


Chapter 4

AI–Powered Integrative Omics Analysis for Predicting Therapeutic Outcomes in Lung Diseases

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ABSTRACT

Lung diseases, encompassing conditions such as chronic obstructive pulmonary disease (COPD), asthma, lung cancer, and interstitial lung diseases, present complex clinical challenges due to heterogeneous pathophysiological mechanisms. Integrative omics approaches—genomics, transcriptomics, proteomics, metabolomics, and epigenomics—have revealed multilayered insights into disease etiology and progression. However, translating this multidimensional data into predictive models for therapeutic outcomes remains elusive. Artificial Intelligence (AI), particularly through deep learning and integrative data frameworks, has emerged as a powerful paradigm for unifying disparate omics layers to predict patient-specific treatment responses. This chapter delineates the architecture and utility of AI-powered integrative omics models in lung diseases, highlighting advances in data

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fusion, interpretability, and precision medicine. We conclude by discussing current limitations, ethical considerations, and future directions for scalable deployment in clinical settings.

INTRODUCTION

Lung diseases, such as chronic obstructive pulmonary disease (COPD), asthma, and interstitial lung disease, are among the top causes of morbidity and mortality globally. Clinical management is difficult because of the heterogeneous and dynamic characteristics of these disorders, where patients with similar clinical presentations can have completely different therapeutic outcomes, (Ramón et al., 2020). Although traditional biomarkers can provide important information, they fail to capture the complete range of molecular reactions responsible for disease initiation, propagation, and therapeutic resistance. The development of high-throughput omics technologies has made available a large volume of multidimensional data that can help decipher the multi-layered biology of pulmonary pathology, (Morabito et al., 2025). However, data formats and experimental artifacts pose significant challenges for integrative analysis. Conventional methods suffer from the curse of dimensionality, whereas there is a straightforward concatenation of the heterogeneous omics layers that threatens to conceal important cross-modal relationships, (Ballard et al., 2024).

Artificial Intelligence (AI) and Deep Learning have been widely used for multi-omics integration, (Ali, 2023). Methods such as deep canonical correlation analysis, graph neural networks on molecular interaction graphs, and transformer-based cross-modal attention permit the learning of high-dimensional latent representations that can help encode both intra- and inter-omics patterns. Furthermore, the latest advancements in explainable AI and clinical interpretability have further helped take an important step towards clinical trust and regulatory endorsement.

In this chapter, we provide a complete overview of AI-driven integrative omics analysis for lung diseases. We have explored the three basic core areas of AI methodology for multi-omics integration: data fusion strategies, neural model architectures, and multi-task learning paradigms implemented on omics data. Lastly, we have addressed the key considerations for clinical deployment, including federated learning under privacy limitations and ethical considerations, with an emphasis on future directions for large-scale AI-based precision medicine in pulmonary medicine.

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