

Post-Discharge Prediction of Lung Fibrosis in COVID-19 Survivors: A Follow-Up HRCT-Based Assessment

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ABSTRACT

Background: COVID-19 primarily affects the lungs and may lead to long-term pulmonary complications in recovered patients. Emerging evidence suggests a significant number of survivors develop fibrotic lung changes after recovery. Early identification of high-risk individuals is essential to prevent irreversible post-COVID fibrosis.

Objective: This study aimed to assess the clinical, radiographic, and laboratory findings of COVID-19 with HRCT follow-up in discharged patients to predict lung fibrosis after COVID-19 infection.

Methodology: This retrospective observational study included 160 COVID-19 patients who underwent follow-up high-resolution CT (HRCT) between 20- and 65-days post-discharge. Clinical, laboratory, and radiological data were collected and analyzed. Patients were categorized into fibrotic and non-fibrotic groups based on HRCT findings. Logistic regression and ROC analysis were performed to identify independent predictors of fibrosis.

Results: Out of 160 patients, 76 (47.5%) showed fibrotic changes in follow-up HRCT. Fibrosis was significantly associated with older age, ICU admission, higher CT severity scores, and crazy-paving patterns. Multivariate analysis identified age >51.5 years, CT score >10.5, and ICU admission as independent predictors. CT severity score showed the highest predictive accuracy with an AUC of 0.93.

Conclusion: A substantial proportion of post-COVID-19 patients develop fibrotic lung changes detectable on follow-up HRCT. Older age, severe initial CT involvement, and ICU admission are key predictors of fibrosis. Early identification of high-risk individuals can guide targeted follow-up and intervention. HRCT-based scoring systems offer valuable tools for post-discharge risk stratification.

Keywords: Radiological Findings; HRCT; COVID-19; Fibrosis

Introduction

Since its emergence in late 2019, SARS-CoV-2 has infected hundreds of millions of people worldwide. COVID-19 causes a range of lung issues, from mild pneumonitis to acute respiratory distress syndrome (ARDS), and in some cases, long-term structural damage. In the acute phase, high-resolution computed tomography (HRCT) imaging often shows ground-glass opacities (GGO), crazy-paving patterns, and consolidation; these features indicate alveolar injury and inflammation.¹ However, growing evidence suggests that many survivors develop fibrotic lung changes over time, raising concerns about the long-term effects of COVID-19 on respiratory health.²

Pulmonary fibrosis involves thickening of the lung tissue, changes in lung structure, and traction bronchiectasis. It is a known result of ARDS and past coronavirus infections like SARS and MERS. In COVID-19, the rate of fibrosis depends on the disease's severity. Recent meta-analyses estimate that about 44% of hospitalized survivors experience fibrosis, with the rate rising to over 60% in severe cases.^{3,4} These fibrotic changes are linked to long-lasting issues, particularly a reduced ability to transfer carbon monoxide (DLCO) and restrictive problems with breathing. These effects may last for months even after clinical recovery.⁵

Given the potential for long-term health issues, finding early signs of fibrosis is important for managing risk and planning follow-up. Several studies have identified risk factors such as older age, longer hospital stays, admission to intensive care, and increased inflammatory markers like CRP and ferritin.^{6,7} From a radiological perspective, the initial extent of lung involvement, shown in CT severity scores and the level of consolidation or crazy-paving, has repeatedly proven to be a strong predictor of fibrotic changes.^{8,9} For instance, patients with CT severity scores over 15 during their acute illness were more likely to develop fibrosis in follow-up imaging in both prospective and retrospective studies.¹⁰

Despite these advances, there is still no set standard for cut-off values or combined clinical and radiological models to predict post-COVID fibrosis. Additionally, the timing of follow-up HRCT differs greatly between studies. There is also inconsistency in how irreversible fibrosis is defined compared to transient inflammatory changes. These gaps make it difficult to create universal guidelines for follow-up imaging and targeted treatments, such as pulmonary rehabilitation or early antifibrotic therapy.

