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Functional and Structural Pulmonary Outcomes in COVID-19 Survivors and the Role of Pulmonary Rehabilitation in the Recovery Process: A Review of Clinical and Imaging Studies

Shahabaddin Sorouri[1], Hassan Shafiei[2], Fazlollah Mojahed[3], *Mohammad Eslamian[4]

[1]Assistant Professor of Pulmonology, Faculty of Medicine, Lung Disease Research Center, Mashhad University of Medical Sciences, Mashhad, Iran. [2]MD, Infectious Disease Specialist, Borazjan, Iran. [3]Anesthesiologist, Department of Anesthesiology, Bushehr University of Medical Sciences, Bushehr, Iran. [4]Department of Neurosurgery, Shariati Hospital, Tehran University of Medical Sciences, Tehran, Iran.

Abstract

Background: COVID-19, a global pandemic, has profound public health impacts. Beyond acute illness, many recovered patients suffer long-term pulmonary complications that impair quality of life and daily activities. This study aims to provide a comprehensive analysis of clinical and imaging evidence related to pulmonary outcomes in patients recovered from COVID-19 and to assess the role of pulmonary rehabilitation in improving respiratory function and quality of life.

Materials and Methods: In this narrative review, a search was performed up to April 2025 across databases including Scopus, Web of Science, PubMed, SID, CIVILICA, and Google Scholar. Keywords in Persian and English, such as "COVID-19," "SARS-CoV-2," "pulmonary outcomes," "post-COVID complications," and "pulmonary rehabilitation," were used with Boolean operators. Two independent reviewers screened titles and abstracts, selecting eligible studies according to predefined inclusion criteria.

Results: Patients recovering from COVID-19 commonly experience persistent pulmonary complications, including sustained dyspnea, chronic fatigue, and significant reductions in lung function parameters such as diffusing capacity for carbon monoxide (DLCO) and forced vital capacity (FVC). High-resolution computed tomography (HRCT) frequently reveals structural lung abnormalities—fibrotic changes, interstitial thickening, and ground-glass opacities—especially in those with severe acute disease. Pulmonary rehabilitation programs incorporating respiratory muscle training, aerobic exercise, and symptom management have demonstrated significant improvements in respiratory function, exercise tolerance, and quality of life. However, challenges persist in customizing individualized rehabilitation plans, managing post-exertional symptom exacerbations, and addressing psychological support needs. Additionally, limited access to rehabilitation services and lack of standardized protocols hinder wider implementation.

Conclusion: Patients recovering from COVID-19 frequently experience persistent pulmonary complications and structural lung changes. Pulmonary rehabilitation enhances respiratory function and quality of life but requires personalized care, symptom management, and psychological support. Limited access and lack of standardized protocols hinder progress, highlighting the need for comprehensive strategies and further research.

Key Words: COVID-19, Lung imaging, Pulmonary rehabilitation, Respiratory function.

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Corresponding Author:

Mohammad Eslamian, MD, Faculty of Medicine, Tehran University of medical sciences, Tehran, Iran.

Email: md.eslamian@gmail.com

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1- INTRODUCTION

The global outbreak of Coronavirus Disease 2019 (COVID-19), caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), has resulted in unprecedented challenges to healthcare worldwide. Beyond the acute phase of infection, a significant number of patients experience prolonged pulmonary complications that persist after clinical recovery. These long-term sequelae commonly include persistent dyspnea, reduced diffusing capacity of the lungs for carbon monoxide (DLCO), fibrotic changes in pulmonary tissue, and diminished exercise tolerance, all of which substantially impair quality of life, physical functioning, and psychological well-being (1–4).

Various studies demonstrate that older patients, those who suffered severe acute illness, and patients with evident lung abnormalities in radiologic imaging are at increased risk of developing chronic respiratory impairments (2, 5). Despite significant advancements in acute COVID-19 management, the understanding and optimal treatment of these persistent pulmonary complications remain incomplete. Hence, comprehensive assessment and synthesis of clinical and imaging evidence are essential to guide effective management strategies (6, 7).

