Medical Research
Volume 7, Issue 3, 2025, Page 13-25
https://doi.org/10.6913/mrhk.070302

Medical Research

Application of Pulmonary Rehabilitation Training in Postoperative Lung Cancer Patients: An In-Depth Examination of Mechanisms, Protocols, and Clinical Outcomes

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Abstract

This review investigates the utilization of pulmonary rehabilitation training among individuals who have undergone surgical treatment for lung cancer, with an emphasis on the underlying theoretical principles, implementation methodologies, clinical results, and future perspectives. Patients recovering from lung cancer surgery frequently encounter a deterioration in pulmonary function, diminished exercise capacity, and a reduced quality of life. As a comprehensive intervention involving multiple disciplines, pulmonary rehabilitation has demonstrated effectiveness in mitigating these challenges. This article methodically evaluates the various elements of pulmonary rehabilitation, the appropriate timing for its initiation, the customization of rehabilitation programs, and its influence on physiological indicators, mental health, and long-term outcomes. Additionally, it addresses the prevailing obstacles within clinical settings and strategies for enhancement, with the goal of offering evidence-based recommendations for healthcare providers and rehabilitation specialists.

Keywords pulmonary rehabilitation; lung cancer postoperative; pulmonary function recovery; exercise tolerance; quality of life; multidisciplinary intervention; individualized rehabilitation

1 Introduction

Lung cancer is recognized as one of the most widespread and deadly cancers worldwide, with surgical resection serving as the primary treatment modality for patients in the early stages of the disease. Nevertheless, even with the progress made in surgical techniques, individuals undergoing surgery for lung cancer often face a range of postoperative complications. These complications can present as respiratory difficulties, cardiovascular issues, and mental health disturbances, all of which can substantially hinder the recovery trajectory and diminish the overall quality of life for these patients. Typical postoperative challenges encompass diminished lung function, shortness of breath, fatigue, anxiety, and depression, which may impede rehabilitation efforts and extend the duration of hospital stays [1].

The introduction of pulmonary rehabilitation (PR) has surfaced as a holistic, non-pharmacological approach designed to enhance both the physiological and psychological health of patients with lung cancer. PR encompasses an array of elements, including exercise training, education on effective breathing

 Article History Received: June 15, 2025; Accpted: July 10, 2025; Published: September 30, 2025. ***Medical Research***, ISSN 2664-0333 (print), ISSN 2664-0341 (online), a Quarterly, founded on 2019, published by Creative Publishing Co., Limited. Email: wtocom@gmail.com, https://mrhk.cc, https://cpcl.hk.

techniques, psychological support, and nutritional advice, to cater to the diverse requirements of these individuals. The underlying principle of PR is to improve respiratory function, augment exercise capacity, and enhance quality of life, thereby promoting a more effective recovery process following surgery [2]. Recent studies indicate that PR can significantly reduce the occurrence of postoperative pulmonary complications (PPCs), which are major contributors to morbidity and extended hospital stays among patients undergoing lung cancer surgery [3].

Understanding the intricate dynamics of pulmonary rehabilitation (PR) in the context of lung cancer surgical recovery is imperative as the discipline of evidence-based medicine progresses. Despite its growing prominence, the underlying mechanisms, implementation methodologies, and clinical ramifications of PR within this specific setting are yet to be thoroughly examined. This review endeavors to systematically evaluate the role of pulmonary rehabilitation in patients recovering from lung cancer surgery, emphasizing its theoretical underpinnings, essential elements in clinical application, recent empirical findings, and prospective avenues for further inquiry. By integrating the current body of literature, this review aspires to facilitate the standardization and customization of PR protocols, ultimately aiming to improve patient outcomes in this particularly vulnerable demographic [4].

Recent investigations underscore the necessity of addressing not solely the physical dimensions of recovery but also the psychological and emotional hurdles encountered by lung cancer patients following surgery. The incorporation of psychological support within PR initiatives has demonstrated efficacy in alleviating anxiety and depression, thereby further enhancing recovery outcomes [5]. Additionally, the provision of nutritional support, especially for patients presenting with sarcopenia or those at heightened risk of malnutrition, is vital for optimizing recovery and mitigating potential complications [2].

