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Review Article

Longitudinal Trajectory of Pulmonary Sequelae After COVID-19: Clinical, Functional, Radiological, and Therapeutic Perspectives

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Abstract

Post-COVID pulmonary sequelae remain a significant source of long-term morbidity, with manifestations that include dyspnea, impaired diffusing capacity, restrictive physiology, ground-glass opacities, bronchiectasis, organizing pneumonia, interstitial abnormalities, and fibrotic-like changes. This narrative review synthesizes current evidence on the clinical, functional, radiologic, and therapeutic course of pulmonary abnormalities after COVID-19, with emphasis on longitudinal recovery patterns and persistent disease phenotypes.

Across longitudinal studies, diffusion impairment emerges as one of the most consistent functional abnormalities, while symptoms and objective physiologic findings often remain dissociated. Radiologic recovery is variable: ground-glass opacities and other inflammatory abnormalities often decline over time, whereas fibrotic-like abnormalities, reticulation, bronchiectasis, and small-airway disease may persist beyond the first year. Acute illness severity is an important population-level predictor of later pulmonary impairment, but persistent abnormalities are not confined to severe disease alone.

Therapeutically, pulmonary rehabilitation has the strongest supportive evidence for improving exercise tolerance, dyspnea, fatigue, and quality of life, whereas corticosteroids appear most appropriate for selected patients with post-COVID organizing pneumonia and active inflammatory features. Evidence for antifibrotic therapy remains limited and does not support routine use outside research settings. Overall, post-COVID pulmonary disease follows a heterogeneous and frequently improving, though sometimes persistent, course, supporting serial multimodal assessment and individualized management rather than assuming that persistent imaging abnormalities represent progressive pulmonary fibrosis.

Keywords: *COVID 19; SARS-CoV-2; Chronic Pulmonary Complications; Chronic Pulmonary Sequelae; Chronic Lung Disease*

Introduction

Coronavirus Disease 2019 (COVID-19) is a highly transmissible disease caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). It has infected approximately 780 million individuals globally (confirmed cases) and posed extraordinary challenges to healthcare systems worldwide. The introduction of vaccines and advances in clinical management have improved survival rates [1,2]. Post-COVID pulmonary sequelae affect a substantial minority of survivors, although prevalence estimates vary considerably according to diagnostic criteria, study populations, and duration of follow-up, with estimates ranging from approximately 10% in some cohorts to substantially higher rates among previously hospitalized patients [3]. Thus, persistent sequelae and delayed pulmonary injury continue to present significant challenges [4]. Reported pulmonary manifestations include persistent dyspnea, impaired diffusion capacity, restrictive physiology, ground-glass opacities (GGO), reticulation, bronchiectasis, organizing pneumonia, interstitial lung abnormalities, and fibrotic-like changes [4-6]. The World Health Organization defines post-COVID condition as symptoms occurring in individuals with probable or confirmed SARS-CoV-2 infection, usually beginning within 3 months of COVID-19 onset, persisting for at least 2 months, and not explained by an alternative diagnosis [7]. These manifestations may persist for months to several years after the initial infection. The pulmonary trajectory of functional recovery, and the persistence of lung impairment following COVID-19, is complex and heterogeneous [8]. Radiographic imaging is useful for identifying structural pulmonary abnormalities; however, radiological findings do not consistently correlate with pulmonary function impairment, symptom burden, or long-term clinical outcomes. Persistent later changes do not always indicate progressive fibrosis. Longitudinal studies indicate that ground-glass opacities and acute interstitial changes usually decrease over time, while fibrotic-like abnormalities may remain.

A longitudinal approach provides greater clarity regarding post-COVID pulmonary disease. Accordingly, this article reviews the current literature on post-COVID-19 pulmonary complications, highlights novel treatment strategies, and identifies opportunities for future research.