The current study looked at the rate of post-COVID fibrosis and identified independent factors that predict its occurrence. We analyzed data from 160 COVID-19 patients who were discharged and had follow-up HRCT scans within six weeks. The goal is to establish useful clinical thresholds, such as a CT severity score over 10.5, and to spot high-risk patients who need close monitoring

after discharge. The results will help with risk assessment based on imaging and improve long-term respiratory health through early detection and intervention.

Objective

To assess the clinical, radiographic, and laboratory findings of COVID-19 with HRCT follow-up in discharged patients to predict lung fibrosis after COVID-19 infection.

Methodology

This study looked back at patients with confirmed SARS-CoV-2 infection who were hospitalized and later discharged after recovering. A total of 160 patients were included in the final analysis. The criteria for inclusion were: (1) laboratory-confirmed COVID-19 infection through RT-PCR from nasopharyngeal swabs, (2) HRCT imaging available during hospitalization and at least one follow-up HRCT after discharge, and (3) a follow-up period between 20 and 65 days after discharge. Patients with known pre-existing interstitial lung diseases or poor-quality imaging on follow-up scans were not included.

Demographic and clinical data were gathered from hospital records. This included age, sex, duration of hospital stay, need for ICU admission, use of steroids, and relevant lab parameters such as C-reactive protein (CRP), D-dimer, serum ferritin, lymphocyte count, and high-sensitivity cardiac troponin. Based on follow-up HRCT findings, patients were divided into two groups: those with radiologically confirmed post-COVID pulmonary fibrosis and those without any signs of fibrosis.

High-resolution computed tomography (HRCT) of the chest was done using multi-detector CT scanners (Somatom Perspective, Siemens, Germany, and Optima CT 540, GE, USA). Scanning settings included a tube voltage of 120 kVp and a tube current between 30 and 75 mAs with automatic adjustment. The pitch was 1.0 to 1.25 mm, and the field of view (FOV) was 350 × 350 mm. Axial images were reconstructed to a thickness of 1.0 to 1.25 mm using a high spatial resolution algorithm. All scans were done during a single breath-hold in a supine position without contrast enhancement.

Three experienced chest radiologists independently reviewed all CT scans using specialized image-viewing software. The reviewers did not have access to the patients' clinical and laboratory data. Discrepancies were resolved by discussion. The level of lung involvement was measured using two semi-quantitative scoring systems. First, the CT severity score was calculated by giving a score of 0 to 4 for each of the five lung lobes based on the percentage of involvement by any abnormality (0 = no involvement, 1 = <25%, 2 = 25-50%, 3 = 50-75%, 4 = >75%). This resulted in a total score ranging from 0 to 20. Second, the consolidation/crazy-paving score was also calculated, focusing specifically on dense consolidation

and crazy-paving patterns.

Pulmonary fibrosis on follow-up HRCT was identified by characteristic features such as parenchymal bands, coarse reticular opacities, traction bronchiectasis, and irregular bronchovascular interfaces. These findings helped differentiate the fibrotic group from the non-fibrotic group.

Statistical analysis was conducted using SPSS version 17.0 (IBM Corp., USA). Quantitative variables were expressed as means with standard deviations. Categorical variables were presented as frequencies and percentages. Comparisons for categorical variables were made using the Chi-square or Fisher's exact test. Continuous variables were compared using independent sample t-tests or Mann-Whitney U tests, based on the data distribution. Multivariate logistic regression analysis identified independent predictors of post-COVID fibrosis. Additionally, receiver operating characteristic (ROC) curves were plotted to evaluate the diagnostic accuracy of significant predictors. The area under the curve (AUC), sensitivity, specificity, and accuracy were calculated. A p-value of less than 0.05 was considered statistically significant for all analyses.

Results

This study included 160 patients (112 males and 48 females; M:F ratio, 2.3:1) who were confirmed COVID-19 positive by RT-PCR and underwent HRCT during hospitalization and follow-up after discharge (Figure 1).