In summary, the exploration of pulmonary rehabilitation in the realm of lung cancer surgery represents a promising research frontier that merits further scholarly attention. Gaining a comprehensive understanding of this subject is essential to advancing clinical practices and improving the quality of life for patients undergoing surgical interventions for lung cancer.

2 Main Body

2.1 Definition and Theoretical Basis of Pulmonary Rehabilitation Training

2.1.1 Definition and Core Components

Pulmonary rehabilitation training is a multidisciplinary intervention designed to improve the overall functional status of patients with chronic respiratory diseases, particularly those undergoing surgical procedures such as lung cancer resections. This comprehensive approach involves a team of healthcare professionals, including respiratory physicians, physical therapists, nurses, and dietitians, who collaborate to tailor rehabilitation programs to individual patient needs. The core components of pulmonary rehabilitation typically include aerobic exercise, resistance training, respiratory muscle training, and educational sessions. Aerobic exercises, such as walking or cycling, aim to enhance cardiovascular fitness and endurance, while resistance training focuses on strengthening peripheral muscles, which is crucial for improving daily functional activities. Respiratory muscle training specifically targets the diaphragm and intercostal muscles to optimize breathing efficiency, thereby alleviating symptoms like dyspnea. Educational components are equally vital, equipping patients with knowledge about their condition, self-management strategies, and the importance of adherence to rehabilitation protocols. By integrating these elements, pulmonary rehabilitation seeks to enhance not only physical capabilities but also the psychological well-being of patients, ultimately leading to improved quality of life and functional independence [6][4].

2.1.2 Physiological Mechanisms

The physiological mechanisms underlying pulmonary rehabilitation training are multifaceted and contribute significantly to the recovery process in patients post-surgery. One of the primary benefits of pulmonary rehabilitation is the enhancement of pulmonary ventilation efficiency, which is achieved through structured exercise regimens that stimulate the respiratory muscles. Improved respiratory muscle strength leads to better lung expansion and gas exchange, thus enhancing oxygenation and reducing the risk of postoperative complications such as atelectasis and pulmonary fibrosis. Furthermore, pulmonary rehabilitation has been shown to modulate inflammatory responses by upregulating anti-inflammatory cytokines like IL-10 while downregulating pro-inflammatory markers such as TNF-α. This shift in the inflammatory profile is crucial for promoting tissue repair and reducing complications associated with surgical interventions. Additionally, regular physical activity can improve exercise tolerance and reduce the sense of fatigue, which is particularly beneficial for lung cancer patients who often experience significant postoperative weakness. The combined effects of these physiological adaptations not only facilitate recovery but also contribute to long-term improvements in lung function and overall health status [7][8].

2.1.3 Psychological and Social Support Mechanisms

The role of psychological and social support mechanisms in pulmonary rehabilitation cannot be understated, as they significantly influence patient outcomes and adherence to rehabilitation protocols. Rehabilitation programs often incorporate psychological interventions aimed at reducing anxiety and depression, which are common among patients facing chronic illnesses such as lung cancer. By fostering a supportive environment, rehabilitation teams can enhance patients' self-efficacy, empowering them to engage actively in their recovery process. Social support from healthcare professionals, family members, and peer groups is essential for promoting motivation and adherence to exercise regimens. The application of cognitive-behavioral theories within rehabilitation programs helps patients develop coping strategies to manage their condition and improve their quality of life. Moreover, the sense of community fostered through group exercises or educational sessions can alleviate feelings of isolation and enhance emotional well-being. As patients progress through their rehabilitation journey, the psychological benefits gained from improved self-image and social interactions further contribute to better health outcomes, creating a virtuous cycle of recovery and empowerment [6][4].

2.2 Common Questions and Rehabilitation Needs of Post-operative Lung Cancer Patients

2.2.1 Physiological Issues

Postoperative pulmonary function indicators such as FEV1 and DLCO often decrease by 20-30%, leading to reduced exercise endurance and limitations in daily activities; additionally, pain and fatigue are common obstacles. Postoperative complications in lung cancer patients often manifest as significant declines in pulmonary function, particularly in key metrics such as Forced Expiratory Volume in 1 second (FEV1) and Diffusing Capacity of the Lung for Carbon Monoxide (DLCO). Research indicates that these parameters can decrease by 20-30% following surgical interventions, leading to marked reductions in exercise tolerance and limitations in daily activities. This decline in lung function is not merely a transient issue; it can result in long-term impairments that affect patients' quality of life. Furthermore, postoperative pain and fatigue are prevalent among this population, compounding the challenges they face during recovery. Pain can limit mobility and engagement in rehabilitation exercises, while fatigue can diminish motivation and overall participation in recovery programs. The interplay between these physical challenges necessitates a comprehensive approach to rehabilitation that addresses both pulmonary function and the management of

pain and fatigue, ensuring that patients can regain their functional independence and improve their quality of life post-surgery [1][2].

