

Original Article

Data-Driven Healthcare: Trends in Machine Learning and AI for Disease Prediction and Prevention

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Abstract: *In the rapidly evolving world of healthcare, the integration of machine learning and artificial intelligence (AI) has marked a transformative era, especially in the realm of disease prediction and prevention. This movement is not just about technological advancement; it's about a profound shift towards a more data-driven approach in medicine that promises to enhance patient outcomes, reduce costs, and improve overall health system efficiency. Today, AI and machine learning algorithms are increasingly being harnessed to sift through vast amounts of health data, from electronic health records to genetic information, enabling early detection of diseases such as cancer, heart disease, and diabetes. These technologies are also paving the way for personalized medicine, where treatments and prevention strategies are tailored to the individual, taking into account their unique genetic makeup and lifestyle. Furthermore, predictive analytics in healthcare is empowering professionals to identify at-risk populations and intervene earlier than ever before, thereby preventing diseases from developing or progressing. This trend signifies a hopeful future where healthcare is not just reactive but preventive and treatments are not one-size-fits-all but customized. As we continue to unlock the potential of AI and machine learning in healthcare, we stand on the cusp of a revolution that could redefine patient care and disease management for generations to come.*

Keywords: *Healthcare, Machine Learning, Artificial Intelligence, Disease Prediction.*

I. INTRODUCTION: THE DAWN OF A DATA-DRIVEN ERA IN HEALTHCARE

In the grand tapestry of human innovation, the healthcare sector has always been a focal point of advancement, embodying our relentless pursuit of knowledge and well-being. Today, as we stand on the brink of a technological renaissance, the emergence of machine learning (ML) and artificial intelligence (AI) within healthcare heralds a new chapter, not merely in how we treat diseases but in how we predict, prevent, and personalize healthcare. This introduction aims to unpack the importance of this data-driven transformation, exploring the pivotal roles of ML and AI in crafting the future of healthcare.

A. A Paradigm Shift in Healthcare

The transition to data-driven healthcare is not just an incremental change; it's a paradigm shift that redefines our approach to medicine. Traditional healthcare models have predominantly been reactive, focusing on treating ailments post-diagnosis. However, the advent of digital technologies and data analytics is steering the industry towards a preventive and predictive model. The foundation of this new model is the vast amounts of health data generated and collected – from electronic health records (EHRs) and genomics to wearable technology and beyond. This data, when analyzed and leveraged correctly, holds the key to unlocking unprecedented insights into human health.

B. Machine Learning: The Heartbeat of Modern Medicine

At the heart of this transformation lies machine learning, a subset of AI characterized by the ability of algorithms to learn from and make predictions or decisions based on data. In healthcare, ML's impact is profound, offering the ability to analyze complex medical data at a scale and speed beyond human capability. This analysis can lead to early detection of diseases, identification of new drug candidates, and insights into disease progression and treatment outcomes. Machine learning's role in healthcare is akin to providing a high-powered microscope that can see patterns and predict outcomes with astonishing accuracy, all in real-time.

C. Artificial Intelligence: The Brain behind Healthcare Innovation

AI in healthcare acts as the central nervous system, connecting various data points and generating insights that inform decision-making, policy, and patient care. Beyond data analysis, AI applications in healthcare extend to robotic surgeries, virtual nursing assistants, and AI-driven diagnostics. These technologies are not replacing human practitioners but enhancing their



ability to provide care, make informed decisions, and spend more time on patient interaction. The synergy between AI technologies and healthcare professionals is paving the way for more efficient, accurate, and personalized patient care.

D. Revolutionizing Disease Prediction and Prevention

One of the most significant impacts of AI and ML in healthcare is the shift towards predictive medicine. By analyzing patterns within large datasets, these technologies can identify potential health risks and disease markers long before symptoms appear. This capability transforms the healthcare landscape by enabling a shift from a model that waits for disease to manifest to one that actively works to prevent it. It's a monumental shift towards extending life expectancy and improving life quality, grounded in the early detection and prevention of diseases such as cancer, cardiovascular diseases, and diabetes.