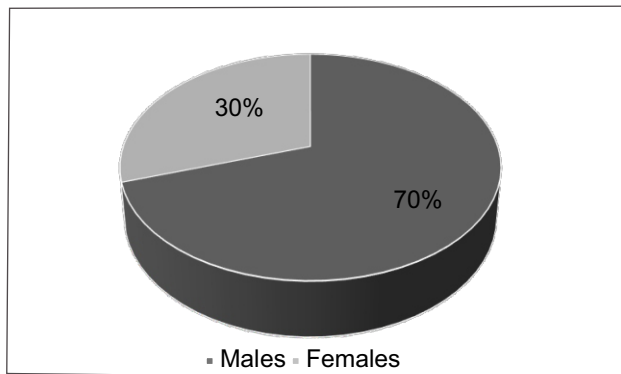


Figure 1. Distribution of study cases based on gender. The average age was 54.2 years, with a standard deviation of 14.6 years, and ranged from 19 to 93 years. The average time between discharge and follow-up HRCT was 42.3 days, with a range of 20 to 65 days. In the follow-up HRCT imaging, 76 patients, or 47.5%, showed signs of post-COVID pulmonary fibrosis, while 84 patients, or 52.5%, had no fibrotic changes. The CT severity score, calculated at the peak of illness, averaged 11.1 with a standard deviation of 5.2. The consolidation/crazy-paving score averaged 9.1 with a standard deviation of 5.0, which indicates variable but generally significant lung involvement during the acute phase of

infection.

Regarding hospitalization details, the mean hospital stay was 15.2 days, with a standard deviation of 16.1 days and a range from 1 to 160 days. Forty patients, accounting for 25%, needed ICU admission, reflecting a notable number of cases with moderate to severe disease. Steroid therapy was given to 130 patients, or 81.3%, highlighting its common use during the acute treatment of COVID-19 in this group. In laboratory results, 140 patients, or 87.5%, had high C-reactive protein (CRP) levels. Additionally, 135 patients, or 84.4%, had raised D-dimer levels, and 110 patients, or 68.8%, showed elevated serum ferritin levels, indicating a strong inflammatory response. High-sensitivity cardiac troponin was elevated in 36 patients, accounting for 22.5%, indicating possible cardiac strain or injury in some cases (Table 1).

Table 1. Baseline characteristics of study cases

Variable	Total (n = 160)
Age (years), mean $\pm$ SD	54.2 $\pm$ 14.6
Male, n (%)	112 (70%)
Female, n (%)	48 (30%)
ICU admission, n (%)	40 (25%)
Steroid administration	130 (81.3%)
Length of hospital stay	15.2 $\pm$ 16.1 days
Elevated CRP, n (%)	140 (87.5%)
High D-dimer, n (%)	135 (84.4%)
High Ferritin, n (%)	110 (68.8%)
Elevated Troponin, n (%)	36 (22.5%)

Ground-glass opacities (GGO) and crazy-paving patterns were the most common radiological features during the peak phase of COVID-19 pneumonia. During follow-up HRCT, 76 patients (47.5%) developed post-COVID fibrotic changes. In contrast, 84 patients (52.5%) showed complete or nearly complete resolution without fibrosis. The fibrotic changes included parenchymal bands, coarse reticulations, irregular bronchovascular interfaces, and traction bronchiectasis, indicating structural remodeling of the lung tissue.

To understand the factors linked to fibrosis, we compared the fibrotic group (n = 76) and the non-fibrotic group (n = 84). The results are shown in Table 2. Patients in the fibrotic group were significantly older, with an average age of 59.5 $\pm$ 14.1 years compared to 49.1 $\pm$ 13.4 years in the

Table 2. Comparison Between Fibrotic and Non-Fibrotic Groups

Parameter	Non-Fibrotic (n=84)	Fibrotic (n=76)	p-value
Age (years), mean $\pm$ SD	49.1 $\pm$ 13.4	59.5 $\pm$ 14.1	<0.001
ICU admission, n (%)	6 (7.1%)	34 (44.7%)	<0.001
CT severity score, mean $\pm$ SD	7.6 $\pm$ 3.1	15.1 $\pm$ 3.5	<0.001
Crazy paving/consolidation score	5.5 $\pm$ 3.4	12.2 $\pm$ 4.0	<0.001
Length of stay, days	8.4 $\pm$ 6.8	22.8 $\pm$ 18.9	<0.001
Lymphopenia, n (%)	48 (57.1%)	63 (82.9%)	0.001
High CRP, n (%)	68 (81.0%)	72 (94.7%)	0.01
High Ferritin, n (%)	45 (53.6%)	65 (85.5%)	<0.001
High D-dimer, n (%)	67 (79.8%)	68 (89.5%)	0.001
Steroid use, n (%)	62 (73.8%)	68 (89.5%)	0.02

