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Opinion

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Artificial intelligence in cardiac metabolism: the next frontier in cardiovascular health

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Abstract

In this article, we aim to explore the rapidly developing role of artificial intelligence (AI) in cardiac metabolism research, highlighting its impact on biomarker discovery, precision medicine, and patient stratification. Cardiac metabolism, a key determinant of cardiovascular health, is often disrupted in cardiovascular diseases (CVDs) like heart failure and coronary artery disease. AI's ability to process and analyze large-scale data offers new chances for understanding and addressing these metabolic dysfunctions. By integrating up-to-date technologies with molecular and clinical insights, AI enables the achievement of personalized treatments, more accurate diagnostics, and the discovery of potential novel therapeutic targets. The main challenges include ethical concerns around data privacy, algorithmic bias, and the need for representative datasets. Future directions focus on developing transparent, accountable, and collaborative AI models that integrate data and enable real-time monitoring, ensuring fairness and accessibility in healthcare. As AI continues to evolve, its role in advancing cardiovascular care is expected to grow, offering new trends in cardiovascular research.

Keywords: Artificial intelligence, cardiac metabolism, cardiovascular disease

INTRODUCTION

The fast-ongoing updates in artificial intelligence (AI) and medical research have boomed in an innovative era[1]. Cardiac metabolism, the fundamental network of connection and signaling pathways that govern energy generation and consumption of the heart, is a key determinant of cardiovascular health. Dysregulation of metabolic processes occurs in cardiovascular diseases (CVDs), including heart failure and coronary artery disease[2,3]. However, current methods are limited in capturing the full scene of metabolic disturbances. AI offers a solution by processing large and integrated datasets to improve diagnostic strategies and enable targeted therapies in CVDs. As researchers dive into the molecular mechanisms driving diseases, AI emerges as an effective and transformative tool, offering new paths for understanding, identifying, and correcting metabolic dysregulation of the heart.

AI-POWERED INSIGHTS INTO CARDIAC METABOLISM

The application of AI in the analysis of complex and bulk biological data is reshaping our understanding of metabolism[4]. AI's ability to process large-scale data, such as genomic, proteomic, and metabolomic data, enables researchers to identify undiscovered metabolic pathways associated with cardiovascular hemostasis and dysfunction. Machine learning algorithms, for instance, help uncover previously unknown patterns in metabolic processes by sifting through vast amounts of molecular data[5].

Recent studies have demonstrated the power of AI in elucidating the relationships between metabolism and cardiovascular conditions. For example, AI-driven models have been used to predict heart failure outcomes by analyzing metabolic performance together with clinical data[6]. These models are faster and more accurate in identifying patients at risk of adverse outcomes compared to traditional methods. Moreover, AI's ability to learn and adapt to new data makes it an ideal tool for advancing research in cardiac metabolism, where complex, dynamic processes are often difficult for conventional analysis.

Despite its potential, the application of AI in cardiac metabolism remains in its early stages. Many studies are still exploratory, and the full scope of AI's capabilities has yet to be realized and fulfilled. However, early research is promising, suggesting that AI has the potential to become a vital component in cardiac metabolism research, driving the discovery and understanding of new therapeutic targets and pathways.

THE ROLE OF AI IN PRECISION MEDICINE AND METABOLIC PROFILING

One of the important applications of AI in cardiac metabolism lies in its potential to enable precision medicine. Traditional approaches to cardiovascular care have been largely under the one-size-fits-all mode, relying on standardized treatments based on the general population that do not account for the unique metabolic profiles of individual patients. AI, however, can help specify treatments to fit the needs of a patient's metabolic traits, improving both the effectiveness and precision of interventions.

By integrating molecular metabolic data with clinical information, AI models can generate detailed metabolic profiles that capture the key points of an individual's cardiovascular health. These profiles enable physicians to develop proper and personalized treatment plans that target specific metabolic dysfunctions driving diseases. AI can be used to identify key metabolic pathways that are dysregulated, offering guidance on therapy selections that are most likely to restore metabolic balance[7,8].

Moreover, AI can help clinicians stratify patients based on their risk of developing CVD by analyzing their metabolic patterns. Such patient stratification can improve preventive care and treatment of CVD, ensuring that high-risk individuals receive timely or in advance interventions, while low-risk patients avoid unnecessary screening and treatments. AI's role in precision medicine has already been explored in several clinical settings, and its potential to revolutionize cardiovascular care is drawing attention[9].

AI-ENHANCED BIOMARKER DISCOVERY AND DIAGNOSTIC TOOLS

Another key area where AI is deeply impacting lies in biomarker discovery concerning cardiac metabolism. Biomarkers, which are measurable indicators of biological processes, are critical for evaluating and diagnosing CVD, monitoring disease progression, and predicting patient outcomes. AI has the ability to process massive data, uncovering biomarkers that would be difficult or even impossible to identify using traditional approaches.

For example, AI algorithms have been used to discover novel biomarkers of cardiac metabolism that are linked to heart failure and other CVDs[10,11]. These biomarkers can inform early warning signs of metabolic dysfunction, allowing for earlier diagnosis and effective treatment. Additionally, AI can integrate various data types, including genomic, proteomic, and medical imaging, and create a more comprehensive landscape of cardiovascular health conditions.

AI also enhances non-invasive diagnostic tools, such as advances in imaging techniques that monitor cardiac metabolism. Advanced AI-driven imaging technologies can provide detailed insights into the metabolic activity of the heart in static and dynamic conditions, improving both the accuracy and details of diagnoses[12,13,14]. These tools are valuable for identifying metabolic abnormalities in asymptomatic patients, enabling earlier interventions for CVDs.

