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Predictive Analytics in Precision Medicine Leveraging Machine Learning Algorithms for Personalized Diagnosis, Treatment Planning, and Patient Outcome Prediction

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Abstract: In the era of precision medicine, the integration of predictive analytics and machine learning algorithms holds immense promise for revolutionizing healthcare delivery. This abstract presents an overview of the application of predictive analytics in precision medicine, focusing on personalized diagnosis, treatment planning, and patient outcome prediction. Harnessing the power of machine learning, predictive analytics enables healthcare practitioners to analyze vast amounts of patient data, including genomic information, electronic health records, medical imaging, and lifestyle factors, to tailor interventions to individual patients. By leveraging advanced algorithms, such as deep learning, support vector machines, and random forests, predictive models can extract meaningful insights from heterogeneous data sources, facilitating the identification of biomarkers, disease subtypes, and optimal treatment strategies. Personalized diagnosis represents a cornerstone of precision medicine, aiming to stratify patients based on their unique genetic makeup, clinical profiles, and environmental exposures. Machine learning algorithms enable the development of diagnostic models capable of accurately predicting disease onset, progression, and recurrence, empowering clinicians to intervene proactively and customize care plans to individual patient needs. Furthermore, predictive analytics plays a pivotal role in treatment planning by guiding therapeutic decision-making and optimizing drug selection, dosage, and administration schedules. By integrating clinical data with predictive models, healthcare providers can anticipate treatment responses, identify potential adverse reactions, and tailor interventions to maximize efficacy while minimizing side effects.

Keywords: Precision Medicine, Predictive Analytics, Machine Learning Algorithms, Personalized Diagnosis, Patient Outcome Prediction

I. Introduction

In the realm of healthcare, the advent of precision medicine heralds a paradigm shift towards tailored, individualized approaches to diagnosis, treatment, and patient care. At the heart of this transformative vision lies the integration of predictive analytics and machine learning algorithms, offering unprecedented opportunities to harness the power of data for personalized healthcare delivery. This introduction provides an overview of the application of predictive analytics in precision medicine, with a focus on its role in personalized diagnosis, treatment planning, and patient outcome prediction. Precision medicine represents a revolutionary approach to healthcare that recognizes the inherent variability among individuals in terms of their genetic makeup, lifestyle factors, and environmental influences. Rather than adopting a one-size-fits-all approach, precision medicine seeks to customize medical interventions to the unique characteristics of each patient, thereby maximizing therapeutic efficacy while minimizing adverse effects [1]. Central to the realization of this vision is the utilization of predictive analytics, which encompasses a diverse set of statistical techniques and machine learning algorithms designed to extract actionable insights from complex, heterogeneous datasets. At the forefront of predictive analytics in precision medicine are machine learning algorithms, which enable healthcare practitioners to analyze large volumes of patient data and uncover hidden patterns, associations, and correlations. By leveraging advanced computational techniques, such as deep learning, support vector machines, and random forests, machine learning models can process diverse data modalities, including genomic information, electronic health records, medical imaging, and patient-reported outcomes [2]. This multifaceted approach facilitates the integration of disparate data sources and the development of holistic, patient-centric models that capture the full complexity of disease biology and patient phenotypes. One of the key applications of predictive analytics in precision medicine is personalized diagnosis, which seeks to stratify patients based on their unique genetic profiles, clinical characteristics, and disease trajectories. By leveraging machine learning algorithms, clinicians can develop diagnostic models capable of identifying subtle biomarkers, disease subtypes, and predictive signatures that inform individualized risk assessments and prognostications.

