Chest CT Patterns from Diagnosis to 1 Year of Follow-up in Patients with COVID-19

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Conflicts of interest are listed at the end of this article.

See also the editorial by Lee and Wi et al in this issue.

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Background: The chest CT manifestations of COVID-19 from hospitalization to convalescence after 1 year are unknown.

Purpose: To assess chest CT manifestations of COVID-19 up to 1 year after symptom onset.

Materials and Methods: Patients were enrolled if they were admitted to the hospital because of COVID-19 and underwent CT during hospitalization at two isolation centers between January 27, 2020, and March 31, 2020. In a prospective study, three serial chest CT scans were obtained at approximately 3, 7, and 12 months after symptom onset and were longitudinally analyzed. The total CT score of pulmonary lobe involvement, ranging from 0 to 25, was assessed (score of 1–5 for each lobe). Univariable and multivariable logistic regression analyses were performed to explore independent risk factors for residual CT abnormalities after 1 year.

Results: A total of 209 study participants (mean age, 49 years ± 13 [standard deviation]; 116 women) were evaluated. CT abnormalities had resolved in 61% of participants (128 of 209) at 3 months and in 75% of participants (156 of 209) at 12 months. Among participants with chest CT abnormalities that had not resolved, there were residual linear opacities in 25 of the 209 participants (12%) and multifocal reticular or cystic lesions in 28 of the 209 participants (13%). Age 50 years or older, lymphopenia, and severe or aggravation of acute respiratory distress syndrome were independent risk factors for residual CT abnormalities at 1 year (odds ratios = 15.9, 18.9, and 43.9, respectively; P < .001 for each comparison). In 53 participants with residual CT abnormalities at 12 months, reticular lesions (41 of 53 participants [77%]) and bronchial dilation (39 of 53 participants [74%]) were observed at discharge and were persistent in 28 (53%) and 24 (45%) of the 53 participants, respectively.

Conclusion: One year after COVID-19 diagnosis, chest CT scans showed abnormal findings in 53 of the 209 study participants (25%), with 28 of the 209 participants (13%) showing subpleural reticular or cystic lesions. Older participants with severe COVID-19 or acute respiratory distress syndrome were more likely to develop lung sequelae that persisted at 1 year.

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Since the global outbreak of the COVID-19 pandemic, more than 100 million people have been infected, resulting in more than three million deaths globally (1). Several of the β coronaviruses have similar clinical course and laboratory, radiologic, and pathologic features. These coronaviruses include severe acute respiratory syndrome (SARS), Middle East respiratory syndrome, and COVID-19 (2–5). However, SARS coronavirus 2 has proven more contagious than other coronaviruses, resulting in a far higher number of cases and a global pandemic (1,6).

Previous chest CT observations of COVID-19 have demonstrated a typical radiologic course from initial bilateral and subpleural ground-glass opacities (GGOs) to a more extensive consolidation, with slow but gradual absorption of the lung lesions in survivors (7–11). However, residual pulmonary lesions, such as GGOs and parenchymal bands, have been observed in more than 90% of patients at hospital discharge (7,9). Because coronavirus infection can result in diffuse alveolar exudation and can lead to fatal acute respiratory distress syndrome (ARDS), postinfection sequelae, such as lung fibrosis, are a concern (12,13). Focal lung fibrosis seen at chest CT has been observed in patients who have recovered from SARS, even after a 7-year follow-up (14,15). Although lung lesions mostly resolve in COVID-19 with mild to moderate severities, an autopsy study has confirmed lung organization and fibrosis in patients with fatal COVID-19, raising the possibility of permanent lung fibrosis sequelae in survivors with severe infection (7,16). In some patients with COVID-19, fibrotic sequelae, including traction bronchiectasis, parenchymal bands, and “honeycombing,” have been observed in more than one-third of participants with severe COVID-19 at 6 months after symptom onset (7,17). However, it is unknown whether COVID-19 survivors develop lung fibrosis after a long follow-up period and whether risk factors at presentation are predictive of long-term loss of function. If so, chest CT could potentially

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help identify patients who might benefit from early antifibrotic therapy (18). The purpose of our study was to evaluate serial chest CT examinations for the 1-year temporal evolution of radiologic findings after COVID-19 infection.