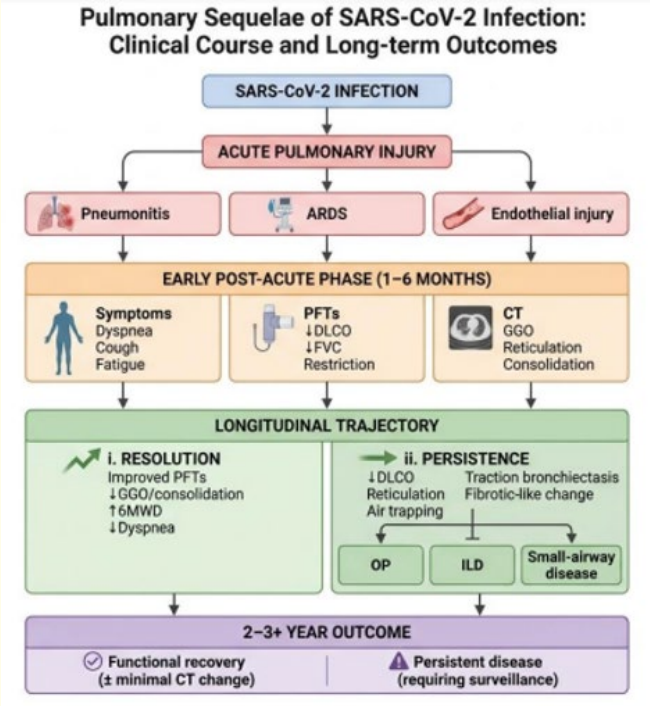


Figure 1: *Clinical course and long-term outcomes of COVID-19 pulmonary sequelae.*

Acute pulmonary injury

Acute respiratory distress syndrome (ARDS) is one of the most severe complications of COVID-19 and is associated with substantial morbidity and mortality. In critically ill patients, management may require supplemental oxygen, non-invasive respiratory support, or invasive mechanical ventilation. The characteristic histopathological pattern of ARDS is diffuse alveolar damage, characterized by alveolar edema, pneumocyte injury and death, microvascular thrombosis, capillary congestion, and hyaline membrane formation [9]. Following epithelial injury, the release of cytokines and chemokines promotes inflammatory responses that contribute to microvascular damage and impaired gas exchange [10,11]. Although mechanical ventilation is often lifesaving, it may contribute to ventilator-induced lung injury through mechanisms including volutrauma, barotrauma, atelectrauma, and biotrauma. According to the Berlin definition, ARDS severity is further stratified by PaO_2/FiO_2 ratio measured with PEEP or CPAP ≥5 cm H_2O: mild ARDS (200-300 mmHg), moderate ARDS (100-200 mmHg), and severe ARDS (≤100 mmHg) [14,15]. Prospective follow-up studies have reported persistent diffusion impairment and fibrotic-like abnormalities on chest CT scans after COVID-19, although some radiographic changes improve over time [5,8]. Importantly, persistent pulmonary abnormalities have also been documented in patients who were never mechanically ventilated, indicating that post-COVID pulmonary sequelae are not solely attributable to ventilator-associated lung injury.

Clinical phenotypes of acute pulmonary disease

Disease severity ranges from asymptomatic to critically ill. As described above, patients with the most severe acute illness, particularly those who develop ARDS, are more likely to exhibit persistent pulmonary function abnormalities and residual radiographic changes during follow-up [5]. Previous NIH treatment guidelines have defined asymptomatic or presymptomatic, mild, moderate, severe, and critical illness [12,13]. Asymptomatic or presymptomatic is defined when a patient tests positive for SARS-CoV-2 via nucleic acid amplification test or antigen test and has no clinical symptoms. Mild illness is characterized by signs and symptoms of COVID-19, such as fever, cough, sore throat, malaise, headache, muscle pain, nausea, vomiting, diarrhea, or loss of taste and smell, in the absence of dyspnea or abnormal lower respiratory tract findings on examination or imaging. Moderate illness is characterized by evidence of lower respiratory tract disease on clinical assessment or imaging and an oxygen saturation (SpO_2) ≥94% on room air at sea level. Severe illness is defined by any of the following: SpO_2 <94% on room air at sea level, respiratory rate >30 breaths/min, PaO_2/FiO_2 <300 mmHg, or lung infiltrates involving >50% of the lung fields. Critical illness is characterized by respiratory failure, septic shock, and/or multiple organ dysfunction.