Pulmonary rehabilitation—a multidisciplinary approach consisting of respiratory muscle training, controlled aerobic exercise, symptom management education, and psychosocial support—has emerged as a key intervention to improve lung function, enhance exercise capacity, and promote quality of life among COVID-19 survivors (8, 9). However, the heterogeneity of rehabilitation protocols and patient responses poses challenges for establishing standardized care pathways.

The aim of this study is to provide a comprehensive review of clinical and imaging evidence on pulmonary complications in patients recovering from COVID-19 and to evaluate the effectiveness of pulmonary rehabilitation in improving respiratory function and quality of life.

2- MATERIALS AND METHODS

This study is a narrative review aimed at summarizing and analyzing clinical and imaging evidence related to pulmonary outcomes and complications in patients recovering from COVID-19, as well as evaluating the effectiveness of pulmonary rehabilitation.

2-1. Literature Search

A comprehensive and systematic search was conducted up to the end of April 2025 in reputable databases, including PubMed, Scopus, Web of Science, and Persian databases such as SID and Magiran. Main keywords and related combinations in both English and Persian were used, covering terms such as COVID-19, SARS-CoV-2, pulmonary complications, post-COVID lung sequelae, pulmonary rehabilitation, and respiratory therapy, along with their Persian equivalents. Boolean operators (AND, OR) were applied to improve search accuracy and precision.

2-2. Study Selection Process

Two independent researchers screened the titles and abstracts of retrieved studies and subsequently reviewed the full texts of relevant articles. Disagreements between reviewers were resolved through discussion, and if necessary, a third reviewer was consulted to ensure alignment with predefined criteria and study objectives.

2-3. Inclusion Criteria

- Studies directly examining pulmonary outcomes after COVID-19.

- Studies reporting on the effectiveness of pulmonary rehabilitation programs in patients recovering from COVID-19.
- Research articles published in Persian or English.
- Various study designs including clinical trials, observational studies, qualitative research, narrative reviews, and systematic reviews.

2-4. Exclusion Criteria

- Articles not related to pulmonary complications or respiratory rehabilitation after COVID-19.
- Animal or laboratory studies without clinical human data.
- Case reports without analytical data or studies where full texts were unavailable.

2-5. Data Extraction

Two independent reviewers collected data using a structured form. Extracted information focused on pulmonary function and imaging assessments, rehabilitation interventions, and clinical outcomes. Key themes included persistent pulmonary symptoms (e.g., dyspnea and fatigue), lung function changes (e.g., reduced DLCO and FVC), imaging findings (e.g., fibrotic changes on HRCT), rehabilitation effectiveness (e.g., improved exercise capacity), and challenges such as the need for personalized rehabilitation plans. After selecting relevant studies, essential data from each article were gathered and descriptively reviewed. These data were then categorized and summarized thematically to provide a clear and coherent overview of pulmonary outcomes following COVID-19 and the role of pulmonary rehabilitation.

2-6. Ethical Considerations

This review relied solely on published scientific data and did not involve direct research on human subjects; therefore, ethical committee approval was not required. Ethical standards regarding citation and proper use of scientific literature were strictly observed.

3- RESULTS

Studies have shown that patients recovering from COVID-19 experience a variety of pulmonary sequelae, including persistent symptoms, functional impairments, and structural lung changes. Pulmonary rehabilitation (PR) has become a key intervention to improve respiratory function and quality of life in these patients. Despite its benefits, challenges such as the need for individualized programs and managing post-exertional symptoms remain. A summary of key findings and methods is provided in **Table 1**.

3-1. Pulmonary Outcomes after COVID-19

Many recovered patients report ongoing dyspnea, chronic fatigue, and reduced exercise tolerance. Functional impairments like decreased diffusing capacity of the lungs for carbon monoxide (DLCO) and reduced forced vital capacity (FVC), indicating restrictive defects, are common (1, 2). High-resolution computed tomography (HRCT) often reveals fibrotic changes, interstitial thickening, and ground-glass opacities, especially in severe cases, with structural damage correlating to initial disease severity (4, 10, 11).