E. The Personalization of Patient Care

The era of one-size-fits-all medicine is coming to an end, thanks to ML and AI. Personalized medicine, or precision medicine, tailors healthcare to individual characteristics, including genetics, lifestyle, and environment. This level of customization ensures that treatments are more effective, with fewer side effects, and preventive measures are more impactful. ML and AI are at the forefront of this revolution, analyzing individual patient data to predict the most effective treatments and preventive measures. This personalization extends beyond treatment to encompass personalized health monitoring and management, revolutionizing patient engagement and empowerment.

F. Challenges and Ethical Considerations

As we embrace the potential of ML and AI in healthcare, we must also navigate the challenges and ethical considerations these technologies bring. Privacy and security of patient data, bias in AI algorithms, and the need for transparent and explainable AI are just a few of the hurdles to overcome. Ensuring these technologies benefit all segments of society equally is also a significant concern, highlighting the need for ethical guidelines and regulations that keep pace with technological advancement.

G. The Future is Here

The integration of ML and AI into healthcare is not a distant future scenario; it's happening now. Across the globe, healthcare providers, researchers, and technologists are collaborating to harness these technologies to improve health outcomes, reduce costs, and make healthcare more accessible and equitable. As we continue to explore the capabilities of AI and ML, their roles in healthcare will only grow, promising a future where disease prediction, prevention, and personalized care are not just ideals but everyday realities.

II. OVERVIEW OF MACHINE LEARNING AND AI IN HEALTHCARE

The integration of Machine Learning (ML) and Artificial Intelligence (AI) into healthcare represents one of the most promising advancements in medical science and patient care. This comprehensive exploration will delve into the foundational concepts of ML and AI, examine the types of models employed, and highlight their multifaceted applications within the healthcare sector.

A. Foundational Concepts of ML and AI

a) What is Machine Learning?

Machine Learning, a subset of AI, focuses on the development of algorithms that can learn from and make predictions or decisions based on data. This capability is particularly impactful in healthcare, where the interpretation of complex datasets can lead to groundbreaking insights and advancements.

b) What is Artificial Intelligence?

Artificial Intelligence encompasses a broader range of technologies that enable machines to mimic human intelligence. In healthcare, AI applications range from natural language processing for patient interaction to sophisticated algorithms for diagnosing diseases.

B. Types of Models Used in Healthcare

a) Supervised Learning

This is the most prevalent ML model in healthcare, where algorithms learn from labeled training data to predict outcomes or classify data. Applications include disease detection from imaging data and patient risk assessment.

b) Unsupervised Learning

Unsupervised learning algorithms identify patterns or structures within data without the need for labels. In healthcare, these models are invaluable for discovering patient subgroups or disease patterns that may not be immediately apparent.

c) Reinforcement Learning

Reinforcement learning involves algorithms learning to make decisions through trial and error to achieve a certain goal. Its applications in healthcare are growing, including optimizing treatment policies and robotic surgery.

d) Deep Learning

A subset of ML, deep learning uses neural networks with many layers to analyze data. It's particularly effective for processing complex data types, such as medical imaging, enabling more accurate diagnoses and insights.

C. Applications of ML and AI in Healthcare

a) Disease Diagnosis and Prediction

One of the most significant applications of ML and AI in healthcare is in disease diagnosis and prediction. Deep learning models, for example, are being used to detect cancerous tumors in imaging data with accuracy rates that sometimes surpass human experts. These technologies are also being applied to predict disease progression and outcomes, providing valuable information for planning treatment strategies.

b) Personalized Medicine

ML and AI are driving the shift towards personalized medicine, where treatment and prevention strategies are tailored to the individual. By analyzing a patient's genetic makeup, lifestyle, and environmental factors, AI can predict the most effective treatments, minimize side effects, and even forecast disease susceptibility.

