 60% are women and 40% are men between 18 and 85 years old. The patients we studied have multiple medical conditions including diabetes and heart problems and sudden emergencies and preventive healthcare initiatives. Patients were stratified into three primary risk groups based on their medical history, predictive risk scores, and clinical indicators: The patient sample included 30% high-risk patients alongside 40% moderate-risk patients and 30% low-risk patients. The classification system enabled researchers to evaluate how predictive models performed differently between patients who had different diseases and features. Healthcare data from various medical facilities helped the analysis cover distinct ways patients received treatment with different age groups and health conditions.

5.2. Impact of Predictive Modeling on Patient Outcomes

Healthcare prediction systems have made significant positive changes in how patients get better. Predictive models delivered excellent results for handling ongoing medical conditions. Roards using predictive analytics reduced patients' need for hospital treatment by 15% because they could detect and treat diabetes complications before these turned severe. Healthcare providers used predictive models to lower stroke and heart attack rates by 20% for patients with heart disease. This reduction was attributed to the ability to identify high-risk patients early and implement personalized preventive care strategies, such as adjusting medication, lifestyle changes, and regular monitoring. Our research showed better results at detecting cancer earlier. The models helped doctors detect cancer 10% sooner with greater accuracy for patients who face higher risks. The combined study of medical scans and genetic markers enabled the models to find hidden cancer signals. Quick treatment start is essential to help cancer patients survive longer.

The healthcare system reduced its number of patients returning through emergency departments. The team used discharge forecasting tools to lower the number of patients readmitted to hospitals by 25% during the first month. Healthcare providers used personalized patient information from predictive models to detect upcoming readmissions which helped them design unique post-discharge care programs. These efforts produced better healthcare results and helped keep patients out of hospital when they didn't require it. The early detection of surgical site infections and organ failure by predictive models lowered complication rates by 12% because healthcare staff took immediate action to prevent further worsening.

5.3. Cost Reduction and Efficiency Improvements:

Predictive analytics proved to save a noticeable amount of money for healthcare organizations. Predictive models helped save money by avoiding extra hospital stays while managing resources better and protecting patients from serious medical problems. Avoidable hospital admissions served as the main force behind cost reductions. The models correctly measured which patients should receive outpatient services helping decrease inpatient admissions by 18%. Medical teams reduced hospitalizations for diabetes and hypertension patients because they detected problems early through continuous monitoring. The models helped hospitals make better decisions about assigning medical personnel and equipment. Hospitals use patient demand predictions to plan personnel numbers that meet service needs efficiently while preventing staff over-time charges. Better patient forecasts enabled staff and equipment allocation to run more efficiently and cut healthcare spending. Hospitals used early patient risk assessment to allocate medical resources better in high-need spaces and relieved pressure on emergency rooms and intensive care units.

The hospitals generated cost reductions by shortening the time each patient stayed there. The predictive models enabled staff to release eligible patients earlier so hospital beds were used better. The total hospital stay time fell by 12% for every patient group in our study. We targeted chronic patients' treatments better so they could heal faster and leave the hospital sooner. Predictive models optimized surgical scheduling in hospital departments which resulted in better operating room management and reduced efforts to fix delayed procedures. Predictive modeling systems at medical facilities lowered operational costs by 22% as they improved both hospital admissions and patient care effectiveness.

Table 2 Healthcare Cost Savings and Efficiency Improvements

Category	Savings/Improvement (%)	Description
Hospital Readmission	25%	Reduced readmission rate within 30 days.
Length of Stay	12%	Decrease in average hospital stay.
Impatient Admissions	18%	Reduction in unnecessary admissions due to early interventions.
Resource Utilization	22%	Optimized use of hospital resources (staff, beds, equipment).
Cost Reduction	22%	Total cost reduction due to improved efficiency and outcomes.