Persistent respiratory symptoms

Common presenting symptoms of COVID-19 include fatigue, fever, and upper respiratory tract infection symptoms. Some individuals may also remain asymptomatic. Dyspnea is the most frequently reported persistent respiratory symptom. Additionally, cough, exercise intolerance, chest discomfort, and reduced functional capacity have also been reported, particularly among patients with persistent post-COVID respiratory sequelae [16,17]. In a longitudinal 6-month follow-up of 1733 COVID-19 patients, approximately 76% reported at least one persistent symptom [18]. Ground-glass opacities and irregular lines were the most common findings on chest imaging. Pulmonary interstitial abnormalities on CT and diffusion impairment suggested persistent parenchymal injury and possible fibrotic remodeling, although radiographic abnormalities alone cannot establish active fibroblast-mediated fibrosis [18]. The authors also noted that acute-phase disease severity is a major risk factor for impaired diffusing capacity for carbon monoxide (DLCO) and abnormal CT findings. Persistent respiratory symptoms (PRS) represent a distinct pattern within prolonged post-acute sequelae of COVID-19 (PASC). A systematic review found that over half of individuals reported at least one PASC symptom at 1 month (54%), 2 to 5 months (55%), and 6 months or longer (54%) after the acute phase [16]. These data indicate that PASC symptoms remain common for months following infection, suggesting persistent physiological and functional sequelae in a substantial proportion of survivors. Additionally, across the studies included, the most prevalent PRS were dyspnea, cough, increased oxygen requirements, pulmonary diffusion abnormalities, ground glass opacities, lung fibrosis, and a restrictive pattern on spirometry [16,17]. These respiratory manifestations were observed across both short- and longer-term follow-up periods, although prevalence estimates varied between studies. The high prevalence of

persistent respiratory symptoms underscores the importance of continued clinical follow-up and rehabilitation services. In a 3-year cohort follow-up of COVID-19 survivors, chest CT abnormalities persisted in most individuals who had abnormalities at 2 years (long COVID), with irregular lines, traction bronchiectasis, and subpleural lines as the most common findings. Despite these abnormalities, the volume ratio of lung lesions to total lung volume remained low (0.2-0.3%), and lung function at 3 years was comparable to matched community controls [19]. Dyspnea, however, remained common at 3 years, affecting 43% of survivors overall, with a significantly higher prevalence among those with long COVID (53%) compared to those without (30%). Reinfection during the Omicron wave was identified as an additional risk factor for new or worsening respiratory symptoms, including dyspnea and cough. Notably, patients may experience dyspnea despite preserved spirometry or DLCO impairment. The observed gap between persistent dyspnea and largely preserved lung function in the 3-year cohort illustrates a wider trend in PASC populations: a dissociation between symptoms and pulmonary function test results. Some individuals report dyspnea despite normal spirometry, while others exhibit impaired DLCO with minimal symptoms. This disconnect suggests that persistent breathlessness in post-COVID-19 conditions often results from a combination of pulmonary and extrapulmonary factors, such as reduced exercise tolerance and frailty, rather than lung function impairment alone [17]. Radiological abnormalities and pulmonary function impairments do not consistently correlate with patient-reported symptom burden. These findings underscore the necessity for multi-modal assessment that integrates pulmonary function tests (PFTs), imaging, and inflammatory or functional markers, rather than relying solely on symptoms or a single PFT parameter [17].

Diffusion impairment

Diffusion capacity impairment remains the most common pulmonary function abnormality observed after COVID-19. A recent systematic review and meta-analysis reported DLCO impairment in approximately 42% of survivors at 6 months, with gradual improvement over time but persistent abnormalities in a substantial proportion of patients. Long-term pooled data extending to 36 months demonstrated a decline in DLCO impairment from 42% at 6 months to 35% at 36 months, indicating progressive but incomplete recovery of pulmonary gas-exchange function [20]. Consistent with these findings, Tarraso., *et al*. reported that 39.8% of patients exhibited impaired lung diffusion 1 year after hospitalization for COVID-19 pneumonia. Although patients with severe disease demonstrated worse diffusion capacity during the early recovery period, no significant differences according to initial disease severity were observed at the 12-month follow-up [21]. Previous reports have seen comparable prevalence estimates [22]. In a systematic review and meta-analysis of seven studies including 380 patients, Torres-Castro., *et al*. found impaired DLCO in 39% of cases, while restrictive and obstructive ventilatory defects were identified in 15% and 7% of patients, respectively [22]. Additionally, a meta-analysis of CT and PFT data indicated that DLCO impairment declined from 39% at six months to 31% at 12 months; however, this difference was not statistically significant [5]. Persistent reductions in DLCO are thought to reflect residual alveolar-capillary membrane injury, ongoing interstitial abnormalities, pulmonary vascular involvement, and incomplete recovery following acute lung injury. Collectively, these findings suggest that although pulmonary function generally improves over time, a substantial proportion of COVID-19 survivors continue to experience persistent diffusion impairment months to years after the acute infection [21].