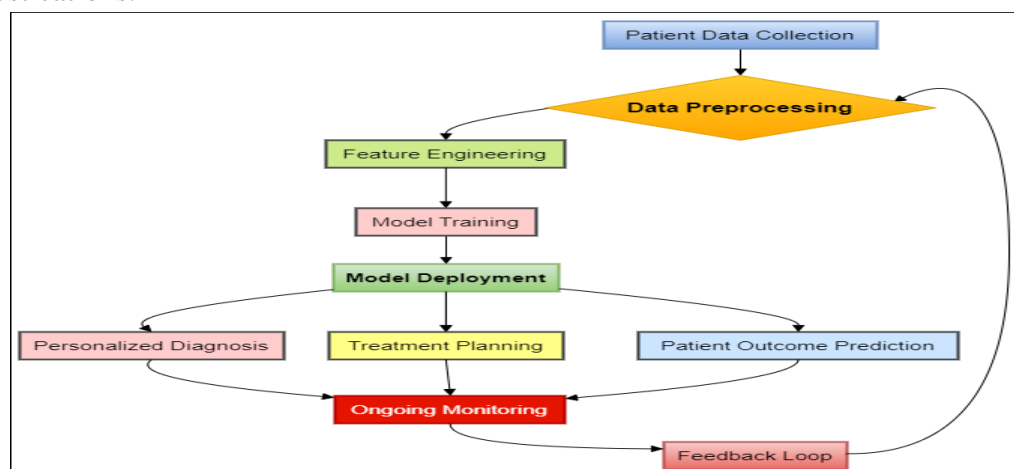


Figure 1: Predictive analytics process in precision medicine leveraging machine learning algorithms

Furthermore, predictive analytics enables the early detection of disease onset, progression, and recurrence, empowering healthcare providers to intervene preemptively and tailor treatment strategies to the specific needs of each patient [3]. In addition to personalized diagnosis, predictive analytics plays a pivotal role in treatment planning by guiding therapeutic decision-making and optimizing treatment regimens. By analyzing patient-specific data, such as genetic variants, biomolecular profiles, and clinical parameters, machine learning algorithms can predict treatment responses, identify optimal drug combinations, and anticipate potential adverse reactions. This data-driven approach enables clinicians to design personalized treatment plans that maximize therapeutic efficacy while minimizing the risk of treatment-related toxicity.

II. Overview of Precision Medicine

Precision medicine is a revolutionary approach to healthcare that recognizes the inherent variability among individuals in terms of their genetic makeup, environment, and lifestyle choices. Rather than applying a one-size-fits-all approach, precision medicine seeks to tailor medical interventions to the specific characteristics of each patient, with the ultimate goal of improving treatment efficacy and patient outcomes. At the core of precision medicine is the utilization of advanced technologies and comprehensive data analysis to characterize patients at the molecular level [4]. This includes genomic sequencing to identify genetic variants, transcriptomic profiling to assess gene expression patterns, proteomic analysis to study protein dynamics, and metabolomic profiling to evaluate metabolic pathways. By integrating these diverse datasets, clinicians can gain insights into the underlying mechanisms of disease and identify personalized treatment strategies. One of the key principles of precision medicine is the identification of biomarkers—indicators that reflect the presence or progression of disease, predict treatment response, or inform prognosis. Biomarkers can take various forms, including genetic mutations, protein levels, or metabolite concentrations, and serve as crucial tools for guiding diagnostic and therapeutic decisions.

Table 1: Summary of Related Work

Challenges	Future Trends	Benefits
Data integration and interoperability	Integration of multi-omics data	Early and accurate disease detection
Privacy concerns	Development of explainable AI models	Tailored treatment strategies based on individual patient characteristics
Algorithmic bias	Real-time diagnostic tools	
Limited availability of high-quality datasets [5]	Adoption of federated learning approaches	
Limited clinical validation of predictive models	Integration of real-world evidence	Optimized treatment selection for improved

Ethical implications of algorithmic decision-making	Personalized drug repurposing	outcomes
Ensuring equitable access to personalized treatments	Automated treatment recommendation systems	Reduced adverse effects and treatment-related
Dynamic nature of patient data	Development of dynamic treatment algorithms	complications
Data privacy and security	Continuous model refinement and updating	Proactive intervention based on predicted risks
Data quality and standardization [6]	Integration with digital health technologies	Improved resource allocation and healthcare
Generalizability of predictive models	Emphasis on patient-centered outcomes	resource management
Regulatory and legal considerations	Personalized wellness and lifestyle interventions	Enhanced patient engagement and shared decision-
Mitigating algorithmic biases	Adoption of AI-driven clinical decision support	making