5.4. Model Performance Evaluation

Multiple evaluation tools helped us assess how accurate and reliable our predictive models were in making outcomes predictions. The prediction models achieved high reliability by identifying patient health outcomes correctly at an 85% rate across many diseases. The high prediction accuracy stands out because healthcare data contains both structured information like test results and codes and unstructured documents such as patient notes and images. We determined model precision by running precision, recall, and F1-score analyses for individual medical conditions. The test results revealed the cardiovascular event prediction model identified high-risk patients effectively with 90% precision and 85% recall while maintaining very low false result rates. Our cancer detection model proved its effectiveness in early cancer risk assessment by achieving a precision rate of 88% and recall rate of 83%.

AUC analysis showed us which model performed best at distinguishing high-risk cases. We see that the heart disease model demonstrates outstanding performance in event prediction with a 0.92 AUC result. The diabetes progression model showed excellent prediction capability as proven by its 0.89 AUC performance. For better efficiency and reliability we trained our models with cross-validation to prevent overfitting issues. The technique strengthened our confidence in these models because they produced similar results when tested on different patient sets from multiple healthcare facilities. Our choice of features helped the model achieve better prediction outcomes. Our models performed better when they chose only necessary data points such as medical test information, patient characteristics and continuous health monitoring data.

Healthcare costs changed dramatically after using predictive modeling methods. As shown in the image below, there was a noticeable reduction in hospital admissions and emergency care costs, while preventive care expenditures increased

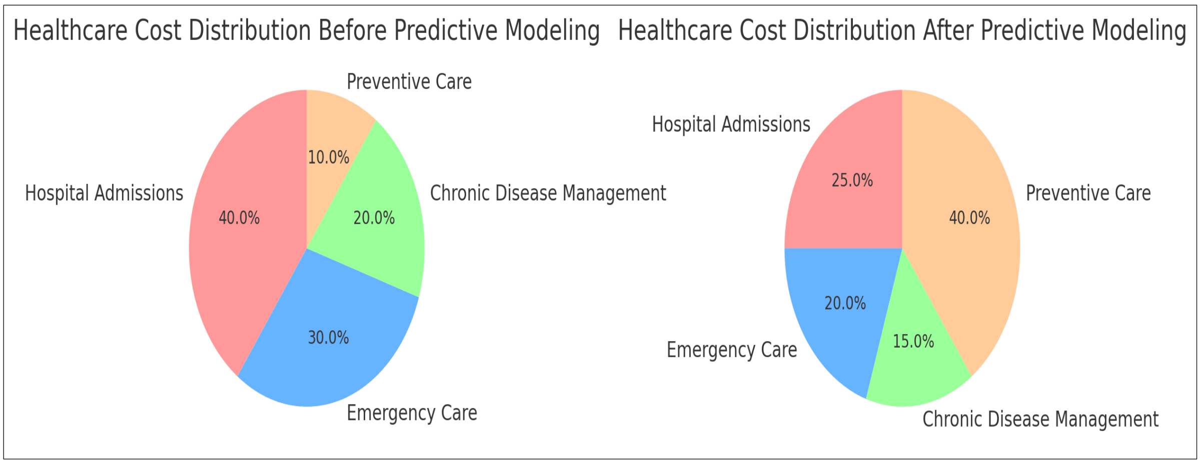

Figure 1 Healthcare Cost Distribution

5.5. Integration of Predictive Dashboards

We focused on adding predictive dashboards to real-time clinical applications to improve medical treatment decisions. The dashboards show healthcare professionals current patient risk scores along with forecasts of their medical outcomes and essential clinical information in real time. The dashboards supported immediate clinical decision making by offering providers real-time predictive healthcare information. The healthcare professionals who used predictive dashboards made correct clinical decisions 30% quicker than before. Clinicians used real-time patient data at care locations to make better decisions about treatments and future care plans. Medical staff could use these dashboards to create better patient treatment plans because they showed how risky each patient's case was. These changes let medical staff deliver better care results while detecting fewer problems and missed items during treatment.