Restrictive and obstructive patterns in pulmonary physiology

In addition to diffusion abnormalities, reductions in FVC and TLC consistent with restrictive patterns have been observed in patients with more severe acute disease [23,24]. A meta-analysis of 23 studies involving 3347 patients reported mean improvements of 3.1% in forced expiratory volume in one second (FEV1), 4.4% in FVC, and 6.6% in DLCO between an initial follow-up at approximately 3 months and a subsequent follow-up at approximately 12 months. Smoking status, pre-existing chronic lung disease, and age were not significantly associated with the degree of pulmonary function recovery [23]. Evidence of small-airway disease and air trapping appears to persist for years after infection. In a 3-year cohort of 102 survivors of severe or critical COVID-19, radiologic air trapping increased significantly among the 35 participants with paired imaging, rising from 48.6% at 15 months to 88.7% at 3 years, although the paired-imaging sample was small [25]. Transbronchial biopsies performed in five patients with the highest fibrosis scores revealed small-airway histopathology consistent with air trapping in all four biopsies containing small airways. Interstitial fibrosis was identified in only one of the five biopsies.

While more data are required, these findings suggest that small-airway injury may be an important contributor to persistent pulmonary abnormalities; however, the limited biopsy sample precludes definitive conclusions regarding the predominant histopathological pattern. Larger longitudinal studies are needed to further characterize the underlying pathology and its clinical significance [25].

The longitudinal course of pulmonary recovery

Building on the first-year recovery pattern described above, the course beyond one year turns less predictable. However, recovery varied by severity. In a separate two-year cohort of 288 patients, those with the most severe acute illness showed greater improvement in pulmonary function from 6 months to 1 year than patients with less severe disease ($p = 0.0167$ for all comparisons). Corticosteroid treatment during the acute or subacute period was also identified as an independent predictor of improvement, with positive correlation coefficients for FVC, TLC, and DLCO [24].

Trajectory beyond one year: Increased variability

Interestingly, in the same 288-patient cohort, DLCO and TLC parameters decreased during the second year of follow-up, a decline not observed in the first year. The authors identified this unexpected trajectory as warranting further investigation. Despite the decline in DLCO and TLC, functional and quality-of-life measures, such as six-minute walk distance and health-related quality of life, remained stable or improved even as pulmonary function tests worsened [24]. A similar dissociation was observed in dyspnea, which followed a nonlinear course: it increased from 23.3% at 6 months to 27.9% at 1 year, then decreased to 13.4% at 2 years, while six-minute walk distance steadily improved over the same period [24]. In a cohort study of 1,359 patients, lung function aligned with matched community controls at 3 years [19]. However, residual radiologic findings, including irregular lines, traction bronchiectasis, subpleural lines, and ground glass opacity, remained detectable, though the volume of these lesions was small, 0.2-0.3% of total lung volume [19]. Overall, longitudinal data indicate that physiological recovery may continue, fluctuate, or remain incomplete for several years, and radiographic abnormalities can persist even after functional measures have normalized [19,24].

Recovery and persistence in radiologic findings

Radiologic findings do not follow a uniform course. In a meta-analysis of 43 studies stratified by disease severity, Babar., *et al*. [26] reported that ground-glass opacity declined significantly over time. Consolidation also appeared to decrease during follow-up, although long-term data were limited. In contrast, fibrotic-like changes, bronchiectasis, reticulation, and interlobular septal thickening showed no significant change over the study period, and honeycombing increased modestly in prevalence [26]. At long-term follow-up, patients with severe acute COVID-19 exhibited significantly higher rates of any residual abnormality, bronchiectasis, fibrotic-like change, and reticulation compared to those with non-severe initial illness [26]. However, in a separate multicenter cohort, fibrotic-like changes at 1 year were not independently associated with acute severity or mechanical ventilation [21]. Furthermore, in a meta-analysis of 152 studies over 3 years and about 25,000 patients, fibrotic-like findings were among the most persistent radiographic abnormalities, with reported prevalence estimates ranging from 25% to 47% across follow-up intervals [20]. Persistent CT findings do not always indicate progressive fibrosis. In a cohort of severe or critical COVID-19 survivors, 91% had stable fibrotic-like abnormalities between 15 months and 3 years, 9% improved, and none worsened [25]. Whether these abnormalities represent stable residual scarring, incomplete remodeling, or slowly resolving injury remains unclear. Longer follow-up is needed to better define their long-term trajectory.