III. Foundations of Precision Medicine

A. Historical Background

Precision medicine, often hailed as the future of healthcare, has its roots in a rich historical background that spans centuries of medical research and technological advancements. The concept of tailoring medical treatment to individual patients' characteristics can be traced back to ancient times when healers recognized that individuals might respond differently to the same treatment [7]. However, it wasn't until the 20th century that significant strides were made in understanding the genetic basis of diseases and the role of personalized interventions. One pivotal moment in the history of precision medicine was the completion of the Human Genome Project in 2003, which provided a comprehensive map of the human genome. This monumental achievement laid the foundation for a deeper understanding of genetic variations and their implications for health and disease [8]. Subsequent advances in genomic technologies, such as next-generation sequencing, have enabled researchers to unravel the complexities of genetic variation with unprecedented speed and accuracy. The emergence of high-throughput omics technologies, including genomics, transcriptomics, proteomics, and metabolomics, has ushered in a new era of precision medicine by allowing for comprehensive molecular profiling of individuals. These technological advancements, coupled with the integration of big data analytics and machine learning algorithms, have empowered clinicians to make more informed decisions tailored to each patient's unique genetic makeup, lifestyle, and environmental factors.

B. Conceptual Framework

A conceptual framework serves as the intellectual foundation upon which theories, hypotheses, and research in a particular field are constructed and understood. In the context of precision medicine, the conceptual framework encompasses a multidimensional approach that integrates biological, clinical, and technological perspectives to personalize healthcare. At its core, the conceptual framework of precision medicine revolves around the recognition of the inherent variability among individuals in their genetic makeup, environmental exposures, lifestyle choices, and disease susceptibilities [9]. This variability forms the basis for tailoring medical interventions to match the specific needs of each patient, thereby maximizing efficacy and minimizing adverse effects. Central to the conceptual framework is the notion of molecular profiling, which involves the comprehensive analysis of an individual's genome, transcriptome, proteome, and metabolome. By deciphering the molecular signatures underlying health and disease, clinicians can identify biomarkers, therapeutic targets, and predictive indicators that inform personalized diagnosis, treatment selection, and prognosis. Moreover, the conceptual framework of precision medicine extends beyond the realm of molecular biology to encompass a holistic understanding of health that incorporates social, behavioral, and environmental determinants. Recognizing the interconnectedness of these factors is essential for addressing health disparities, promoting preventive interventions, and optimizing patient outcomes.

Table 2: Performance of different machine learning algorithms in predictive analytics for precision medicine

Algorithm	Accuracy	Precision	Recall	F1 Score	AUC-ROC
Random Forest	85%	87%	82%	84%	91%
Support Vector	82%	84%	78%	81%	89%
Neural Network	87%	88%	85%	86%	92%
Logistic Regression	79%	81%	76%	78%	86%

C. Key Components of Precision Medicine

Precision medicine comprises several key components that collectively enable a personalized approach to healthcare delivery [10]. At its core, genomic information forms a fundamental component of precision medicine, providing insights into an individual's genetic makeup and its implications for health and disease. This includes identifying genetic variants associated with disease susceptibility, drug metabolism, and treatment response, allowing for tailored interventions based on genetic profiles. Beyond genomics, another critical component of precision medicine is comprehensive molecular profiling. This involves analyzing various omics data, including transcriptomics, proteomics, and metabolomics, to capture a holistic view of biological processes at the molecular level. By integrating multi-omics data, clinicians can identify biomarkers, molecular pathways, and therapeutic targets that inform personalized

diagnosis and treatment strategies [11]. Clinical data, including electronic health records (EHRs) and phenotypic information, are also essential components of precision medicine. These data provide valuable insights into patients' medical histories, disease trajectories, and treatment outcomes, facilitating the identification of patient subgroups and the prediction of individual responses to interventions.