2.2.2 Psychological Issues

Up to 40% of patients experience anxiety or depression, affecting treatment adherence and quality of life; social isolation and changes in body image are also key concerns. Psychological issues, particularly anxiety and depression, are prevalent in lung cancer patients, affecting up to 40% of this population. These mental health challenges can significantly impede treatment adherence and overall quality of life. The emotional burden of a cancer diagnosis, coupled with the stress of surgical recovery, can exacerbate feelings of anxiety and depression, leading to a vicious cycle that further complicates recovery. Social isolation is another critical concern, as many patients may withdraw from social interactions due to their condition or fear of stigma, which can intensify feelings of loneliness and despair. Additionally, changes in body image resulting from surgery and treatment can lead to decreased self-esteem and further psychological distress. Addressing these psychological factors is essential in the rehabilitation process, as they can influence patients' willingness to engage in physical rehabilitation and adhere to treatment regimens. Therefore, integrating psychological support into the rehabilitation framework for lung cancer patients is crucial for enhancing their overall recovery and ensuring better treatment outcomes [9][2].

2.2.3 Rehabilitation Needs Analysis

Based on the patient's age, type of surgery (such as lobectomy or pneumonectomy), and comorbidities, needs vary from basic respiratory training to high-intensity aerobic interventions, emphasizing personalized assessment. The rehabilitation needs of lung cancer patients post-surgery vary significantly based on several factors, including age, type of surgery (such as lobectomy or pneumonectomy), and comorbid conditions. Younger patients or those undergoing less invasive procedures may benefit more from high-intensity aerobic interventions, while older patients or those with significant comorbidities may require more basic respiratory training to improve lung function and endurance. Personalized assessments are essential to tailor rehabilitation programs that address the specific needs and capabilities of each patient. For instance, patients with advanced age or significant pre-existing lung conditions may need a more gradual approach, focusing on breathing exercises and low-intensity activities to build their strength and confidence. Conversely, patients who are younger and in better overall health may be able to engage in more vigorous rehabilitation efforts sooner. This individualized approach not only optimizes recovery outcomes but also enhances patient engagement and satisfaction with the rehabilitation process, ultimately leading to improved quality of life and functional independence post-surgery [10][9].

2.3 Implementation Strategies and Program Design for Pulmonary Rehabilitation

2.3.1 Timing of Implementation

Early Rehabilitation (1-2 weeks post-surgery) focused on complication prevention, such as deep breathing exercises; Mid-term (2-6 weeks) integrating progressive exercise; Late Stage (6 weeks and beyond) focused on maintaining gains. The timing of pulmonary rehabilitation (PR) implementation is crucial for optimizing outcomes in lung cancer patients post-surgery. Early rehabilitation, initiated within the first two weeks after surgery, is primarily aimed at preventing complications, including respiratory issues and reduced lung function. During this phase, interventions like deep breathing exercises are emphasized to enhance lung expansion and prevent atelectasis, which is a common postoperative complication. Studies have shown that patients who engage in early rehabilitation experience a reduction in pulmonary complications, which significantly impacts their recovery trajectory [4]. As the rehabilitation progresses into

the mid-term phase (2-6 weeks post-surgery), the focus shifts to integrating progressive exercise regimens. This approach allows patients to gradually increase their physical activity levels, which is essential for improving exercise capacity and overall functional status. The incorporation of aerobic and resistance training during this period has been linked to enhanced physical fitness and quality of life [10]. Finally, in the late stage (6 weeks and beyond), the emphasis is on maintaining the gains achieved through earlier rehabilitation efforts. This phase is critical as it helps patients sustain their functional improvements and continue engaging in physical activities that promote long-term health benefits. Continuous monitoring and adjustments to the rehabilitation program based on individual progress are vital to ensure that patients do not regress in their recovery [6]. Thus, a structured and phased approach to pulmonary rehabilitation is essential for maximizing recovery and enhancing the quality of life for lung cancer patients post-surgery.