Organizing pneumonia within post-COVID-19 interstitial lung disease

Organizing pneumonia (OP) is a commonly reported inflammatory pattern within post-COVID interstitial lung disease phenotypes [27]. On CT, OP typically presents as ground-glass opacities accompanied by subpleural or peribronchial consolidation. In a single-center United Kingdom cohort of 837 patients, 39% reported persistent respiratory symptoms. Among these, 59 patients exhibited ongoing parenchymal changes on CT; 35 of these individuals demonstrated an OP pattern with restrictive physiology and persistent symptoms and were recommended for treatment. This subgroup represented 4.8% of the original cohort [27]. Thirty patients completed a short course of prednisolone and were reassessed after three weeks. These individuals demonstrated a mean relative increase in DLCO (referred to as

transfer factor in the study) of 31.6% (SD ± 27.6, p < 0.001) and in FVC of 9.6% (SD ± 13.0, p = 0.014), accompanied by both symptomatic and radiological improvement [27]. Regarding treatment, the NORCOVID trial, a randomized, single-center non-inferiority study, compared 3-months and 6-months prednisone (standard regimen) in 79 patients with post-COVID OP. Over six months, DLCO improvements were similar between groups (11.7% with the shorter course versus 12.8% with the standard course; between group differences 1.16%, within the 10% non-inferiority margin). Non-severe complications occurred less frequently with the shorter regimen (22.5% versus 56.4%, p = 0.003), while rates of severe prednisone related complications were comparable and rare. At twelve months, DLCO improved more in the standard arm, but the difference was not statistically significant; FEV1 improved more with the standard course at six months [28]. The prevalence of OP after COVID-19 ranges from 12% to 32% following a severe initial course [28]. Post-COVID interstitial lung disease has been reported in approximately 7% to 24% of patients, with prevalence varying according to follow-up duration [29]. Macrolides such as clarithromycin have been reported in isolated cases of COVID-associated OP because of their anti-inflammatory properties; however, evidence remains limited to case reports and small anecdotal experiences [29].

Collectively, the evidence base for treating post-COVID OP is limited with no RCTs available, leaving the optimal dose and duration of therapy unclear [27,29]. Corticosteroids have been associated with improvement in patients exhibiting an active OP pattern, restrictive physiology, and persistent symptoms, whereas patients with limited involvement (<15%) and preserved function, who may represent typical recovery, were not treated. Therefore, corticosteroids may be appropriate for selected patients with active inflammatory OP, but not for indiscriminate use in all cases of residual CT abnormality or OP cases but further research is needed.

Pathogenesis of pulmonary fibrosis and disease progression

Several mechanistic studies support a biologically plausible pathway linking acute SARS-CoV-2 infection to pulmonary fibrosis. *In vitro*, direct stimulation of human lung epithelial cells with SARS-CoV-2 increases TGF-β1, a potent pro-fibrotic cytokine, and its downstream effector, connective tissue growth factor [30]. CD163+ M2 macrophages were identified in severely affected COVID patients [30]. The transcriptomic analysis of infected cells showed fibrotic features similar to those of idiopathic pulmonary fibrosis (IPF), including activation of TGFβ pathway genes. Direct viral stimulation of normal macrophages in vitro may induce a profibrotic phenotype, suggesting that the virus itself may contribute to fibrogenic immune responses [30]. Th2-skewed cytokines were also implicated in this response. O'Reilly., *et al*. [30] observed that IL-4 and IL-13 levels were elevated, and IL 13, a known fibrosis mediator, was associated with the need for mechanical ventilation [30]. Neutrophil extracellular traps generated in the early post-acute period have been implicated in fibrogenesis when applied exogenously to epithelial cells [17]. Further causes of fibrosis include the upregulation of the pro-fibrotic protein TIMP1 [30] and Viral interaction with ACE2 may promote receptor internalization and enhanced alveolar TGF-β signaling, which could contribute to fibroblast proliferation and extracellular matrix deposition, including collagen and fibronectin [17]. More globally, elevated eosinophils, mast cells, and CD8+ lymphocytes have been associated with persistent pulmonary function abnormalities and more extensive radiologic changes following COVID-19 [17]. Several risk factors linked to persistent post-COVID pulmonary abnormalities overlap with those implicated in fibrotic lung disease and severe COVID-19, including older age, male sex, hypertension, ischemic heart disease, type 2 diabetes, and DPP9 gene variants [17].