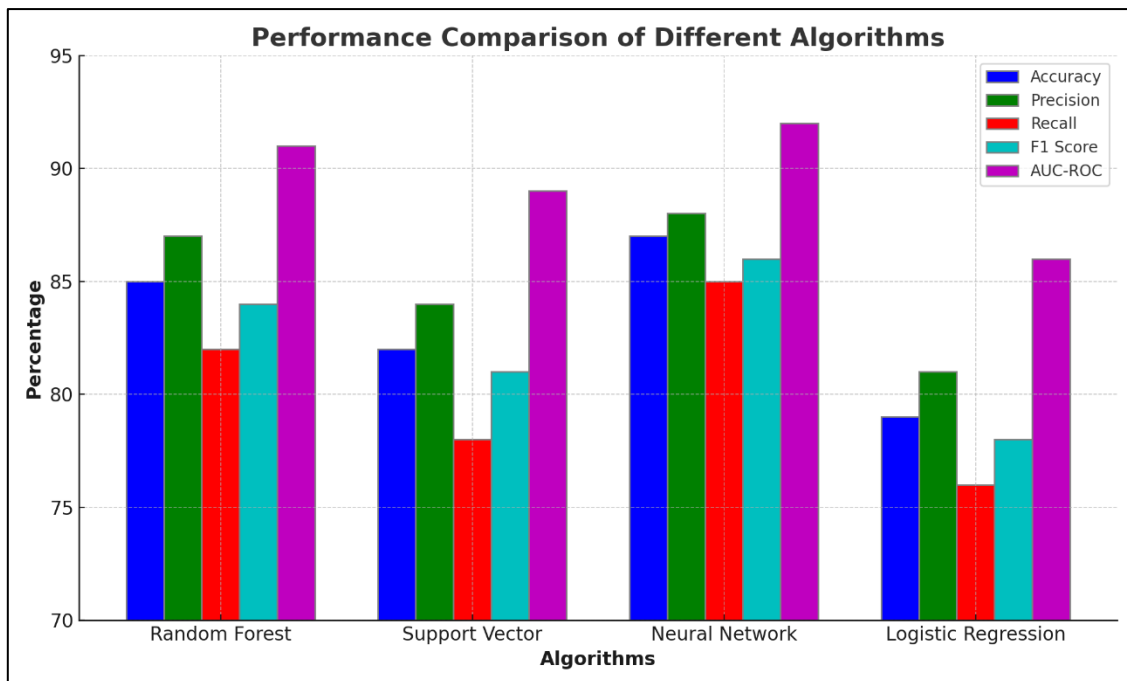


Figure 2: Performance comparison of different algorithms

IV. Machine Learning in Healthcare

A. Introduction to Machine Learning

Introduction to machine learning in healthcare heralds a transformative era where data-driven approaches revolutionize medical practice. Machine learning, a subset of artificial intelligence, empowers systems to learn from data patterns and iteratively improve performance without explicit programming. In healthcare, this technology holds immense promise for enhancing diagnostic accuracy, treatment efficacy, and patient outcomes [12]. At its essence, machine learning algorithms analyze vast amounts of healthcare data, including electronic health records (EHRs), medical imaging, genetic information, and patient-generated data, to extract meaningful insights and inform clinical decision-making. By identifying patterns, correlations, and anomalies within these data streams, machine learning models can predict disease risk, stratify patient populations, and optimize treatment regimens tailored to individual patient characteristics. The application of machine learning in healthcare spans various domains, including diagnostic imaging interpretation, drug discovery, predictive analytics, and personalized medicine. In diagnostic imaging, for instance, machine learning algorithms can assist radiologists in detecting abnormalities and interpreting complex imaging studies with greater accuracy and efficiency [13]. Similarly, in drug discovery, machine learning techniques expedite the identification of novel therapeutic targets, drug candidates, and biomarkers, thereby accelerating the development of precision therapies.