CHALLENGES AND FUTURE PROSPECTS

While the potential of AI in cardiac metabolism is promising, there are still challenges that shall be addressed before these technologies can be fully integrated into clinical practice. One major concern is the ethical concern of applying AI in healthcare, particularly regarding data privacy issues and the risk of algorithmic bias. The vast amounts of data required to train AI models inevitably include sensitive patient information, raising concerns about how these data are collected, stored, and used. Solutions like differential privacy technology can be employed to mitigate these risks to protect patient confidentiality and ensure secure data sharing across platforms. Additionally, AI algorithms can be biased if trained on unrepresentative datasets, potentially leading to unequal outcomes for different patient populations or even patients from different socioeconomic backgrounds. To address this, it is essential to develop diverse and representative data collection strategies and adopt algorithmic transparency to ensure fairness and reduce disparities in healthcare. AI development in cardiac metabolism research must focus on transparency, accountability, and collaboration. Researchers, clinicians, and AI experts must work together to ensure that AI models are accurate and equitable, and implemented to protect patient privacy and promote fairness.

In the future, AI has the potential to revolutionize cardiac metabolism research and cardiovascular care. Through real-time monitoring, AI could enable continuous, personalized metabolic tracking via wearable devices, allowing for adjustments based on real-time data. Additionally, AI will integrate multi-omics data to predict cardiovascular risks, enhancing early intervention. In the realm of drug discovery, AI will accelerate the identification of novel therapeutic targets, leading to more precise and personalized medicine. Assisted or autonomous diagnostic systems powered by AI could enable highly accurate, and automated detection of metabolic dysfunction. As AI continues to evolve, its integration into cardiac metabolism research will enhance diagnosis and treatment, while addressing ethical and accessibility challenges.

CONCLUSION

The application of AI in cardiac metabolism represents a major step forward in the combat against CVDs. By providing deeper insights into the metabolic processes that drive CVDs, AI is facilitating the development of precise diagnostics and targeted strategies. As AI technology continues to evolve, its ongoing integration into cardiac metabolism will be crucial in shaping the future of cardiovascular medicine, leading to more effective, targeted care and even transforming the landscape of cardiovascular health.

DECLARATIONS

Authors' contributions

Wrote the manuscript: Chen AT

Supervised this project: Zhang Y, Zhang J

All authors have read the final manuscript and approved it for publication.

Availability of data and materials

Not applicable.

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Conflicts of interest

All authors declared that there are no conflicts of interest.

Ethical approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

REFERENCES

1. Haug CJ, Drazen JM. Artificial intelligence and machine learning in clinical medicine, 2023. *N Engl J Med.* 2023;388:1201-8. DOI PubMed
2. Takada S, Maekawa S, Furihata T, et al. Succinyl-CoA-based energy metabolism dysfunction in chronic heart failure. *Proc Natl Acad Sci U S A.* 2022;119:e2203628119. DOI PubMed PMC
3. Talmor-Barkan Y, Bar N, Shaul AA, et al. Metabolomic and microbiome profiling reveals personalized risk factors for coronary artery disease. *Nat Med.* 2022;28:295-302. DOI PubMed
4. Xu Y, Ritchie SC, Liang Y, et al. An atlas of genetic scores to predict multi-omic traits. *Nature.* 2023;616:123-31. DOI PubMed PMC
5. Poss AM, Maschek JA, Cox JE, et al. Machine learning reveals serum sphingolipids as cholesterol-independent biomarkers of coronary artery disease. *J Clin Invest.* 2020;130:1363-76. DOI PubMed PMC
6. Chen AT, Zhang Y, Zhang J. Explainable machine learning and online calculators to predict heart failure mortality in intensive care units. *ESC Heart Fail.* 2024;Online ahead of print. DOI PubMed
7. Lee AM, Hu J, Xu Y, et al; CKD Biomarkers Consortium. Using machine learning to identify metabolomic signatures of pediatric chronic kidney disease etiology. *J Am Soc Nephrol.* 2022;33:375-86. DOI PubMed PMC
8. Shen X, Wang C, Liang N, et al. Serum metabolomics identifies dysregulated pathways and potential metabolic biomarkers for

hyperuricemia and gout. *Arthritis Rheumatol.* 2021;73:1738-48. DOI PubMed

9. Krittanawong C, Zhang H, Wang Z, Aydar M, Kitai T. Artificial intelligence in precision cardiovascular medicine. *J Am Coll Cardiol.* 2017;69:2657-64. DOI PubMed
10. Michelhaugh SA, Januzzi JL Jr. Using artificial intelligence to better predict and develop biomarkers. *Heart Fail Clin.* 2022;18:275-85. DOI PubMed
11. Antoniades C, Tousoulis D, Vavlukis M, et al. Perivascular adipose tissue as a source of therapeutic targets and clinical biomarkers. *Eur Heart J.* 2023;44:3827-44. DOI PubMed PMC
12. Pan J, Ng SM, Neubauer S, Rider OJ. Phenotyping heart failure by cardiac magnetic resonance imaging of cardiac macro- and microscopic structure: state of the art review. *Eur Heart J Cardiovasc Imaging.* 2023;24:1302-17. DOI PubMed PMC
13. Jin X, Ji X, Yin H, et al. Identification of potential targets of stress cardiomyopathy by a machine learning algorithm. *CVIA.* 2024;9:27. DOI
14. Zhou J, You D, Bai J, et al. Machine learning methods in real-world studies of cardiovascular disease. *CVIA.* 2023;7:25. DOI