Taken together, these findings support the biological plausibility of fibrotic remodeling following SARS-CoV-2 infection. However, they do not establish that all persistent radiographic abnormalities represent active or progressive fibrosis, as many imaging abnormalities remain stable or improve over time.

Determinants of persistent pulmonary abnormalities

Consistent predictors of adverse pulmonary outcomes include illness severity, mechanical ventilation, or ARDS [17,31]. In the CovILD study, among patients who completed CT imaging at 1 year, more than half had residual CT abnormalities: 34% had subtle subpleural

reticulation, ground-glass opacity, or both, and 20% had bronchial dilation and microcystic change. Age greater than 60 years, critical illness, and male sex were independently associated with persistence. Among those with abnormal imaging, 63% showed no radiologic improvement after 6 months [31]. Interpretation across cohorts remains challenging because reported risk factors vary between studies. In a 448-patient cohort, risk factors for DLCO impairment included age, female sex, BMI, and elevated ferritin, which contrasts with the male predominant findings in CovILD study. This variability highlights the heterogeneity of post-COVID pulmonary sequelae and suggests that no single risk-factor profile applies universally [21].

Moreover, persistent pulmonary sequelae are not confined to severe disease; fibrotic-like changes were observed in 23% of the 448-patient cohort, affecting individuals with both severe and mild acute illness, and were not significantly associated with conventional ARDS severity markers [21]. Therefore, while severity remains a dominant risk factor at the population level, individual susceptibility to persistent pulmonary injury cannot be explained by acute disease severity alone.

Clinical assessment of persistent respiratory symptoms

The differential diagnosis of persistent dyspnea in post-COVID-19, is varied and includes residual diffusion impairment, restrictive physiology, small-airway disease with air trapping, organizing pneumonia, interstitial lung abnormality, fibrotic-like remodeling, pulmonary vascular or thromboembolic disease, deconditioning, respiratory muscle weakness, ongoing systemic inflammation, and non-pulmonary contributors [17,32]. Thromboembolic events also warrant attention. Pulmonary embolism has been reported in hospitalized patients with COVID-19 who do not require intensive care, although its incidence is higher among critically ill patients admitted to the ICU [17]. DLCO impairment remains the most reproducible physiologic abnormality reported after COVID-19 [20]. Chest CT provides valuable information regarding structural abnormalities and may help differentiate residual inflammatory changes from more established remodeling patterns when interpreted in the appropriate clinical context [26]. Functional testing, such as the six-minute walk distance, assesses exercise capacity, which may not correlate with pulmonary function. For instance, in a two-year cohort, walking distance improved even as pulmonary function tests declined [24]. Because each assessment, symptom report, PFT, or CT, offers only a limited perspective, serial evaluations over time are necessary to differentiate stable residual abnormalities from those that are progressing. This approach is discussed further in the section on Long-Term Surveillance [19].

Role of pulmonary rehabilitation

Pulmonary rehabilitation has a strong evidence base among the interventions considered. A meta-analysis of 37 randomized controlled trials with 3,363 patients found that rehabilitation improved physical capacity (6MWD, 30-second sit-to-stand, handgrip strength), lung function (FEV1, FVC, maximal inspiratory and expiratory pressures), health-related quality of life, fatigue, dyspnea, and anxiety [33]. Program duration appeared important: programs of 4 weeks or less improved only walk distance, while 4-8 weeks programs produced significant gains in walking distance, lung function, quality of life, and fatigue, identifying this window as most effective. Programs for longer than 8 weeks improved quality of life and fatigue but not physical performance measures [33]. The exercise type also impacted outcomes; for example, breathing exercises alone improved walk distance, lung function, and quality of life; additionally, a multicomponent program improved walk distance and reduced fatigue; and combining both approaches produced the broadest benefit, improving walk distance, FEV1, FVC, quality of life, and fatigue [33]. Lastly, in a review of twelve guidance documents, eight recommended pulmonary rehabilitation for patients with persistent dyspnea, functional limitation, or abnormal findings such as radiographic abnormality or exercise-induced desaturation, consistently emphasizing individualized programs [34]. Despite these findings, heterogeneity among rehabilitation protocols remains substantial, and the specific components of many multicomponent programs were incompletely reported [34]. Overall, pulmonary rehabilitation is well supported for improving symptoms, exercise capacity, pulmonary function, and quality of life; however, current evidence does not demonstrate reversal of structural fibrotic lung abnormalities [34].