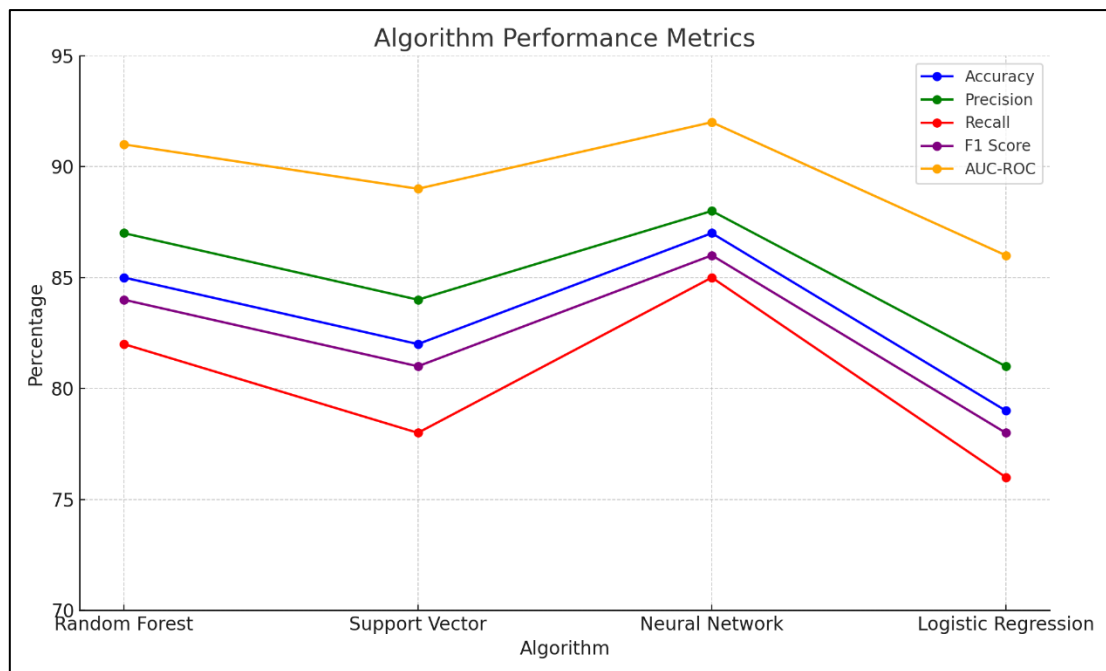


Figure 3: Depicting the performance metrics of various algorithms

B. Applications of Machine Learning in Healthcare

Machine learning (ML) applications in healthcare represent a significant advancement with the potential to transform various aspects of medical practice. One prominent application is in medical imaging interpretation. ML algorithms can analyze radiological images, such as X-rays, MRIs, and CT scans, to assist clinicians in detecting abnormalities, diagnosing diseases, and monitoring treatment responses [14]. By leveraging pattern recognition and deep learning techniques, ML algorithms enhance diagnostic accuracy and efficiency, ultimately improving patient outcomes. Another key area of ML application is predictive analytics and risk stratification. By analyzing electronic health records (EHRs), genetic data, and other patient information, ML models can predict disease onset, progression, and patient outcomes. These predictive insights enable clinicians to intervene proactively, tailor treatment plans, and allocate resources more effectively, thereby improving patient care and reducing healthcare costs. Moreover, ML plays a crucial role in drug discovery and development. ML algorithms can analyze large-scale biological and chemical datasets to identify potential drug targets, optimize drug candidates, and predict drug-drug interactions [15]. By streamlining the drug discovery process and accelerating the identification of promising therapeutics, ML contributes to the development of innovative treatments for various diseases.