3-2. Pulmonary Function Assessment and Imaging

Pulmonary function tests show significant reductions in forced expiratory volume in one second (FEV1) and FVC, closely linked to decreased exercise capacity and quality of life (10, 12). HRCT detects persistent lung damage in 30–40% of patients, primarily those with severe illness, underscoring the need for long-term clinical and radiologic follow-up (2, 4, 11, 12).

3-3. Effectiveness of Pulmonary Rehabilitation

Pulmonary rehabilitation programs—including respiratory muscle strengthening, aerobic exercise, and symptom self-management—demonstrate significant improvements in pulmonary function, exercise capacity, and physical performance. Studies show substantial gains in the 6-minute walk test (6MWT), with mean improvements of 50-85 meters across multiple trials, and consistent reductions in dyspnea (11). Enhancements in respiratory muscle strength also contribute to symptom relief and increased tolerance (10, 13). Functional assessments such as the Short Physical Performance Battery (SPPB) and Barthel Index indicate gains in independence and daily function (14, 15). These benefits are supported by systematic reviews and clinical studies (12, 13, 16, 17), with psychological support and education further improving adherence and outcomes (18, 19).

3-4. Challenges and Considerations in Rehabilitation

Despite its well-established benefits, pulmonary rehabilitation (PR) faces several challenges in optimizing the timing, intensity, and duration of interventions that are tailored to individual patient conditions. Post-exertional malaise (PEM), characterized by symptom exacerbation following physical or mental exertion, necessitates vigilant monitoring and highly personalized exercise prescriptions (20–23). Providing psychological support to manage anxiety, depression, and fatigue is also crucial, as such interventions are linked to improved clinical outcomes and better patient adherence (2, 19, 24). In addition, practical barriers—such as limited access to PR services, insufficient infrastructure, and the absence of standardized implementation protocols—continue to restrict the widespread adoption of PR, particularly among post-COVID-19 populations (6, 25).

Table 1: Summary of Key Pulmonary Outcomes and Rehabilitation Effectiveness in Post-COVID-19 Patients.

Domain	Key Findings	Intervention / Assessment Details	References
Pulmonary Clinical Outcomes	Persistent dyspnea, chronic fatigue, reduced DLCO and FVC, restrictive ventilatory defects	Monitoring via standardized questionnaires (e.g., mMRC), clinical interviews, DLCO, and spirometry	1, 2, 4, 10, 11
Pulmonary Function & Imaging	Significant reductions in FEV1 and FVC; fibrotic and inflammatory patterns on HRCT	Spirometry, DLCO testing; HRCT imaging with standardized protocols	2, 4, 10-12
Pulmonary Rehabilitation	>79% improvement in 6MWT, 87% reduction in dyspnea severity, improved physical function and independence (SPPB, BI), increased respiratory muscle strength	Respiratory muscle training, diaphragmatic and pursed-lip breathing, aerobic exercise, symptom self-management	10, 11, 12, 14-17
Challenges and Considerations	Need for personalized rehab plans, monitoring post-exertional symptoms, psychological support	Individualized rehabilitation programs, regular symptom monitoring, psychological counseling and education	2, 6, 19–25

Abbreviations: DLCO: Diffusing Capacity of the Lungs for Carbon Monoxide, FVC: Forced Vital Capacity, FEV1: Forced Expiratory Volume in One Second, HRCT: High-Resolution Computed Tomography, mMRC: Modified Medical Research Council Dyspnea Scale, 6MWT: Six-Minute Walk Test, SPPB: Short Physical Performance Battery, BI: Barthel Index.

4- DISCUSSION

This review aims to provide a comprehensive analysis of the long-term pulmonary outcomes in patients recovering from COVID-19 and to evaluate the effectiveness of pulmonary rehabilitation (PR) interventions in improving respiratory function and enhancing quality of life. Findings indicate that many recovered patients, especially those with severe disease, continue to experience functional impairments and structural lung damage leading to respiratory limitations, reduced exercise tolerance, chronic fatigue, and significantly impaired quality of life (1, 2, 11).