Consideration of antifibrotic therapy

Evidence for antifibrotic agents in post-COVID pulmonary fibrosis is less clear than the evidence for pulmonary rehabilitation in reducing symptom burden and improving exercise capacity and pulmonary function as described above. A meta-analysis of seven trials with 496 participants found no significant difference between antifibrotic and standard care in chest CT score, hospital length of stay, or mortality [35]. However, antifibrotic therapy was associated with improvements in FEV1% predicted and FEV1/FVC ratio [35]. Thus, improvements in selected pulmonary function measures were observed without corresponding improvements in radiographic outcomes, hospital length of stay, or mortality. The use of antifibrotics in post-COVID pulmonary fibrosis remains largely empirical and theory-driven, rather than supported by reliable outcome data. This distinction should be considered when evaluating their role in clinical practice [35].

A longitudinal framework for post-COVID pulmonary disease

The findings above can be organized into a working model of five overlapping phases. The first phase, acute injury, involves direct epithelial, endothelial, and inflammatory damage from the initial infection, ranging from mild pneumonitis to ARDS [17]. The second phase, early post-acute recovery, is dominated by residual inflammatory changes, with ground-glass opacity and diffusion impairment most prominent in the first months after infection [18]. The third phase, pulmonary repair, spans roughly 3 to 12 months and is identified by substantial improvement in FEV1, FVC, DLCO, dyspnea, and exercise capacity [23,24]. After this, a fourth phase of persistent disease appears in some patients, who retain reduced DLCO, small-airway disease, organizing pneumonia, interstitial abnormality, or fibrotic-like CT changes [20,25]. The fifth phase, long-term stabilization or continued recovery, extends beyond the first year: many abnormalities remain stable or slowly improve, and by 3 years some cohorts show near-normal function despite persistent structural findings [19,24].