2.3.2 Exercise Prescription

Including moderate-intensity aerobic exercise (such as walking or cycling, 30-45 minutes/session, 3-5 times/week), resistance training (targeting upper and lower limbs, using weights or bands), and flexibility exercises. The exercise prescription for lung cancer patients undergoing pulmonary rehabilitation is designed to be comprehensive, incorporating various modalities to address different aspects of physical fitness. Moderate-intensity aerobic exercise, such as walking or cycling, is recommended for 30 to 45 minutes per session, three to five times a week. This level of aerobic activity is crucial for improving cardiovascular fitness, enhancing endurance, and facilitating better oxygen utilization during daily activities [7]. Additionally, resistance training targeting both upper and lower limbs is an integral component of the exercise regimen. Utilizing weights or resistance bands helps to improve muscle strength, which is often compromised in lung cancer patients due to the disease and its treatments [11]. Furthermore, flexibility exercises are included to enhance range of motion and prevent stiffness, which can occur due to prolonged inactivity or surgical interventions. The combination of these exercise modalities not only aids in physical recovery but also contributes to psychological well-being by promoting a sense of accomplishment and improving overall quality of life [4]. Tailoring the exercise prescription to the individual' s capabilities and preferences is essential to ensure adherence and maximize the benefits of the rehabilitation program.

2.3.3 Breathing Technique Training

Such as pursed-lip breathing and diaphragmatic breathing, aimed at improving gas exchange and reducing dyspnea; commonly used devices such as incentive spirometry. Breathing technique training plays a pivotal role in pulmonary rehabilitation for lung cancer patients, particularly in enhancing respiratory function and alleviating symptoms such as dyspnea. Techniques such as pursed-lip breathing and diaphragmatic breathing are specifically designed to improve gas exchange and optimize lung function. Pursed-lip breathing helps to keep the airways open longer, facilitating the expulsion of trapped air and thus improving oxygenation [4]. Diaphragmatic breathing, on the other hand, encourages the use of the diaphragm rather than accessory muscles for breathing, which can lead to more efficient ventilation and reduced work of breathing. The integration of these techniques into the rehabilitation program not only aids in symptom management but also empowers patients by providing them with tools to control their breathing during episodes of dyspnea [6]. Additionally, the use of devices such as incentive spirometry is commonly recommended to encourage deep breathing and lung expansion. These devices serve as motivational tools, providing visual feedback that can enhance patient engagement and compliance with breathing exercises. Overall, the incorporation of breathing technique training within pulmonary rehabilitation is essential for improving respiratory outcomes and enhancing the quality of life for lung cancer patients.

2.3.4 Personalized and Adaptive Programs

Adjusting intensity based on Cardiopulmonary Exercise Testing (CPET) results, considering patient tolerance; for example, low-intensity interval training for elderly or frail patients. The personalization of pulmonary rehabilitation programs is crucial for optimizing outcomes, particularly for lung cancer patients who may present with varying degrees of physical fitness and tolerance levels. Utilizing cardiopulmonary exercise testing (CPET) results allows healthcare providers to tailor the intensity and type of exercise prescribed to each patient's specific needs and capabilities. This individualized approach ensures that patients are not overexerted, which can lead to adverse effects and decreased adherence to the rehabilitation program [4]. For instance, elderly or frail patients may benefit from low-intensity interval training, which has been shown to improve exercise tolerance without overwhelming the patient's physiological capacity. This method allows for short bursts of activity followed by rest periods, making it more manageable for those with compromised fitness levels [4]. Furthermore, ongoing assessments and adjustments to the rehabilitation program based on patient feedback and progress are essential for maintaining engagement and ensuring that rehabilitation goals are met. By focusing on personalized and adaptive rehabilitation strategies, healthcare providers can enhance the effectiveness of pulmonary rehabilitation, ultimately improving the quality of life and functional outcomes for lung cancer patients.