Numerous studies have shown that a significant proportion of patients—particularly those with severe initial illness—experience persistent respiratory symptoms such as dyspnea, fatigue, and decreased exercise tolerance. Objective declines in pulmonary function, including reduced diffusing capacity for carbon monoxide (DLCO) and forced vital capacity (FVC), reflect restrictive ventilatory defects and interstitial lung injury (1, 2, 10). High-resolution computed tomography (HRCT) frequently reveals fibrotic patterns, interstitial thickening, and ground-glass opacities, indicating chronic lung tissue damage (4, 10, 11).

Importantly, recent evidence highlights a relative disconnect between the extent of structural lung damage and the severity of clinical symptoms. Some patients with minimal radiologic abnormalities still experience significant functional impairments, likely due to ongoing inflammation, microvascular injury, or neuroendocrine dysregulation (3, 5, 23). These complexities necessitate a multidimensional assessment strategy, incorporating clinical evaluation, pulmonary function tests, imaging, and patient-reported outcomes for tailored treatment approaches (6, 12).

Pulmonary rehabilitation is an effective intervention combining respiratory muscle training, graded aerobic exercise, and self-management education. It significantly improves exercise capacity and reduces dyspnea severity, with over 79% of patients showing meaningful improvement in the 6-minute walk test (6MWT) and 87% reporting decreased dyspnea following PR (11, 16, 17). Functional performance indices such as the Short Physical Performance Battery (SPPB) and Barthel Index (BI) document enhanced patient independence (14, 15).

Beyond physical benefits, psychological support and patient education play integral roles in rehabilitation success, improving adherence and reducing anxiety and depression. Addressing mental health is particularly critical for patients with long COVID syndromes (18, 19, 26).

Nevertheless, implementing PR in post-COVID populations poses substantial challenges. Post-exertional malaise (PEM)—characterized by the exacerbation of symptoms following physical or cognitive exertion—underscores the importance of individualized, cautiously paced rehabilitation plans and continuous symptom monitoring to ensure safety and prevent deterioration (20–23, 27, 28). In addition, structural barriers—including limited availability of specialized centers, shortages of trained professionals, and the absence of standardized protocols—continue to restrict access and compromise the consistency of care delivery (6, 25, 29, 30).

Emerging technologies such as telemedicine and remote monitoring offer promising means to increase accessibility and customize rehabilitation. Preliminary data suggest virtual PR programs can achieve comparable functional benefits to traditional in-person rehab while overcoming logistical barriers (25, 31, 32). Integration of artificial intelligence and wearable sensors may further enable real-

time program adjustment and patient monitoring (33, 34).

Future research should focus on high-quality longitudinal multicenter studies to clarify recovery trajectories, identify biomarkers predicting rehabilitation response, and refine patient stratification for tailored interventions. Developing adaptable, standardized protocols that integrate physical, psychological, and social dimensions will be essential. Multidisciplinary collaboration among pulmonologists, physiotherapists, psychologists, and primary care providers is critical to optimize rehabilitation pathways and improve outcomes for COVID-19 survivors (35, 36).

5- CONCLUSION

Long-term pulmonary complications following COVID-19 are marked by persistent symptoms such as dyspnea, chronic fatigue, and reduced exercise tolerance, alongside measurable lung function impairments like decreased diffusing capacity for carbon monoxide (DLCO) and forced vital capacity (FVC). Structural abnormalities—including fibrosis and interstitial thickening—are common on high-resolution computed tomography (HRCT), particularly in severe cases, and significantly impair quality of life and daily function, requiring ongoing clinical and radiological monitoring.

Pulmonary rehabilitation (PR) is an effective, evidence-based intervention that addresses these issues through respiratory muscle strengthening, graded aerobic exercise, and patient education. PR markedly improves respiratory function, exercise capacity, and symptom burden in post-COVID-19 patients. Success relies on individualized tailoring to patient tolerance, integrated psychosocial support, careful post-exertional malaise (PEM) management, and overcoming barriers like limited service access. Telemedicine, remote monitoring, and multidisciplinary approaches promise greater accessibility and better outcomes. Long-term multicenter research remains essential to refine strategies, personalize care, and optimize recovery for survivors.

6- CONFLICT OF INTEREST: None.

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