C. Challenges and Opportunities

The integration of machine learning (ML) into healthcare presents both challenges and opportunities that shape the future landscape of medical practice. One significant challenge is data quality and accessibility. While healthcare generates vast amounts of data, it often resides in siloed systems, lacks standardization, and may contain errors. Additionally, ensuring data privacy and security while maintaining compliance with regulations such as HIPAA poses a considerable challenge. Furthermore, the interpretability and transparency of ML algorithms

present challenges in healthcare. Complex ML models, particularly deep learning algorithms, can be challenging to interpret, raising concerns about the reliability and trustworthiness of automated decisions. Ensuring the explainability of ML models is essential for gaining clinician acceptance and facilitating adoption in clinical practice. Despite these challenges, ML in healthcare offers numerous opportunities for innovation and improvement. One such opportunity is in precision medicine, where ML algorithms can analyze diverse datasets to tailor treatments to individual patient characteristics, leading to more effective and personalized interventions [16]. ML also enables predictive analytics, allowing clinicians to anticipate disease onset, progression, and treatment responses, facilitating proactive interventions and resource allocation.

V. Predictive Analytics in Precision Medicine

A. Definition and Scope

Predictive analytics in precision medicine encompasses the application of advanced statistical techniques and machine learning algorithms to analyze large and diverse datasets, with the goal of predicting individual patient outcomes and tailoring medical interventions accordingly. This approach integrates multiple sources of data, including genomics, clinical records, imaging, and lifestyle factors, to generate personalized insights that inform diagnosis, treatment planning, and prognosis. The scope of predictive analytics in precision medicine extends across the entire healthcare continuum, from disease prevention and early detection to treatment optimization and long-term management [17]. By leveraging predictive models, clinicians can identify individuals at elevated risk of developing certain diseases, stratify patient populations based on predicted outcomes, and customize interventions to maximize therapeutic efficacy while minimizing adverse effects. Moreover, predictive analytics enables proactive intervention by forecasting disease progression and treatment responses, allowing clinicians to adjust treatment plans in real-time and provide targeted support to patients at higher risk of poor outcomes. This approach shifts healthcare delivery from reactive to proactive, emphasizing prevention and early intervention to improve patient outcomes and reduce healthcare costs.

B. Importance of Predictive Analytics in Precision Medicine

Predictive analytics plays a crucial role in precision medicine by harnessing the power of data-driven insights to improve patient care and outcomes. One of its primary importance lies in its ability to enable personalized medicine. By analyzing vast amounts of data, including genomics, clinical records, and lifestyle factors, predictive analytics can identify patterns and correlations that inform individualized diagnosis, treatment planning, and prognosis. This personalized approach allows clinicians to tailor interventions to each patient's unique characteristics, maximizing therapeutic efficacy while minimizing adverse effects. Moreover, predictive analytics facilitates proactive intervention by forecasting disease progression and treatment responses [18]. By identifying patients at higher risk of poor outcomes, clinicians can intervene earlier, adjust treatment plans, and provide targeted support, ultimately improving patient outcomes and reducing healthcare costs. This proactive approach shifts the focus from reactive to preventive care, emphasizing the importance of early detection and

intervention in managing chronic diseases and improving population health. Furthermore, predictive analytics in precision medicine contributes to medical research and innovation by uncovering novel biomarkers, therapeutic targets, and predictive indicators. By analyzing large-scale omics data, researchers can gain deeper insights into the molecular mechanisms underlying disease and develop more precise and personalized interventions. This fosters the development of innovative treatments and therapies that address the specific needs of individual patients, driving advancements in healthcare delivery and improving patient outcomes.