2.4 Clinical Effectiveness Assessment: Improvement of Physiological Parameters

2.4.1 Pulmonary Function Indicators

Multiple RCTs show that pulmonary rehabilitation training can improve FEV1 by 10-15% and DLCO by 5-10%, enhancing alveolar-capillary membrane function. Pulmonary rehabilitation (PR) has emerged as a cornerstone in the management of patients with lung cancer, particularly those undergoing surgical interventions. Recent randomized controlled trials (RCTs) have consistently demonstrated that structured pulmonary rehabilitation programs can lead to significant improvements in key pulmonary function indicators, notably forced expiratory volume in one second (FEV1) and diffusing capacity of the lungs for carbon monoxide (DLCO). Specifically, these studies report enhancements in FEV1 ranging from 10% to 15% and improvements in DLCO between 5% and 10% following rehabilitation interventions. The underlying mechanism for these improvements is primarily attributed to the enhanced functionality of the alveolar-capillary membrane, which is critical for gas exchange. This physiological enhancement is particularly vital for lung cancer patients, as compromised lung function can severely impact postoperative recovery and overall quality of life. The integration of exercise training, breathing techniques, and education within PR programs facilitates not only the physical rehabilitation of patients but also fosters a better understanding of their condition, thereby promoting adherence to treatment protocols. Furthermore, the positive outcomes associated with PR underscore the necessity of incorporating such programs into standard care practices for lung cancer patients, especially those at risk of postoperative pulmonary complications [12][13].

2.4.2 Exercise Endurance and Body Composition

The 6-minute walk distance increases by an average of 50-100 meters, muscle mass improves, and the risk of sarcopenia decreases; mechanisms involve improved cardiovascular efficiency and mitochondrial biogenesis. The implementation of pulmonary rehabilitation in lung cancer patients has also shown remarkable effects on exercise endurance and body composition. Notably, the 6-minute walk distance (6MWD), a widely used measure of functional exercise capacity, has been reported to increase by an average of 50 to 100 meters following participation in structured rehabilitation programs. This improvement in exercise endurance is crucial, as it correlates with enhanced overall physical functioning and quality of life. Addi-

tionally, pulmonary rehabilitation has been associated with improvements in muscle mass, which is particularly significant in the context of sarcopenia—a condition characterized by the loss of muscle mass and strength that often accompanies chronic illness, including cancer. The mechanisms underlying these benefits are multifaceted, involving enhanced cardiovascular efficiency and increased mitochondrial biogenesis, which collectively contribute to improved energy metabolism and physical performance. By addressing both aerobic capacity and muscle strength, pulmonary rehabilitation not only aids in the recovery of lung cancer patients post-surgery but also mitigates the risks associated with sarcopenia, thereby promoting a more favorable prognosis and enhancing patients' ability to engage in daily activities [14][15].

2.4.3 Symptom Relief

Dyspnea scores (such as the Borg scale) decrease, pain and fatigue lessen, benefiting from endorphin release and inflammatory modulation. The impact of pulmonary rehabilitation extends beyond physiological improvements to encompass significant symptom relief for lung cancer patients. Notably, assessments of dyspnea using scales such as the Borg scale have shown marked reductions in perceived breathlessness following rehabilitation interventions. This alleviation of dyspnea is critical for enhancing the quality of life and functional capacity of patients, allowing them to engage more fully in daily activities. In addition to improvements in dyspnea, patients frequently report reductions in pain and fatigue, which are common and debilitating symptoms associated with lung cancer and its treatment. The mechanisms contributing to these symptom improvements are likely linked to the release of endorphins during exercise, which act as natural pain relievers, as well as the modulation of inflammatory responses that can exacerbate symptoms. By addressing both the physical and psychological dimensions of symptom management, pulmonary rehabilitation offers a holistic approach to care that not only improves clinical outcomes but also enhances the overall well-being of lung cancer patients. The integration of such rehabilitation programs into standard oncology care is therefore essential for optimizing patient recovery and quality of life [16][17].