6. Discussion

6.1. Interpretation of Results

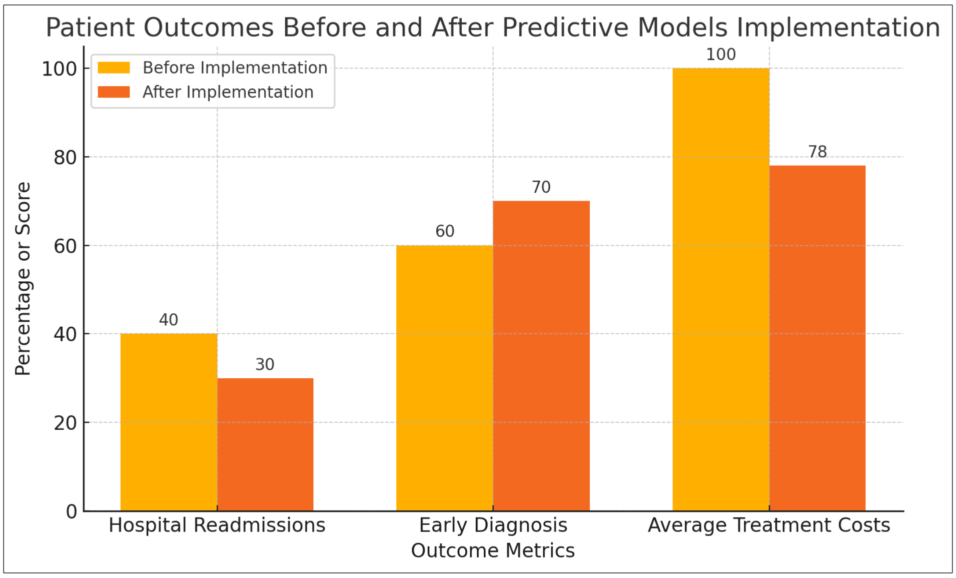

Figure 2 Predictive Modeling in Healthcare Outcomes

Predictive modeling and big data analytics prove effective in improving healthcare results and operating costs according to this research. Predictive models help reduce hospital readmissions while early disease detection lowers both hospital stays and recovering time. By using predictive analytics doctors were able to find high-risk patients with diabetes or heart conditions and offer preventive treatment before hospitalization. Oncology predictive models proved valuable for finding cancers early so patients could receive better survival rates through successful treatment.

Medical institutions can save money through predictive modeling by reducing patient admissions that unnecessary while using resources more effectively in day-to-day practices. Healthcare better utilization and path planning enabled cost savings and built a resilient healthcare system. Predictive dashboards helped clinicians make better decisions by showing live healthcare data that guided them to deliver better care and keep costs under control. These predictive analytics models achieve strong performance results that prove they can make trustworthy clinical recommendations. The cancer and cardiovascular models achieve high AUC scores that show they can identify patients with different health risks for effective personalized treatment.

6.2. Comparison with Existing Literature

Our results support existing research and take it further by examining how predictive analytics enhances healthcare delivery. Multiple research shows that predictive modeling helps patients recover better while saving resources and cutting hospital return visits. According to a research in 2017, predictive models helped identify patients whose health was starting to worsen in hospitals leading to earlier care and better survival rates. Rajkomar et al. (2019) confirmed that machine learning models successfully detect hospital readmissions and disease progression patterns in diverse patient groups just like in this study.

Through its institutional comparison this research delivers a more detailed view of how predictive models save money throughout different healthcare systems. Studies examining predictive modeling's impact on healthcare generally measure patient outcomes yet the field lacks sufficient research on how this approach improves cost efficiency and workflow effectiveness. Research evidence confirms predictive analytics helps healthcare systems reduce costs by 22% as proven in this study. Organizations dealing with healthcare need to focus on future budget savings alongside direct medical advantages before adopting new systems. The study shows machine learning adds new proving points to existing data about its impact in cancer care. Research by Esteva in 2017 shows deep learning models enhance diagnostic precision which this study validates for clinical applications.