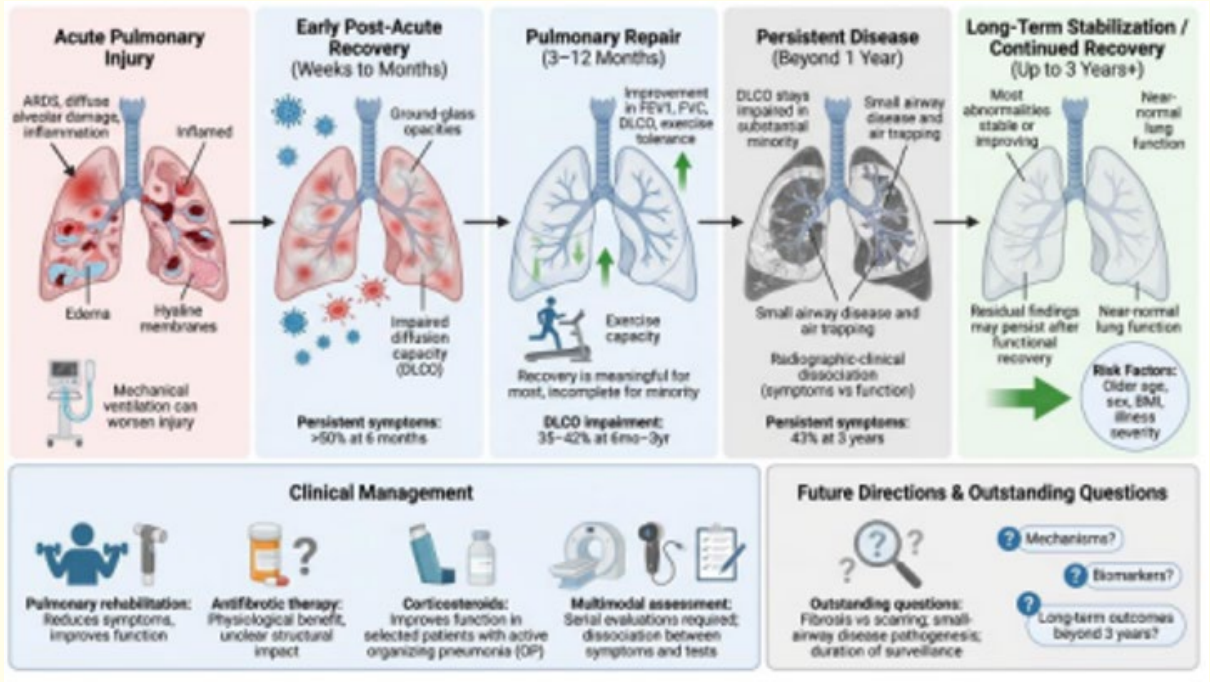


Figure 2: *Phase management of COVID-19.*

Approach to long-term surveillance

This phased model enables clinicians to tailor management strategies, ranging from conservative to aggressive, based on the disease phase. It also supports a spectrum of interventions, from symptomatic relief to rehabilitation. Patients with persistent symptoms, abnormal pulmonary function tests (PFTs), significant pneumonia during acute illness, severe or critical disease, or persistent radiographic abnormalities are appropriate candidates for ongoing monitoring. Current expert guidance supports individualized pulmonary follow-up during the first year after COVID-19, particularly for patients with severe disease, persistent respiratory symptoms, abnormal pulmonary function tests, or ongoing radiographic abnormalities [5]. Rather than relying on a single measurement, clinicians should monitor changes over serial visits and combine clinical, pulmonary function and radiologic assessment. Although individual trajectories may vary, improvement over time generally denotes ongoing recovery, stability indicates a residual but non-progressive process, and worsening requires evaluation for alternative or progressive pathology [25,24]. Three-year data from a 1,359-patient cohort afforded reassurance at the population level, as overall lung function approached that of matched controls. However, individual patients with ongoing symptoms, abnormal organ function, or limited mobility still require timely clinical attention, regardless of population averages [19].

Future directions

Several questions remain open. Chief among them is the distinction between radiographic "fibrotic-like" abnormality and genuinely progressive pulmonary fibrosis, a distinction that current imaging alone cannot consistently make [25]. Related to this is the wider problem of radiographic-clinical dissociation: a meaningful subset of patients has persistent CT findings despite normal pulmonary function and minimal symptoms, and the clinical significance of these isolated findings is unclear [19]. The mechanisms underlying small-airway disease and air trapping, which limited biopsy and imaging data suggest may be more prevalent than previously appreciated, remain incompletely characterized [25]. Furthermore, the appropriate duration of surveillance is similarly uncertain: while data now extend to the 3-year mark, whether further physiological or radiographic changes occur or progress beyond that point is unknown [20]. Finally, therapies remain individualized rather than protocolized. Corticosteroids appear justified for patients with active OP in addition to their standard use during the acute stage of severe COVID-19, pulmonary rehabilitation for those with functional limitation, and antifibrotic therapy is still unproven for routine use outside of a research context [27,28,35].

Conclusion

The pulmonary consequences of COVID-19 encompass a heterogeneous spectrum, extending from acute infection to several years of follow-up [20]. While most patients experience meaningful recovery, particularly within the first year [23], a substantial minority continue to exhibit DLCO impairment, persistent symptoms, and small-airway, interstitial, or fibrotic-like abnormalities even years later [20,25]. The central conclusion of this review is that persistence of abnormalities does not necessarily indicate progression. Longitudinal evidence suggests that most fibrotic-like changes are stable or slowly improving, rather than actively worsening [25].

Authors' Contribution

Samuel Saad, MBBCh: Conceptualization, data evaluation, writing, and literature review.

Leonardo Guerra: Conceptualization, data evaluation, writing, and literature review.

Akram Mahreen, MD: Data evaluation, literature review, and editing.

James Toth, DO: Data evaluation, literature review, and editing.

Irina Dashkova, MD: Data evaluation, literature review, and editing.

Khalid M. Alzwahereh, MD: Data evaluation, literature review, and editing.

Cyril Ibrahim: Net surfing and fixing grammatical mistakes.

Herman Lebovitch, MD: Data evaluation, literature review, and editing.

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