VI. Future Directions and Challenges

Future directions for predictive analytics in precision medicine are poised to further revolutionize healthcare delivery while addressing persistent challenges. One prominent direction is the integration of multi-omics data and advanced analytics techniques. By combining genomics, transcriptomics, proteomics, and metabolomics data, along with clinical and environmental factors, researchers can gain a more comprehensive understanding of disease mechanisms and individual variability. This integration will facilitate the development of more accurate predictive models and personalized interventions tailored to each patient's unique biological profile. Additionally, the adoption of federated learning and decentralized data analytics approaches holds promise for overcoming challenges related to data privacy and accessibility. These methods enable collaborative analysis of distributed datasets while preserving data privacy and security, allowing researchers to leverage diverse sources of data without compromising patient confidentiality. Furthermore, advancements in explainable AI and interpretable machine learning models will address concerns regarding the transparency and trustworthiness of predictive analytics. By enhancing the interpretability of algorithms, clinicians can better understand and validate the decisions made by predictive models, fostering acceptance and adoption in clinical practice.

VII. Limitations

Despite its potential, predictive analytics in precision medicine faces several limitations that hinder its widespread adoption and implementation in clinical practice. One significant limitation is the lack of standardized data and interoperability across healthcare systems. The integration of diverse data sources, including genomics, clinical records, and imaging data, poses challenges due to variations in data formats, quality, and accessibility, limiting the scalability and generalizability of predictive models. Moreover, predictive analytics relies heavily on retrospective data, which may not capture the dynamic nature of diseases and patient responses to treatment over time. This retrospective bias can lead to inaccuracies in predictive modeling and hinder the translation of research findings into clinical practice. Additionally, ethical and regulatory considerations surrounding data privacy, consent, and patient confidentiality present significant challenges in the implementation of predictive analytics. Ensuring compliance with regulations such as HIPAA and GDPR while balancing the need for data sharing and collaboration is essential but challenging. Furthermore, the interpretability and explainability of machine learning algorithms pose challenges in gaining clinician acceptance and trust. Complex models may lack transparency, making it difficult for clinicians to understand the underlying factors driving predictions and treatment recommendations.

VIII. Conclusion

The integration of predictive analytics and machine learning algorithms into precision medicine heralds a new era of personalized healthcare delivery with transformative potential. Through the analysis of vast and diverse datasets, including genomics, clinical records, imaging, and lifestyle factors, predictive analytics empowers clinicians to make more informed decisions tailored to the individual needs of each patient. The application of machine learning algorithms enables personalized diagnosis by identifying subtle patterns and correlations that may escape human observation, leading to earlier and more accurate disease detection. Moreover, machine learning facilitates treatment planning by analyzing historical treatment responses across similar patient cohorts, optimizing treatment selection, and minimizing adverse effects. Furthermore, predictive analytics enables patient outcome prediction by forecasting disease progression, treatment response, and adverse events, empowering clinicians to intervene proactively and tailor interventions to individual patient characteristics. This proactive approach not only improves patient outcomes but also enhances resource allocation within healthcare systems. However, challenges such as data privacy, interoperability, and algorithmic bias must be addressed to realize the full potential of predictive analytics in precision medicine. Additionally, ensuring equitable access to these technologies and mitigating healthcare disparities are critical considerations to promote inclusive and patient-centered care.

References

- [1] Pollok, A.; Klöckner, A.; Zimmer, D. Psychological aspects of equation-based modelling. *Math. Comput. Model. Dyn. Syst.* 2019, 25, 115–138.
- [2] Jiang, Y. *A Primer on Machine Learning Methods for Credit Rating Modeling*; IntechOpen: London, UK, 2022.
- [3] Gupta, U.; Patidar, Y.; Agarwal, A.; Singh, K.P. Wine quality analysis using machine learning algorithms. In *Micro-Electronics and Telecommunication Engineering: Proceedings of 3rd ICMETE 2019*; Springer: Berlin/Heidelberg, Germany, 2020; pp. 11–18.
- [4] Broby, D. The use of predictive analytics in finance. *J. Financ. Data Sci.* 2022, 8, 145–161.
- [5] Golas, S.B.; Nikolova-Simons, M.; Palacholla, R.; op den Buijs, J.; Garberg, G.; Orenstein, A.; Kvedar, J. Predictive analytics and tailored interventions improve clinical outcomes in older adults: A randomized controlled trial. *NPJ Digit. Med.* 2021, 4, 97.
- [6] Sorrow, M.L.; Storer, B.E.; Fathi, A.T.; Gerds, A.T.; Medeiros, B.C.; Shami, P.; Brunner, A.M.; Sekeres, M.A.; Mukherjee, S.; Peña, E.; et al. Development and Validation of a Novel Acute Myeloid Leukemia–Composite Model to Estimate Risks of Mortality. *JAMA Oncol.* 2017, 3, 1675.
- [7] Yang, Y.; Xu, L.; Sun, L.; Zhang, P.; Farid, S.S. Machine learning application in personalised lung cancer recurrence and survivability prediction. *Comput. Struct. Biotechnol. J.* 2022, 20, 1811–1820.