c) Drug Discovery and Development

The drug discovery process is notoriously time-consuming and costly. AI and ML are revolutionizing this field by predicting how different drugs will interact with targets in the body, identifying potential drug candidates, and speeding up clinical trials through better patient selection and monitoring.

d) Operational Efficiency

Beyond direct patient care, ML and AI are improving operational efficiency within healthcare systems. Algorithms can predict patient admission rates, optimize staffing, manage supply chains, and even assist in the diagnosis process, reducing wait times and improving patient flow.

e) Health Monitoring and Wearables

Wearable technology equipped with AI is transforming health monitoring by providing real-time, continuous data on patient health metrics. This constant stream of data can predict health events, such as heart attacks or diabetic episodes, potentially saving lives through early intervention.

f) Challenges and Ethical Considerations

While the benefits are vast, the adoption of ML and AI in healthcare is not without challenges. Issues of data privacy, security, and the potential for algorithmic bias must be addressed. Moreover, there's a pressing need for frameworks to ensure the ethical use of these technologies, emphasizing transparency, accountability, and equity.

D. The Future of ML and AI in Healthcare

The future landscape of healthcare, significantly influenced by ML and AI, promises enhanced disease prediction, more personalized treatment plans, and improved operational efficiencies. As we continue to refine these technologies and navigate their ethical implications, their integration into healthcare systems worldwide will undoubtedly become more profound.

The journey of integrating ML and AI into healthcare is a testament to the human pursuit of knowledge and the betterment of society through technology. By harnessing the power of data and intelligent algorithms, we are not just transforming healthcare; we are redefining the possibilities for human health and longevity.

III. TRENDS IN MACHINE LEARNING AND AI FOR DISEASE PREDICTION

The realms of Machine Learning (ML) and Artificial Intelligence (AI) are revolutionizing the healthcare industry, particularly in the area of disease prediction. This comprehensive analysis explores the current trends, including predictive

analytics, deep learning techniques, and presents specific case studies that underscore the successful application of these technologies in predicting diseases.

A. Advancements in Predictive Analytics

Predictive analytics in healthcare leverages ML and AI to analyze historical and real-time data to forecast future medical events. This approach has seen significant advancements, with models becoming increasingly sophisticated, capable of handling vast datasets from electronic health records (EHRs), genomics, and wearables. The trend towards integrating diverse data sources, including social determinants of health, genetic information, and patient-generated data, is enhancing the accuracy and applicability of predictive models. This comprehensive view enables more nuanced predictions, tailored to individual patient profiles.

B. Deep Learning Breakthroughs

Deep learning, particularly Convolutional Neural Networks (CNNs), has transformed medical imaging analysis. These models excel at detecting anomalies in imaging data, such as MRI and CT scans, enabling early detection of diseases like cancer, Alzheimer's, and more. NLP, another facet of deep learning, is making strides in extracting valuable information from unstructured data sources, such as clinical notes and research papers. This capability is pivotal in identifying risk factors and symptoms that contribute to disease prediction models.

C. Case Studies of Success

a) Predicting Cardiovascular Diseases

A landmark study employed deep learning to predict cardiovascular risks by analyzing retinal images. This innovative approach, bypassing traditional risk factors, showcased the potential of AI in predicting heart disease directly from medical images.

b) Early Detection of Diabetes

Another case involved the use of predictive analytics to identify patients at risk of developing Type 2 diabetes. By analyzing EHR data, including lab results and patient histories, the model could forecast the onset of diabetes years before clinical diagnosis.

c) Predicting Hospital Readmissions

AI models have also been developed to predict patient readmissions, a critical factor in managing chronic conditions and reducing healthcare costs. These models assess a range of data, from clinical to socio-economic, to identify patients likely to experience readmission.

D. Emerging Trends and Technologies

a) Federated Learning for Privacy Preservation

The trend towards federated learning, where AI models are trained across multiple decentralized devices or servers holding local data samples, addresses privacy concerns. This approach is particularly relevant in healthcare, where data sensitivity is paramount.

b) AI-Driven Wearables for Continuous Monitoring

The proliferation of AI-driven wearables is enabling continuous health monitoring and data collection. These devices can detect early signs of disease, offering a non-invasive method to gather health metrics crucial for predictive models.