2.5 Psychological and Social Outcomes

2.5.1 Mental Health

Using HADS or SF-36 scales, studies report anxiety and depression scores decreased by 20-30%, enhanced coping strategies through group sessions and counseling. The psychological well-being of lung cancer patients undergoing postoperative rehabilitation is a critical aspect of their overall recovery. Research utilizing standardized scales such as the Hospital Anxiety and Depression Scale (HADS) and the Short Form-36 (SF-36) has demonstrated significant reductions in anxiety and depression scores, with decreases ranging from 20% to 30% in patients participating in structured rehabilitation programs. These improvements are often attributed to the incorporation of group sessions and counseling, which not only provide emotional support but also foster the development of coping strategies. The social interaction inherent in group settings allows patients to share experiences and challenges, thereby reducing feelings of isolation and helplessness. Furthermore, counseling sessions tailored to address specific fears and anxieties related to cancer treatment and recovery can empower patients, enhancing their resilience and ability to cope with the psychological burdens of their diagnosis. This multifaceted approach to mental health care is essential, as psychological distress has been linked to poorer treatment outcomes and quality of life in lung cancer patients. Therefore, integrating mental health support into postoperative rehabilitation programs is crucial for fostering a holistic recovery process that addresses both physical and psychological needs.

2.5.2 Quality of Life Improvement

Overall QoL scores (e.g., EORTC QLQ-C30) show significant improvement, especially in physical and emotional domains; social functioning recovery promotes return to work. The impact of pulmonary rehabilitation on the quality of life (QoL) of lung cancer patients post-surgery is profound, as evidenced by significant improvements in overall QoL scores measured by instruments such as the European Organization for Research and Treatment of Cancer Quality of Life Questionnaire (EORTC QLQ-C30). Patients typically report marked enhancements in both physical and emotional domains, reflecting not only an increase in physical capabilities but also a reduction in psychological distress. These improvements are crucial, as they contribute to a more favorable perception of health and well-being among patients. Additionally, the recovery of social functioning plays a pivotal role in facilitating a return to work and normal daily activities, which is often a significant concern for lung cancer survivors. The ability to engage in social interactions and professional responsibilities not only enhances a patient's self-esteem but also reinforces their sense of normalcy and purpose following treatment. This comprehensive enhancement of QoL underscores the importance of incorporating structured rehabilitation programs that address both the physical and psychosocial aspects of recovery, ultimately leading to better long-term outcomes for lung cancer patients.

2.5.3 Long-term Adherence and Self-management

Educational components empower patients, reducing hospital readmissions; digital health tools (e.g., apps) support remote monitoring. Long-term adherence to self-management practices is a crucial factor in the postoperative recovery of lung cancer patients, significantly influencing their health outcomes and quality of life. Educational components embedded within rehabilitation programs empower patients by equipping them with the knowledge and skills necessary to manage their health effectively. This empowerment is associated with a reduction in hospital readmissions, as patients who are well-informed about their condition and treatment options are more likely to adhere to prescribed regimens and recognize early signs of complications. Furthermore, the integration of digital health tools, such as mobile applications, enhances patient engagement by facilitating remote monitoring and providing ongoing support. These tools allow patients to track their symptoms, medication adherence, and rehabilitation exercises, fostering a sense of accountability and self-efficacy. The use of technology in healthcare not only improves access to information but also enables healthcare providers to maintain regular communication with patients, ensuring timely interventions when necessary. As a result, the combination of educational initiatives and digital health resources creates a supportive environment that promotes sustained self-management and adherence, ultimately leading to improved health outcomes for lung cancer patients in the long term.

2.6 Latest Research Findings and Evidence-Based Evidence

2.6.1 Meta-Analysis of Randomized Controlled Trials (RCTs): Publications from 2020-2023

Recent meta-analyses of randomized controlled trials (RCTs) conducted between 2020 and 2023 have provided compelling evidence supporting the efficacy of pulmonary rehabilitation in reducing postoperative complications and enhancing survival rates in lung cancer patients. For instance, a study by Jones et al. (2022) demonstrated that pulmonary rehabilitation could reduce postoperative complications by approximately 25% and significantly improve survival rates among patients undergoing lung cancer surgery. The analysis included a substantial sample size, often exceeding 100 patients, thereby reinforcing the robustness of the findings. The studies included in the meta-analysis consistently highlighted the multifaceted benefits of pulmonary rehabilitation, which encompasses physical training, education, and psychological support, ultimately leading to improved postoperative outcomes. These findings underscore the importance of in-

tegrating pulmonary rehabilitation into the standard care protocols for lung cancer patients, particularly in the context of enhancing recovery and minimizing complications post-surgery [18][18].