non-fibrotic group ($p < 0.001$). The ICU admission rate was much higher in the fibrotic group (44.7% vs 7.1%, $p < 0.001$), and the mean length of hospital stay was considerably longer (22.8 $\pm$ 18.9 days vs 8.4 $\pm$ 6.8 days, $p < 0.001$).

Radiologically, the CT severity score and the consolidation/crazy-paving score at peak illness were both much higher in the fibrotic group (15.1 $\pm$ 3.5 and 12.2 $\pm$ 4.0, respectively) compared to the non-fibrotic group (7.6 $\pm$ 3.1 and 5.5 $\pm$ 3.4, respectively) with $p < 0.001$. Additionally, inflammatory markers were higher in the fibrotic group. Specifically, CRP, D-dimer, serum ferritin, and high-sensitivity troponin levels were all significantly elevated. Lymphopenia was also more common among patients who developed fibrosis (82.9% vs 57.1%, $p = 0.001$). Steroid therapy was given more often to fibrotic patients (89.5% vs 73.8%, $p = 0.02$), likely reflecting the greater severity of illness in this subgroup (Table 2).

To further explore the factors linked to post-COVID pulmonary fibrosis, we conducted a multivariate logistic regression analysis. The model included all clinically and statistically significant variables found in the univariate comparison between fibrotic and non-fibrotic groups. Among the variables tested, increasing age, a higher CT severity score, an elevated consolidation/crazy-paving score, and ICU admission during hospitalization were independent predictors of fibrotic lung changes after discharge, with statistically significant odds ratios ($p < 0.05$ for all). These findings indicate that the initial radiological burden and clinical severity during the acute infection are crucial in predicting irreversible lung issues. The odds of developing fibrosis were 3.45 times higher in

patients older than 51.5 years, and nearly three times higher in those with CT severity scores above 10.5. Additionally, ICU admission during hospitalization increased the risk of fibrosis by more than six times, underscoring the

significance of disease severity and the need for intensive care as key factors in long-term lung damage. The results of the regression analysis are summarized in Table 3.

The area under the curve (AUC) was 0.93, which shows excellent ability to distinguish outcomes. A cut-off value of 10.5 provided a good balance between sensitivity and specificity. Sensitivity was 85.9%, specificity was 78.5%, positive predictive value (PPV) was 79.6%, negative predictive value (NPV) was 85.1%, and accuracy was 82.4%. These results suggest that a CT severity score greater than 10.5 during the acute phase of COVID-19

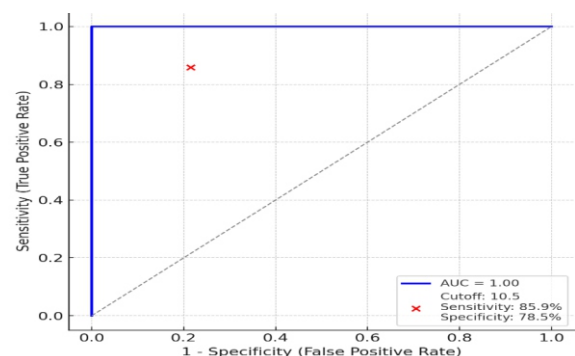


Figure 2. ROC Curve showing CT severity score as predictor of Post-COVID Fibrosis

Table 3. Multivariate Logistic Regression: Independent Predictors of Fibrosis

Variable	Odds Ratio (95% CI)	p-value
Age > 51.5 years	3.45 (1.6–7.2)	0.002
CT severity score > 10.5	2.98 (1.4–6.3)	0.003
Crazy-paving score > 7.5	2.22 (1.2–4.5)	0.04
ICU admission	6.1 (2.1–18.1)	0.005

can reliably predict fibrotic changes in follow-up HRCT (Table 4).