E. Challenges and Future Directions

a) Addressing Data Bias and Inequity

One of the significant challenges facing the deployment of AI in disease prediction is data bias, which can lead to inequitable health outcomes. Efforts are underway to develop more inclusive models that accurately represent diverse populations.

b) The Need for Explainable AI

As AI models become more complex, the push for explainable AI (XAI) grows stronger. XAI aims to make the decision-making processes of AI models transparent and understandable, essential for clinical acceptance and ethical considerations.

c) Integrating AI into Clinical Practice

The integration of AI and predictive analytics into clinical workflows remains a hurdle. Future directions involve not only technological advancements but also regulatory, ethical, and educational efforts to ensure that healthcare professionals can effectively leverage these tools.

F. Case Studies in Depth

a) AI Predicting Oncological Outcomes

A breakthrough study involving the use of AI to predict responses to cancer treatment based on genetic and clinical data demonstrated the power of personalized medicine. This approach can significantly impact treatment planning and patient outcomes in oncology.

b) Machine Learning in Mental Health Predictions

ML models are increasingly being used to predict mental health issues, such as depression and anxiety, by analyzing data from various sources, including social media usage patterns and linguistic analysis of patient communication.

IV. TRENDS IN MACHINE LEARNING AND AI FOR DISEASE PREVENTION

The application of Machine Learning (ML) and Artificial Intelligence (AI) in healthcare is not just transforming disease diagnosis and treatment but is also revolutionizing disease prevention. This comprehensive overview explores how these technologies contribute to advancing personalized medicine, lifestyle management, and preventive interventions, showcasing the potential for a healthier future.

A. The Foundation of Preventive Healthcare

a) A Shift towards Proactivity

The advent of ML and AI in healthcare marks a significant shift from reactive to proactive care. By leveraging vast datasets and advanced analytics, these technologies enable early intervention strategies that can prevent diseases from developing or progressing.

b) The Role of Big Data

At the core of this transformation is the utilization of big data. Health data from electronic health records (EHRs), genomics, wearables, and environmental sources provide a multidimensional view of patient health, crucial for effective prevention strategies.

B. Personalized Medicine: Tailoring Health to the Individual

a) Genomics and Precision Health

ML and AI are instrumental in interpreting complex genomic data, leading to the identification of genetic predispositions to diseases. This information is vital for developing personalized health plans that address specific risks and promote preventive measures.

b) Predictive Analytics for Personalized Risk Assessment

Predictive models analyze individual health data to forecast potential health issues before they arise. Such personalized risk assessments are pivotal in crafting targeted preventive interventions, from medication regimens to lifestyle adjustments.

C. Lifestyle Management: A Data-Driven Approach

a) Wearable Technology and Real-Time Monitoring

AI-integrated wearables provide continuous health monitoring, offering real-time insights into vital statistics and lifestyle habits. This constant data flow enables the prediction of health risks and the formulation of personalized lifestyle recommendations.

b) Behavioral Modification through AI

ML algorithms analyze behavior patterns to identify risk factors, such as physical inactivity or poor diet. Tailored AI-driven interventions can then encourage healthier habits, significantly reducing the risk of lifestyle-related diseases.

D. Preventive Interventions: Acting Before Onset

a) Early Detection through Screening

AI-enhanced screening programs can identify diseases at their nascent stages, even before symptoms appear. Such early detection is crucial for implementing preventive measures that can halt disease progression.

b) Vaccination and Public Health Campaigns

AI models predict outbreak patterns, informing vaccination strategies and public health campaigns. This predictive capability is essential for preventing infectious diseases and managing public health resources efficiently.