Materials and Methods

This study was approved by the Ethics Committees of Union Hospital of Tongji Medical College at Huazhong University of Science and Technology (serial no. 2020–0026) and followed the 1964 Helsinki Declaration and its later amendments. All study participants provided informed consent.

Study Sample

We prospectively evaluated participants with COVID-19 consecutively discharged from two isolation centers (ie, Western Campus and Zhanhuaou Fangcang Shelter Hospitals, affiliated with Union Hospital of Tongji Medical College at Huazhong University of Science and Technology) between January 27, 2020, and March 31, 2020. This cohort included participants reported in a previous study that involved only data at admission and discharge for the longitudinal analysis in our study (7). The criteria for diagnosis, therapy, and discharge followed the nationally standardized protocols (19). Patients with a respiratory rate greater than 30 breaths per minute or an oxygen saturation of 93% or less while breathing room air were classified as having severe COVID-19, whereas ARDS was diagnosed when the ratio of arterial partial pressure of oxygen to fraction of inspired oxygen was 300 mm Hg or less (19–21). The inclusion criteria were as follows: (a) age 18 years or older; (b) no medical history of pulmonary, autoimmune, or malignant disease; (c) COVID-19 survivors who underwent hospitalized treatment; (d) chest CT performed at admission and discharge; (e) chest CT at discharge showing residual lung lesions related to COVID-19; and (f) voluntary, written informed consent for chest CT follow-up. We excluded participants who dropped out of the study, had a subsequent positive result after a COVID-19 nucleic acid test, or acquired an additional lung infection after discharge.

Chest CT Protocol

Unenhanced chest CT examinations were performed using the same commercial CT scanner (Ingenuity Core 128, Philips Medical Systems). Images were obtained during breath holding at full inspiration. The fixed tube voltage was set to 120 kVp with adaptive current modulation, resulting in a mean volume CT dose index of 7.1 mGy ± 2.2 (standard deviation) (range, 3.1–12.2 mGy) and a dose-length product of 286.0 mGy ∙ cm ± 97.2 (range, 99.2–506.3 mGy ∙ cm). Other acquisition parameters were as follows: pitch, 0.999; collimation, 64 × 0.625 mm; gantry rotation time, 0.75 second; and DoseRight (Philips) index, 18. From the raw data, axial CT scans were reconstructed with a matrix size of

| Abbreviations |
|---------------|
| ARDS = acute respiratory distress syndrome, GGO = ground-glass opacity, SARS = severe acute respiratory syndrome |

Summary

One year after COVID-19 diagnosis, chest CT scans showed persistent abnormalities in 53 of 209 adult study participants (25%).

Key Results

- A total of 209 individuals who had been hospitalized with COVID-19 underwent serial chest CT examinations at approximately 3, 7, and 12 months.
- CT scans obtained at 1-year follow-up showed one of three patterns—complete resolution (156 of 209 participants [75%]), residual linear opacities (25 of 209 participants [12%]), or multifocal reticular or cystic lesions (28 of 209 participants [13%]).
- Independent risk factors for long-term chest CT changes at 1 year included age 50 years or older, lymphopenia, and severe or aggravation of acute respiratory distress syndrome (odds ratio = 15.9, 18.9, and 43.9, respectively; P < .001 for each comparison).

Figure 1: Flowchart of participant inclusion. ARDS = acute respiratory distress syndrome.