2.6.2 Innovative Interventions: Telerehabilitation Using Video Conferencing

The advent of telerehabilitation, particularly through video conferencing platforms, has emerged as a promising alternative to traditional in-person rehabilitation, especially for lung cancer patients. Recent trials have shown that telerehabilitation can be non-inferior to in-person care, offering similar clinical outcomes while providing increased accessibility and convenience for patients. This innovative approach is particularly beneficial for those who may face barriers to attending in-person sessions, such as mobility issues or geographical constraints. Moreover, the integration of wearable devices for real-time feedback during telerehabilitation sessions has further enhanced patient engagement and adherence to rehabilitation protocols. Evidence suggests that these technological advancements not only facilitate effective monitoring of patient progress but also empower patients by providing them with the tools to manage their rehabilitation actively. As such, telerehabilitation represents a significant step forward in the delivery of pulmonary rehabilitation, aligning with contemporary healthcare trends towards digital health solutions [19][19].

2.6.3 Mechanistic Studies: Omics Approaches Revealing Gene Expression Changes

Recent mechanistic studies utilizing omics approaches, particularly transcriptomics, have shed light on the underlying biological processes associated with pulmonary rehabilitation in lung cancer patients. These studies have revealed significant changes in gene expression linked to inflammation reduction and muscle adaptation, which are crucial for recovery following surgery. For instance, specific gene expression profiles associated with improved muscle function and reduced inflammatory markers have been identified, indicating that pulmonary rehabilitation not only enhances physical capacity but also modulates the inflammatory response at the molecular level. This understanding of the mechanistic pathways involved in pulmonary rehabilitation can inform the development of targeted interventions that optimize recovery and improve overall patient outcomes. By elucidating the connections between rehabilitation, gene expression, and inflammatory processes, these studies contribute to a more comprehensive understanding of how pulmonary rehabilitation can be effectively implemented in clinical practice for lung cancer patients [20][20].

2.7 Challenges and Future Directions

2.7.1 Implementation Barriers

Including resource limitations (e.g., shortage of trained personnel), patient barriers (e.g., mobility issues or motivation), and reimbursement issues in healthcare systems. The implementation of pulmonary rehabilitation programs for lung cancer patients faces numerous challenges that can significantly hinder their effectiveness and accessibility. One major barrier is the shortage of trained personnel who can deliver these specialized rehabilitation services. Many healthcare systems, particularly in underserved areas, lack the necessary workforce to implement comprehensive rehabilitation programs, which can lead to inadequate patient support and supervision [21]. Furthermore, patients themselves may encounter barriers such as mobility issues, which can limit their ability to participate in rehabilitation activities. This is particularly relevant for lung cancer patients who may experience physical limitations due to their condition or treatment side effects. Additionally, motivation plays a crucial role in patient engagement; those who are less motivated may struggle to adhere to rehabilitation protocols, further complicating the implementation process [22]. Lastly, reimbursement issues pose a significant challenge, as many healthcare systems do not adequately cover the costs associated with pulmonary rehabilitation, making it financially unfeasible

for both patients and providers. Addressing these barriers requires a multifaceted approach, including increasing funding for rehabilitation programs, enhancing training for healthcare providers, and developing patient-centered strategies to improve motivation and adherence.

2.7.2 Optimization Strategies

Promoting standardized protocols (e.g., ATS/ERS Guidelines), integrating into Enhanced Recovery After Surgery (ERAS) Pathways, and use of AI for personalized prescription. To enhance the effectiveness of pulmonary rehabilitation in lung cancer patients, several optimization strategies can be employed. First, promoting standardized protocols, such as those outlined by the American Thoracic Society (ATS) and European Respiratory Society (ERS), can ensure that rehabilitation practices are evidence-based and uniformly applied across different healthcare settings [23]. These guidelines provide a framework for the assessment and management of patients, which can lead to improved outcomes. Integrating pulmonary rehabilitation into Enhanced Recovery After Surgery (ERAS) pathways is another promising strategy. ERAS protocols focus on optimizing postoperative care to enhance recovery and reduce complications, and incorporating rehabilitation into these pathways can facilitate a smoother transition for lung cancer patients post-surgery [24]. Furthermore, the use of artificial intelligence (AI) in developing personalized rehabilitation prescriptions can significantly enhance patient outcomes. AI can analyze individual patient data to tailor rehabilitation programs that address specific needs and challenges, thereby improving adherence and effectiveness [24]. By implementing these strategies, healthcare providers can create a more robust and effective rehabilitation framework that meets the diverse needs of lung cancer patients.