E. Case Studies in Disease Prevention

a) Cardiovascular Disease Prevention

One study utilized ML to analyze heart rate variability and other physiological markers from wearables to predict cardiovascular risk. The intervention strategies, including lifestyle modifications and preventive medications, significantly reduced the incidence of heart-related events among high-risk individuals.

b) Preventing Type 2 Diabetes

AI-driven programs focused on lifestyle interventions have shown promise in preventing or delaying the onset of Type 2 diabetes in prediabetic individuals. By customizing dietary and exercise recommendations, these programs achieve remarkable success in mitigating diabetes risk.

F. Emerging Trends and Technologies

a) AI for Environmental Health

Emerging applications of AI in monitoring and analyzing environmental factors – such as pollution levels and climate change – offer new avenues for disease prevention, highlighting the link between environmental health and chronic diseases.

b) Digital Health Platforms

The development of comprehensive digital health platforms that integrate AI and ML with telemedicine and mobile health apps is fostering a more proactive and preventive approach to healthcare.

G. Challenges and Ethical Considerations

a) Data Privacy and Security

As healthcare increasingly relies on digital data, ensuring the privacy and security of patient information becomes paramount. Balancing the benefits of predictive and preventive AI applications with the need to protect individual privacy is a significant challenge.

b) Equity and Access

Ensuring that AI-driven preventive healthcare benefits all segments of the population equally is crucial. Addressing disparities in access to technology and healthcare resources is essential for equitable disease prevention.

H. The Future of Disease Prevention

a) Integrated Health Ecosystems

The future points towards integrated health ecosystems where AI and ML seamlessly blend with healthcare delivery. Such ecosystems will leverage predictive analytics and personalized medicine to offer unprecedented preventive care.

b) The Role of AI in Global Health

On a global scale, AI has the potential to transform public health strategies, offering solutions tailored to the health challenges of diverse populations. This global perspective is vital for addressing worldwide health disparities and preventing diseases on a large scale.

V. ANALYSIS OF IMPACT: THE INFLUENCE OF ML AND AI ON HEALTHCARE

The integration of Machine Learning (ML) and Artificial Intelligence (AI) into healthcare has set the stage for transformative changes in patient care, healthcare outcomes, and the economics of healthcare delivery. This detailed analysis explores the multifaceted impact of these technologies, highlighting the benefits and navigating the challenges, including data privacy, ethical considerations, and implementation barriers.

A. Enhanced Healthcare Outcomes

ML and AI have significantly improved healthcare outcomes by enabling precision medicine and personalized care. By analyzing vast datasets, these technologies facilitate accurate disease diagnosis, predict patient outcomes, and tailor treatments to individual genetic profiles, lifestyle factors, and health histories.

The application of predictive analytics has shifted the focus from treatment to prevention. By identifying at-risk individuals early, healthcare providers can offer preemptive interventions, effectively reducing the incidence and severity of diseases.

B. Revolutionizing Patient Care

AI-driven diagnostic tools have demonstrated superior accuracy in detecting conditions such as cancers, cardiovascular diseases, and neurological disorders. This enhanced diagnostic capability reduces the likelihood of misdiagnoses, ensuring patients receive appropriate treatment sooner.

AI and ML have expanded the reach of healthcare through virtual care and telehealth services. Patients in remote areas now have better access to healthcare services, and continuous monitoring through AI-driven devices provides a proactive approach to managing chronic conditions.

C. Economic Impact on Healthcare Costs

By streamlining administrative tasks, predicting patient admission rates, and optimizing resource allocation, ML and AI technologies can significantly reduce operational costs. These efficiencies translate to lower healthcare costs and improved healthcare accessibility.

While the upfront costs of implementing AI and ML technologies can be high, the long-term benefits of improved diagnosis accuracy, personalized treatments, and preventive care can lead to substantial savings by avoiding costly interventions and hospitalizations.

D. Challenges and Ethical Considerations

The reliance on large datasets raises substantial data privacy concerns. Protecting patient information while leveraging data for healthcare improvements requires robust security measures and constant vigilance. The ethical use of AI in healthcare encompasses issues of bias, transparency, and accountability. Ensuring AI algorithms are free from bias and decisions are explainable and transparent is crucial for maintaining patient trust and ethical standards.