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Table 1: Basic Characteristics of Study Sample

| Characteristic                          | Value              |
|----------------------------------------|--------------------|
| Age (y)*                                | 49 ± 13 (20–82)    |
| Sex                                     |                    |
| Men                                    | 93/209 (45)        |
| Women                                  | 116/209 (56)       |
| Comorbidity                             |                    |
| Hypertension                           | 28/41 (68)         |
| Type 2 diabetes mellitus               | 13/41 (32)         |
| Coronary heart disease                 | 11/41 (27)         |
| Smoking history                         |                    |
| Initial symptom                         |                    |
| Fever                                  | 177/209 (85)       |
| Cough                                  | 91/209 (44)        |
| Chest distress                          | 25/209 (12)        |
| Fatigue                                | 27/209 (13)        |
| Myalgia                                | 15/209 (7)         |
| Headache                               | 5/209 (2.4)        |
| Diarrhea                               | 2/209 (1.0)        |
| Time between admission and initial      | 6.9 ± 4.4 (1.0–18.0)|
| symptom onset (d)*                     |                    |
| COVID-19 severity                       |                    |
| Pneumonia                              | 107/209 (51)       |
| Severe pneumonia                       | 80/209 (38)        |
| Acute respiratory distress syndrome    | 22/209 (11)        |
| Length of hospital stay (d)*           | 24.8 ± 13.3 (5.0–80.0) |
| Laboratory results at admission†       |                    |
| White blood cell count (×10³/L)        | 6.07 ± 2.67 (2.25–21.00) [3.50–9.50] |
| Lymphocyte count (×10³/L)              | 1.13 ± 0.42 (0.26–3.10) [1.10–3.20] |

(Table 1 continues)

512 × 512 (thickness of 1.5 mm and interval of 1.5 mm) using iterative reconstruction (iDose level 5, Philips Healthcare).

Serial Chest CT Assessments

Chest CT data at admission and discharge were retrospectively collected from the institutional picture archiving and communication system (version 11.3.5.8902, Vue PACS; Carestream Health). In addition, three serial chest CT examinations were performed at 3, 7, and 12 months since initial symptom onset. Visual assessments were independently performed by three senior radiologists (B.L., L.Y., and C.Z., with 26, 23, and 27 years of clinical experience in thoracic radiology, respectively). Afterward, any disagreement was resolved by discussion and consensus. Three radiologists were blinded to the clinical progress of all participants. Abnormalities were described using the standard terms defined in the Fleischner Society glossary and peer-reviewed literature (Fig E1 [online]) (7,8,11,17,22–24). Complete resolution was defined as the disappearance of any COVID-19–related lung abnormalities at chest CT (7). The distribution of lung lesions was categorized as a subpleural, diffuse, or random distribution (8). Following the methods in previous studies of COVID-19, we used the same semiquantitative CT scoring system to estimate the involvement of the lung lesions in each lobe from 0 to 5 points (ie, 0, no lesion; 1, <5%; 2, 5%–25%; 3, 26%–49%; 4, 50%–75%; 5, >75%) (8,17,25). The sum of the CT score in each lobe was calculated as the total CT score, ranging from 0 to 25. At 12 months after symptom onset, participants with or without residual CT abnormalities were compared.

Statistical Analysis

All statistical analyses were performed using SPSS statistics software (version 26, IBM). Quantitative and counting data were presented as means ± standard deviations, with ranges and the percentages of the total, respectively. Mann-Whitney tests were performed to estimate continuous variables between different groups according to the nonnormal distribution assessed with the Shapiro-Wilk tests. We performed χ² tests to evaluate categoric variables between different groups. The Fisher exact test was performed instead of a χ² test if the expected count was less than five. Univariable and multivariable logistic regression analyses (ie, forward conditional method) were used to investigate the independent risk factors for chronic CT changes after 1 year, and odds ratios with 95% CIs were calculated. Linear mixed models of repeated measures were established to estimate the fixed effects of the time and participant grouping on the number of involved lung lobes and total CT score changes after 1 year, and odds ratios with 95% CIs were calculated.
using type III tests. Further intertime point comparisons were performed using Bonferroni adjustments. Statistical significance was defined as two-tailed \( P < .001 \).

