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Advances in Lung Cancer: Current Perspectives and Future Directions – A Mini Review

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Mini Review

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Abstract

Lung cancer remains the leading cause of cancer-related mortality worldwide, accounting for a substantial proportion of global cancer deaths. Despite significant advances in screening, molecular diagnostics, targeted therapies, and immunotherapy, prognosis remains poor for many patients because of late-stage diagnosis and tumour heterogeneity. Recent developments in precision medicine, artificial intelligence (AI), liquid biopsy, and biomarker-guided treatment have transformed the diagnosis and management of lung cancer, leading to improved survival and more individualized therapeutic approaches. This mini review summarizes the current epidemiology, risk factors, molecular mechanisms, diagnostic approaches, treatment strategies, emerging technologies, and future directions in lung cancer management.

Keywords: Lung Cancer; Non-Small Cell Lung Cancer; Small Cell Lung Cancer; Immunotherapy; Targeted Therapy; Liquid Biopsy; Artificial Intelligence; Precision Oncology

Abbreviations

AI: Artificial Intelligence; NSCLC: Non-Small Cell Lung Cancer; SCLC: Small Cell Lung Cancer; COPD: Chronic Obstructive Pulmonary Disease; LDCT: Low-Dose Computed Tomography; CT: Computed Tomography.

Introduction

Lung cancer is one of the most frequently diagnosed malignancies and remains the leading cause of cancer-related deaths worldwide. According to recent global cancer statistics, lung cancer accounts for approximately 2.5 million new cases annually and continues to impose a considerable healthcare burden. The disease is broadly classified into non-small cell lung cancer (NSCLC), representing nearly 85% of cases, and small cell lung cancer (SCLC), which is characterized by rapid growth and early metastasis.

Although cigarette smoking remains the primary risk factor, increasing numbers of lung cancer cases occur among never-smokers due to environmental pollution, occupational exposure, genetic susceptibility, and radon exposure. Advances in molecular biology and precision medicine have significantly improved understanding of lung cancer pathogenesis and enabled the development of highly effective targeted therapies [1].

Epidemiology and Risk Factors

Lung cancer incidence varies considerably across different geographical regions and is strongly influenced by smoking prevalence, environmental exposures, and socioeconomic factors. Cigarette smoking remains the leading risk factor and

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is responsible for approximately 85% of lung cancer cases.

Nevertheless, the incidence of lung cancer among never-smokers has increased over recent decades, indicating the involvement of additional etiological factors. Environmental pollutants, including fine particulate matter (PM2.5), radon gas, occupational exposure to asbestos, silica, arsenic, chromium, and diesel exhaust, have all been associated with an increased risk of lung carcinogenesis. Genetic predisposition, chronic pulmonary diseases such as chronic obstructive pulmonary disease (COPD) and pulmonary fibrosis, as well as family history, also contribute to disease susceptibility. Comprehensive tobacco control policies, environmental protection measures, and implementation of lung cancer screening programmes remain essential strategies for reducing the global burden of this disease.

Molecular Pathogenesis

Lung cancer develops through the accumulation of genetic and epigenetic alterations that disrupt normal cellular regulation. Frequently altered oncogenic pathways include mutations in EGFR, KRAS, BRAF, MET, HER2, and rearrangements involving ALK, ROS1, RET, and NTRK genes. Tumour suppressor genes such as TP53 and RB1 are also commonly inactivated [2].

The tumour microenvironment, composed of immune cells, fibroblasts, endothelial cells, and extracellular matrix components, plays a critical role in tumour progression, angiogenesis, immune evasion, and metastasis. Understanding these molecular mechanisms has facilitated the development of biomarker-driven therapies that improve patient outcomes.

Advances in Diagnosis

Early diagnosis is essential because survival decreases dramatically with advanced-stage disease.

Low-Dose Computed Tomography

Low-dose computed tomography (LDCT) has become the preferred screening modality for high-risk individuals and has demonstrated a significant reduction in lung cancer mortality through earlier detection.

Molecular Diagnostics

Comprehensive molecular profiling has become standard practice for advanced NSCLC. Next-generation sequencing enables simultaneous detection of multiple actionable genomic alterations, guiding targeted therapy selection.

Liquid Biopsy

Liquid biopsy using circulating tumour DNA (ctDNA) offers a minimally invasive approach for identifying actionable mutations, monitoring treatment response, detecting minimal residual disease, and identifying mechanisms of therapeutic resistance.