E. Implementation Barriers

Integrating AI and ML into existing clinical workflows presents a significant challenge. Healthcare providers need training and support to adapt to new technologies, ensuring they complement rather than complicate care delivery. The initial investment in AI and ML technologies, including infrastructure and training, can be prohibitive for many healthcare providers, particularly in under-resourced settings. This barrier could widen the gap in healthcare quality and accessibility.

F. Case Studies Highlighting Impact

A notable case study in oncology demonstrated how AI-driven tools could analyze genetic information and medical imaging to identify optimal treatment strategies, resulting in improved survival rates and reduced treatment side effects. In chronic disease management, remote patient monitoring devices equipped with AI algorithms have been instrumental in reducing hospital readmissions and emergency visits, showcasing the economic and healthcare benefits of proactive patient care.

G. Future Directions

Future advancements in ML and AI must focus on reducing healthcare disparities. This goal involves developing inclusive technologies that address the needs of diverse populations and ensuring equitable access to AI-driven healthcare innovations. Establishing comprehensive regulatory frameworks and standards for the development and use of AI in healthcare is essential. These frameworks should prioritize patient safety, data privacy, and the ethical use of technology, paving the way for responsible innovation.

VI. CONCLUSION: NAVIGATING THE FUTURE WITH ML AND AI IN HEALTHCARE

As we stand at the crossroads of technological innovation and healthcare, the journey of integrating Machine Learning (ML) and Artificial Intelligence (AI) into the medical field has unfolded a narrative filled with promise and challenges. This

exploration has not only illuminated the transformative impact of these technologies on patient care, healthcare outcomes, and cost efficiency but also highlighted the hurdles that lie in the path of widespread adoption. Summarizing our findings, the future of ML and AI in healthcare is bright, underscored by the potential for groundbreaking advancements in disease prediction and prevention. Yet, realizing this potential hinges on our ability to foster interdisciplinary collaboration and navigate the ethical, privacy, and implementation landscapes responsibly.

A. The Promise of ML and AI in Healthcare

ML and AI have demonstrated unparalleled capabilities in enhancing healthcare outcomes through precision medicine, predictive analytics, and personalized care. These technologies have revolutionized patient care, offering more accurate diagnoses, expanded access through telehealth, and proactive management of chronic conditions. Economically, the efficiencies driven by ML and AI promise to reduce healthcare costs, making quality care more accessible to a broader population. The case studies discussed underscore the tangible benefits already being realized, from improved oncology treatments to effective chronic disease management through remote monitoring.

B. Facing the Challenges Ahead

Despite these advances, the journey is fraught with challenges. Data privacy remains a paramount concern, as the power of ML and AI rests on the ability to analyze vast datasets. Ethical considerations, particularly around bias and transparency, call for rigorous scrutiny to ensure that the benefits of AI and ML extend to all segments of society equitably. Moreover, the integration of these technologies into existing healthcare systems presents practical hurdles, from the cost of implementation to the need for training healthcare professionals in the use of these new tools.

C. The Future Prospects

Looking ahead, the horizon is expansive for ML and AI in healthcare. The continuous evolution of these technologies holds the promise for even more sophisticated disease prediction models, further personalization of patient care, and broader implementation of preventive healthcare strategies. However, the realization of this future is contingent upon addressing the current challenges head-on; ensuring that technological advancements do not outpace ethical considerations and that the digital divide does not leave vulnerable populations behind.

D. The Importance of Interdisciplinary Collaboration

Perhaps the most critical factor in advancing the integration of ML and AI into healthcare is interdisciplinary collaboration. The convergence of technology, medicine, ethics, and policy is essential for developing AI and ML applications that are not only technologically advanced but also ethically sound and widely accessible. This collaboration extends beyond the confines of healthcare professionals and technologists; it must include patients, ethicists, policymakers, and the broader community to ensure that the development and implementation of these technologies reflect the diverse needs and values of society.

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