**Results**

**Characteristics of Study Sample**

A total of 2171 patients discharged from the hospital were screened for our study. Of these, 209 participants were included in the final analysis, 1063 patients were excluded owing to the lack of chest CT at admission, and 285 patients were excluded because of complete resolution of CT abnormalities at discharge (Fig 1). During follow-up, 15 patients were excluded because of study dropout, and three were excluded because of secondary lung infection (Fig 1). The mean age of participants was 49 years 6 13 (range, 20–82 years), with a 1:1.25 male-to-female ratio. Twenty percent of participants (41 of 209) had comorbidities, including hypertension, type 2 diabetes mellitus, and coronary heart disease. Four of 209 participants (2%) had a history of smoking. The mean interval between symptom onset and admission was 6.9 days 4 4.4 (range, 1.0–18.0 days). Pneumonia, severe pneumonia, and ARDS were diagnosed in 107 (51%), 80 (38%), and 22 (11%) participants, respectively. All participants who developed ARDS underwent mechanical ventilation in an intensive care unit. The mean hospitalized period was 24.8 days 13.3 (range, 5.0–80.0 days). The chest CT examinations at admission and discharge were performed at 6.3 days 4 4.5 and 28.3 days 13.8 after symptom onset, respectively. The detailed information is summarized in Table 1.

**Visual CT Assessments**

The complete resolution rate gradually increased over time from 61% (128 of 209 participants) at 3 months to 75% (156 of 209 participants) at 12 months after symptom onset (Fig 2A and Table E1 [online]). At admission, GGOs (201 of 209 participants [96%]), consolidation (124 of 209 participants [59%]), and “crazy paving” pattern (53 of 209 participants [25%]) were the most common findings (Fig 2B and Table E1 [online]). Thereafter, consolidation and crazy paving gradually improved over time, whereas other pulmonary abnormalities, including GGOs, parenchymal bands, reticular lesions, bronchial dilation, and volume loss, tended to increase after admission but started to resolve after discharge (Fig 2B and Table E1 [online]). However, at 3 months after symptom onset, CT abnormalities had stabilized except for GGOs and parenchymal bands, which gradually resolved (Fig 2B and Table E1 [online]). Nevertheless, GGOs were the predominant radiologic pattern throughout (Fig 2C and Table E1 [online]). The mean total CT score and the number of involved lung lobes gradually decreased from admission (9.7 7.0 and 3.7 1.5, respectively) to 12 months (1.8 3.9 and 0.9 1.7, respectively) after symptom onset (\( P < .001 \) for both) (Fig 2D, Table E1 [online]).
After 3 months, the decrease in mean total CT score and mean number of involved lung lobes became nonsignificant ($P \geq 0.33$ and $P \geq .06$, respectively) (Fig 2D).

**Comparisons between Participants with or without Complete Resolution at 12 Months**

Participants were divided into two groups based on the CT abnormalities at 12 months after symptom onset—participants with complete resolution (156 of 209 participants [75%]) (Fig 3) and participants with residual CT abnormalities (53 of 209 participants [25%]) (Figs 4, 5). In participants with complete resolution, no recurrent pulmonary abnormalities were observed at further follow-up after complete resolution was initially achieved (Fig 3). Age, previous comorbidities, COVID-19 severities, time between admission and symptom onset, hospitalized period, lymphocyte count, lactate dehydrogenase level, albumin level, number of involved lobes, and total CT score at admission all demonstrated differences between the two groups ($P \leq .001$ for each comparison) (Tables 2, 3). Age 50 years or older, lymphopenia, and severe or aggravation of ARDS were independent risk factors for residual CT abnormalities at 1 year (odds ratio = 15.9, 18.9, and 43.9, respectively; $P < .001$ for each comparison) (Table 4).