Current Treatment Strategies

The management of lung cancer depends on tumour histology, disease stage, molecular profile, and the patient's overall health status. Surgical resection remains the treatment of choice for patients with early-stage non-small cell lung cancer (NSCLC) and offers the greatest potential for long-term survival. Patients who are not suitable surgical candidates may benefit from stereotactic body radiotherapy (SBRT), which provides excellent local tumour control while preserving lung function [4].

Systemic therapy continues to play a central role in the management of locally advanced and metastatic disease. Platinum-based chemotherapy remains an important treatment option for both NSCLC and small cell lung cancer (SCLC), particularly when combined with immunotherapy. The introduction of molecular profiling has transformed treatment selection by identifying actionable genetic alterations. Patients with mutations involving EGFR, ALK, ROS1, BRAF, RET, MET, HER2, and KRAS G12C can now receive targeted therapies that have significantly improved progression-free survival and quality of life compared with conventional chemotherapy.

Immunotherapy has revolutionized lung cancer treatment over the past decade. Immune checkpoint inhibitors targeting programmed cell death protein-1 (PD-1), programmed death-ligand 1 (PD-L1), and cytotoxic T-lymphocyte-associated protein 4 (CTLA-4) have demonstrated durable clinical responses in selected patients with advanced NSCLC. Combination regimens involving chemotherapy and immunotherapy have become standard first-line treatment for many patients, resulting in improved overall survival and disease control.

Emerging Technologies

Rapid technological advances are reshaping the diagnosis and management of lung cancer. Artificial intelligence (AI) has emerged as a valuable clinical tool capable of improving pulmonary nodule detection, image interpretation, risk prediction, and treatment planning. Deep learning algorithms applied to computed tomography (CT) scans can assist radiologists in identifying suspicious

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pulmonary nodules with greater accuracy and consistency while reducing diagnostic variability.

Radiomics represents another promising innovation by extracting quantitative imaging features that reflect tumour heterogeneity, biological behaviour, and treatment response. Combined with machine learning algorithms, radiomic signatures may improve prognostic prediction and support personalized therapeutic decision-making.

Liquid biopsy has also become an important component of precision oncology. Analysis of circulating tumour DNA (ctDNA) enables non-invasive detection of actionable mutations, monitoring of treatment response, identification of minimal residual disease, and early recognition of acquired resistance to targeted therapies. Furthermore, integration of genomic sequencing, digital pathology, AI, and clinical information is facilitating the development of precision medicine strategies that tailor treatment according to each patient's molecular profile [5].

Current Challenges

Despite significant therapeutic advances, numerous challenges continue to limit improvements in lung cancer outcomes. A large proportion of patients are still diagnosed at an advanced stage because early disease is frequently asymptomatic. Tumour heterogeneity and the emergence of acquired resistance to targeted therapies and immunotherapy remain major obstacles to long-term disease control. In addition, access to comprehensive molecular testing, advanced therapeutics, and specialized oncology services varies substantially across healthcare systems, contributing to disparities in patient outcomes. The high cost of targeted therapies and immunotherapeutic agents also presents economic challenges, particularly in low- and middle-income countries. Addressing these barriers will require expanded access to early detection programmes, standardized molecular testing, multidisciplinary care, and continued translational research.

Future Directions

Future research in lung cancer should focus on developing more effective strategies for early diagnosis, individualized treatment, and resistance prevention. Artificial intelligence is expected to enhance screening programmes by improving early detection and risk stratification. Broader implementation of liquid biopsy may facilitate real-time monitoring of tumour evolution and enable earlier therapeutic intervention. Advances in multi-omics technologies, including genomics, transcriptomics, proteomics, and metabolomics, are expected to improve biomarker discovery and refine precision oncology approaches.

In addition, ongoing clinical trials investigating next-generation immunotherapies, antibody-drug conjugates, personalized cancer vaccines, and combination treatment strategies may further improve survival outcomes. Continued international collaboration and equitable access to innovative diagnostics and therapies will be essential to reducing the global burden of lung cancer.

Conclusion

Lung cancer remains a major global health challenge despite remarkable progress in diagnosis and treatment. Advances in molecular profiling, targeted therapies, immunotherapy, liquid biopsy, and artificial intelligence have transformed clinical management and improved patient outcomes. Continued research aimed at early detection, overcoming therapeutic resistance, and expanding access to precision medicine will be essential to further reduce lung cancer mortality and improve quality of life. A multidisciplinary approach integrating innovative technologies with evidence-based clinical care offers the greatest opportunity to advance lung cancer management in the coming decade.

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