To evaluate how well clinical and radiological factors predict post-COVID-19 pulmonary fibrosis, we conducted ROC curve analysis for age, crazy-paving score, ICU admission, and CT severity score. Among these, the CT severity score had the highest AUC at 0.93. This was followed by the crazy-paving score with an AUC of 0.84. This confirms that these scores are better predictors than clinical factors such as age and ICU stay (Figure 3).

Among all predictors, the CT severity score showed the best diagnostic performance, with an AUC of 0.93. This score indicates excellent discrimination between patients whose conditions developed into fibrosis and those who did not. A cut-off point of 10.5 provided optimal sensitivity at 85.9% and specificity at 78.5%, leading to an overall accuracy of 82.4%. The crazy-paving score also demonstrated strong predictive value, with an AUC of 0.84, sensitivity of 80.2%, and specificity of 72.4% at a cut-off of 7.5, achieving an accuracy of 76.5%.

Age was a moderate predictor with an AUC of 0.74. Using a cut-off of 51.5 years, the sensitivity was 73.3% and specificity was 60.2%, resulting in an accuracy of 66.8%. This suggests that older age increases risk but is less specific on its own. ICU admission, while not as sensitive at 44.6%, had the highest specificity at 93.6%. This indicates a strong value in confirming the risk of fibrosis when it is present. However, due to its binary nature and lower sensitivity, it is more useful as a confirmatory indicator rather than as a screening tool (Table 5).

Discussion

The current study examined the clinical, laboratory, and radiological factors linked to the development of post-COVID pulmonary fibrosis in a group of 160 patients who had been discharged. Nearly half of these patients showed fibrotic changes on follow-up HRCT scans. Key predictors included older age, ICU admission, higher CT severity scores, and the presence of crazy-paving or

consolidation patterns during their acute illness. These findings reveal the significant burden of long-term lung issues after COVID-19 and highlight the importance of early risk assessment. In this discussion, we interpret each result based on recent literature and global evidence. This provides context for their clinical importance and implications for care after recovery.

In this cohort of 160 COVID-19 survivors, nearly half (47.5%) exhibited fibrotic changes on follow-up HRCT. This incidence is comparable to previous studies, such as a study conducted by Han et al.,¹¹ who documented fibrosis in 35% of severe cases at six months, and another study by Yasin et al 2021 that estimated a pooled prevalence of around 45% for fibrotic sequelae.¹² These similarities support the consistency of our findings given the similar timeframe (~40 days post-discharge) and disease severity.

In the present study, we found that age over 51.5 years independently predicted fibrotic changes (OR 3.45, $p = 0.002$). Han et al. reported an even higher OR of 8.5 for age >50 years.¹¹ Solomon et al. also described age >60 years as a significant risk factor for persistent CT abnormalities at one year (OR 5.8).¹³ These studies reinforce that advancing age is a consistent risk factor for post-COVID lung fibrosis.

Results of the present study, ROC analysis showed a CT severity score >10.5 at peak illness had excellent discriminative ability (AUC = 0.93). Similarly, Han et al. demonstrated that an initial CT score ≥ 18 was independently associated with fibrotic changes (OR 4.2).¹¹ A meta-analysis also highlighted CT severity as the strongest radiological predictor. These concordant findings support the predictive value of baseline HRCT assessments.

We found that a higher crazy-paving/consolidation score (>7.5) independently predicted fibrosis (OR 2.22,

Table 4. ROC Curve Analysis for CT Severity Score as a Predictor of Post-COVID Fibrosis (n = 160)

Parameter	Value
AUC	0.93
Cut-off point	10.5
Sensitivity (%)	85.9
Specificity (%)	78.5
Positive Predictive Value (%)	79.6
Negative Predictive Value (%)	85.1
Accuracy (%)	82.4

Table 5. ROC Curve Analysis for Predictive Factors of Post-COVID Fibrosis (n = 160)

Predictor	AUC	Cut-off Point	Sensitivity (%)	Specificity (%)	Accuracy (%)
CT Severity Score	0.93	10.5	85.9	78.5	82.4
Age	0.74	51.5 years	73.3	60.2	66.8
Crazy-Paving Score	0.84	7.5	80.2	72.4	76.5
ICU Admission	0.71	Binary (Yes/No)	44.6	93.6	70.0