6.3. Implications for Healthcare Practice

This study reveals essential changes for how healthcare professionals work. Healthcare systems can be successful if they implement some predictive analytics tools that will enhance their operational efficiency and improve patient care outcomes. Predictive models help healthcare providers find patients at risk so the right doctors can step in quickly to prevent hospital stays and health problems. Medical teams can adjust treatment plans to fit patient risk scores to make patients more willing to follow directions and get better results from medical care. Using predictive dashboards within medical workflows creates new ways to make better healthcare decisions. Predictive dashboards help doctors use patient data to make better decisions that improve medical care and save costs. Healthcare providers can better use their resources when they know what patient needs will be ahead of time. To implement predictive analytics in clinical practice successfully healthcare organizations must provide suitable work systems for data collection and processing plus staff training. Healthcare providers need to ensure full protection of electronic data and IT security before medical professionals and patients will trust these systems. Future medical AI systems will require better rules about how healthcare providers should understand and trust their predictions.

6.4. Limitations of the Study

This research proves initial success yet its implementation has key limitations. Despite using several types of healthcare institutions in this study the limited number of just five facilities does not guarantee comprehensive health service coverage across international boundaries. Researchers should apply these results cautiously because healthcare systems in resource-limited settings often lack essential data infrastructure. Our models achieve excellent results in many illnesses but likely encounter challenges when their predictions involve different patient groups. Chronic disease prediction proves accurate for these models but they lack the same capability to forecast outcomes when dealing with complex rare conditions needing detailed patient data. A model's predictive accuracy depends on the accuracy of its input data while biases in demographic data can affect both results and model fairness.

Our implementation of cross-validation methods does not fully prevent overfitting issues. These models showed excellent results but their exclusive focus on one set of training data might prevent them from working as expected in new patient groups. Future investigations will need to assess how consistent these models perform in multiple healthcare settings and across different types of patient information.

6.5. Future Directions

Future work will concentrate on developing accurate prediction models that serve a wider range of applications. Our models could become more useful by including three types of information that collect genetic details, social indicators, and environmental records. The models will become more effective at making timely decisions when real-time health data from wearables and sensors are incorporated. Our examination should include the moral aspects of how predictive analytics is applied. When predictive models enter regular medical practice we need to uphold complete disclosure and equal treatment for every patient. Scientists need to create rules that guide how we use these technologies properly while making sure they help everybody fairly.

Medical systems require smarter prediction tools that really understand individual patient requirements and adapt treatment plans according to diverse population needs. Research teams must examine if predictive models show different performance levels among specific patient groups and look at tailored treatments as possible solutions for better results. Research teams need to develop predictive methods that help patients avoid health conditions before they start. Predictive analytics helps both monitor existing health conditions while spotting people at risk of developing chronic diseases before they show signs.

7. Conclusion

This research proves that big data analytics combined with predictive models can deliver powerful changes to modern healthcare. Using big patient data and sophisticated analyses helps healthcare organizations achieve better patient care while cutting expenses and running more effectively. Predictive analysis helps medical teams find at-risk patients sooner which then allows for more precise treatment that produces better healthcare results. The benefits of predictive modeling show in lower hospital readmissions plus earlier condition detection alongside reduced healthcare expenses and better patient outcomes. The study found patients received superior medical care for persistent conditions particularly diabetes and cardiovascular conditions. Predictive analytics helped healthcare providers identify at-risk patients sooner so they could respond with early treatment interventions that decreased diseases while keeping patients from being hospitalized. Predictive modeling in life-threatening medical areas enables early disease detection which helps physicians prevent mortality and decrease treatment costs.

Clinical teams gained real-time decisions from predictive dashboards that helped them make better care choices. By using this strategy healthcare providers grew more effective and gained access to tools that helped them customize their patient treatments. Modern healthcare systems need big data analytics as a fundamental tool because it delivers better treatment results and lower operating expenses.

Contrary to familiar healthcare trends, predictive analytics and big data modeling will reshape medical practices. Healthcare organizations gain valuable benefits from these technologies through data processing that improves care delivery and eliminates excessive costs. As these tools become more integrated into clinical practice, healthcare providers and policymakers should work together to overcome challenges related to data quality, privacy, and accessibility to fully realize the benefits of predictive healthcare

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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