2.7.3 Research Gaps

Need for more long-term follow-up studies, focus on underserved populations (e.g., advanced cancer patients), and exploration of novel modalities (e.g., virtual reality training). Despite the growing body of literature on pulmonary rehabilitation, significant research gaps remain that must be addressed to optimize care for lung cancer patients. One critical area is the need for more long-term follow-up studies that assess the sustainability of rehabilitation benefits over time. Many existing studies focus on short-term outcomes, leaving a gap in understanding the long-term effects of rehabilitation on quality of life and functional status in lung cancer survivors [23]. Additionally, there is a pressing need to focus research efforts on underserved populations, particularly advanced cancer patients who may face unique barriers to accessing rehabilitation services. These populations often experience disparities in care and outcomes, and targeted research can help identify effective interventions that cater to their specific needs [24]. Finally, the exploration of novel modalities, such as virtual reality training, presents an exciting opportunity to enhance rehabilitation experiences and outcomes. Virtual reality can provide immersive and engaging environments for patients, potentially increasing motivation and adherence to rehabilitation programs [24]. Addressing these research gaps will be essential in developing a comprehensive understanding of pulmonary rehabilitation's role in improving outcomes for lung cancer patients, particularly those from underserved backgrounds.

3 Conclusion

The integration of pulmonary rehabilitation training into the postoperative care of lung cancer patients represents a significant advancement in clinical practice. This review has highlighted the multifaceted benefits of such interventions, which not only improve pulmonary function and exercise tolerance but also enhance psychological well-being and overall quality of life. The current body of evidence strongly supports the inclusion of pulmonary rehabilitation as a standard component of care for lung cancer survivors, underscoring its critical role in the continuum of cancer treatment and recovery.

However, the successful implementation of pulmonary rehabilitation programs is not without challenges. Individualization of rehabilitation protocols is essential to address the diverse needs of patients, as factors such as age, comorbidities, and the extent of surgical intervention can significantly influence rehabilitation outcomes. Moreover, resource constraints, including access to trained professionals and facilities, pose additional barriers to widespread adoption. Addressing these challenges requires a concerted effort from healthcare providers, policymakers, and researchers to develop innovative solutions that ensure equitable access to rehabilitation services.

Looking ahead, future research should prioritize the exploration of remote rehabilitation technologies, which have gained traction in recent years, particularly in the wake of the COVID-19 pandemic. These technologies hold the potential to bridge the gap for patients who may face barriers to traditional in-person rehabilitation. Furthermore, long-term outcome assessments are crucial to understanding the sustained impact of pulmonary rehabilitation on lung cancer survivors. Investigating the underlying mechanisms that contribute to the observed benefits will also provide valuable insights, enabling the refinement of rehabilitation strategies and enhancing their efficacy.

In conclusion, pulmonary rehabilitation training stands as a pivotal element in the management of lung cancer patients post-surgery. Its broad applicability and potential to significantly improve patient outcomes highlight the necessity for ongoing research and development in this field. By balancing diverse research perspectives and findings, we can better understand the complexities of rehabilitation and tailor interventions that meet the unique needs of lung cancer survivors. Ultimately, the goal is to optimize rehabilitation programs, ensuring that they not only enhance physical recovery but also contribute to the holistic well-being of patients navigating the challenges of life after lung cancer surgery. As we move forward, it is imperative to foster collaboration among researchers, clinicians, and patients to maximize the benefits of pulmonary rehabilitation and improve the quality of care for this vulnerable population.

To Cite This Article Ting ZHANG, Qiwei ZHANG. (2025). Application of Pulmonary Rehabilitation Training in Postoperative Lung Cancer Patients: An In-Depth Examination of Mechanisms, Protocols, and Clinical Outcomes. *Medical Research*, 7(3), 13-25. https://doi.org/10.6913/mrhk.070302

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