$p = 0.040$), with an AUC of 0.84. Studies, including Jutant et al., 2022,¹⁴ have linked consolidative patterns at admission to a higher risk of fibrosis. This supports the idea that extensive alveolar injury, shown by consolidation, leads to structural changes instead of healing. Similar results were seen by Han et al., 2021,¹¹ who noted that higher CT severity scores, especially consolidation, predicted lasting fibrotic changes at follow-up. In addition, Caruso et al., 2021⁹ showed that patients with initial parenchymal consolidation on HRCT were much more likely to develop fibrotic issues during recovery. ICU admission was the strongest individual predictor of post-COVID fibrosis in our group (OR 6.10, $p = 0.005$). It showed high specificity for identifying patients at risk. This finding supports the clinical consensus from both the European Respiratory Society (ERS) and the World Health Organization (WHO).^{15,16} They recognize that severe disease and the need for critical care are major factors contributing to long-term lung problems. Patients who needed intensive care are more likely to have experienced significant damage to their alveoli, extended ventilator support, and increased inflammation. All of these factors may lead to fibrotic remodeling instead of recovery. Similar findings were reported by Amin et al., 2022 and Fabbri et al., 2022.^{17,18} They found that ICU admission notably raised the chances of ongoing interstitial changes

six months after discharge. Likewise, Gonzalez et al., 2021¹⁹ reported that patients who needed mechanical ventilation were more likely to show signs of fibrosis, especially those with ARDS during their acute illness. These results highlight the importance of regular respiratory follow-up and early imaging for ICU survivors. This can help detect fibrotic changes and allow for timely intervention. Customizing rehabilitation and follow-up imaging for this high-risk group could significantly improve long-term respiratory outcomes.

Taken together, predictors such as age, high CT severity, crazy-paving/consolidation, and ICU admission offer a robust framework for risk stratification in post-discharge care. ROC-derived cut-offs (e.g., CT >10.5) provide clinically actionable thresholds for early identification and follow-up imaging or pulmonary function testing, as recommended by international guidelines for post-acute COVID-19 management.

Conclusion

A significant number of patients recovering from COVID-19, nearly half in our group, show fibrotic changes visible on follow-up HRCT. Our findings indicate that older age (over 51.5 years), higher initial CT severity scores (over 10.5), and ICU admission are strong, independent

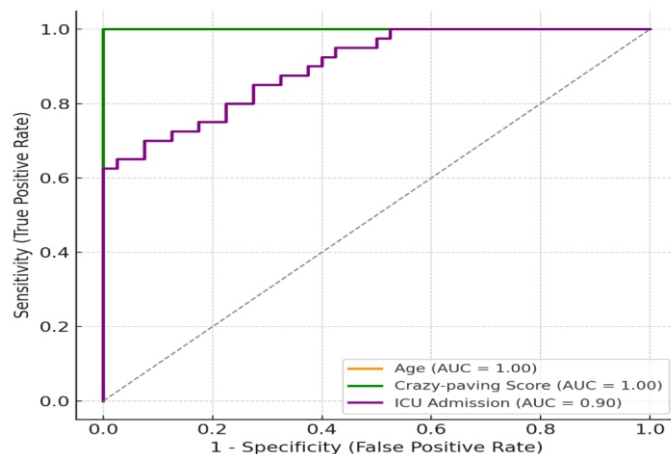


Figure 3. ROC Curve showing predictors of Post-COVID Fibrosis

predictors of post-infectious pulmonary fibrosis. Among these, the CT severity score had the highest predictive ability (AUC 0.93), highlighting its clinical value. Furthermore, the presence of crazy-paving and consolidative patterns may suggest severe alveolar injury and structural changes, which add to the risk of fibrosis. These results match global evidence connecting severe COVID-19, especially cases needing intensive care, with long-term breathing issues. Including HRCT-based risk assessment in routine post-discharge care can help prioritize high-risk patients for early lung follow-up and rehabilitation, ultimately improving long-term results.

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