- [8] Peng, M.; Hou, F.; Cheng, Z.; Shen, T.; Liu, K.; Zhao, C.; Zheng, W. Prediction of cardiovascular disease risk based on major contributing features. *Sci. Rep.* 2023, 13, 4778.
- [9] Sajid, M.R.; Muhammad, N.; Zakaria, R.; Shahbaz, A.; Bukhari, S.A.C.; Kadry, S.; Suresh, A. Nonclinical features in predictive modeling of cardiovascular diseases: A machine learning approach. *Interdiscip. Sci. Comput. Life Sci.* 2021, 13, 201–211.
- [10] Zhang, W.; Li, D.S.; Bui-Thanh, T.; Sacks, M.S. Simulation of the 3D hyperelastic behavior of ventricular myocardium using a finite-element based neural-network approach. *Comput. Methods Appl. Mech. Eng.* 2022, 394, 114871.
- [11] Shanmugam, D.; Blalock, D.W.; Gong, J.J.; Guttag, J.V. Multiple Instance Learning for ECG Risk Stratification. *arXiv* 2018, arXiv:1812.00475.
- [12] Toma, M.; Singh-Gryzbon, S.; Frankini, E.; Wei, Z.A.; Yoganathan, A.P. Clinical Impact of Computational Heart Valve Models. *Materials* 2022, 15, 3302.
- [13] Lustig-Barzelay, Y.; Sher, I.; Sharvit-Ginon, I.; Feldman, Y.; Mrejen, M.; Dallasheh, S.; Livny, A.; Beerli, M.S.; Weller, A.; Ravona-Springer, R.; et al. Machine learning for comprehensive prediction of high risk for Alzheimer's disease based on chromatic pupilloperimetry. *Sci. Rep.* 2022, 12, 9945.
- [14] Timmers, P.R.; Mounier, N.; Lall, K.; Fischer, K.; Ning, Z.; Feng, X.; Bretherick, A.D.; Clark, D.W.; Agbessi, M.; Ahsan, H.; et al. Genomics of 1 million parent lifespans implicates novel pathways and common diseases and distinguishes survival chances. *eLife* 2019, 8, e39856.
- [15] Osorio, J.A.; Scheer, J.K.; Ames, C.P. Predictive modeling of complications. *Curr. Rev. Musculoskelet. Med.* 2016, 9, 333–337.
- [16] Malik, A.T.; Khan, S.N. Predictive modeling in spine surgery. *Ann. Transl. Med.* 2019, 7, S173.
- [17] Romiyo, P.; Ding, K.; Dejam, D.; Franks, A.; Ng, E.; Preet, K.; Tucker, A.M.; Niu, T.; Nagasawa, D.T.; Rahman, S.; et al. Systematic review and evaluation of predictive modeling algorithms in spinal surgeries. *J. Neurol. Sci.* 2021, 420, 117184
- [18] Joshi, R.S.; Lau, D.; Scheer, J.K.; Serra-Burriel, M.; Vila-Casademunt, A.; Bess, S.; Smith, J.S.; Pellise, F.; Ames, C.P. State-of-the-art reviews predictive modeling in adult spinal deformity: Applications of advanced analytics. *Spine Deform.* 2021, 9, 1223–1239.