Diffuse consolidation was more common at chest CT at admission and discharge in participants with residual CT abnormalities than in those with complete resolution (Table 3). At discharge, complicated CT abnormalities, including reticular lesions, bronchial dilation, and volume loss, were more commonly observed in participants with residual CT abnormalities than in participants with complete resolution, whereas predominant GGOs were common to both groups (Table 3). Over time, the total CT score and number of involved lung lobes gradually decreased, with statistically significant improvements at 3 months (Fig 6) but were higher in participants with residual CT abnormalities than participants with complete resolution (Table E2 [online]). Noticeably in participants with complete resolution, reticular lesions (21 of 156 participants [14%]) and bronchial dilation (18 of 156 participants [12%]) were observed at discharge but had almost completely resolved at 3 months (Fig 6 and Fig E2 [online]). In participants with residual...
CT abnormalities, reticular lesions (41 of 53 participants [77%]) and bronchial dilation (39 of 53 participants [74%]) observed at discharge were incompletely resorbed and persisted in 53% (28 of 53) and 45% (24 of 53) of participants at 12 months, respectively (Figs 4–6; Table E2 [online]).

**Different Residual Abnormalities at 12 Months**

On the basis of the different residual CT abnormalities at 12 months, participants could be further divided into two subgroups (Table E3 [online]): participants with residual linear opacities (25 of 53 participants [47%]) and those with multifocal reticular or cystic lesions (28 of 53 participants [53%]). Participants with residual linear opacities demonstrated gradual resolution of pulmonary lesions since discharge, leaving residual parenchymal bands or thin linear opacities (Fig 4; Figs E3, E4 [online]; Table E4 [online]). In contrast, participants with multifocal reticular or cystic lesions presented persistent subpleural reticular or cystic lesions at follow-up (Fig 5; Figs E4, E5, and Table E4 [online]). At 12 months, the total CT score was 3.9 ± 2.6 versus 10.1 ± 4.3, and the number of involved lung lobes was 2.6 ± 1.0 versus 4.5 ± 1.2 in participants with residual linear opacities and multifocal reticular or cystic lesions, respectively ($P < .001$ for both comparisons) (Tables E3, E4 [online]). However, the improvements in total CT scores in both subgroups were observed at 3 months after symptom onset ($P < .001$) (Fig E4 [online]).

**Discussion**

This study analyzed the chest CT patterns of 209 participants with COVID-19 over 1 year after symptom onset. On the basis of the CT findings at 12 months, participants could be categorized into three groups—complete resolution (156 of 209 [75%]), residual linear opacities (25 of 209 [12%]), and multifocal reticular or cystic lesions (28 of 209 [13%]). Complete resolution mainly occurred in the first 3 months after symptom onset (128 of 209 [61%]). After 3 months, residual lesions became increasingly persistent, highlighted by the insignificant decrease in total CT score from 2.7 ± 4.6 to 1.8 ± 3.9 at 3 and 12 months, respectively ($P = .33$). Compared with par-
Participants with complete resolution, participants with residual linear opacities or multifocal reticular or cystic lesions demonstrated extensive and diffusive pulmonary involvement at admission (total CT score, 16.0 ± 6.5 vs 7.5 ± 5.8; P < .001). Independent risk factors for these residual CT abnormalities at 1 year included age 50 years or older, lymphopenia, and severe or aggravation of acute respiratory distress syndrome. Similar to previous studies, bilateral subpleural GGOs with partial consolidation and GGOs with parenchymal bands were the most frequent CT findings at admission and discharge, respectively (7–9,11). Any consolidation at admission had been gradually absorbed, typically with a “melting sugar” pattern of resorption whereby the density of consolidation gradually decreases to GGO, but the lesion volume initially enlarges (7,17). After 1 year, complete resolution was observed in 98% of participants with moderate pneumonia (105 of 107) but only in 50% of participants with severe pneumonia or ARDS (51 of 102) (P < .001), corroborating the findings of a previous study (7). We found that older age, lymphopenia, and severe or aggravation of ARDS, which correlated with mortality, were risk factors of residual CT abnormalities (4,10,26,27).

The presence of multifocal reticular or cystic lesions at discharge was persistent in 28 participants and was accompanied by bronchial dilation in 24 of the 28 participants (86%). Although some articles prompted a potential correlation between mechanical ventilation and these changes, we observed that a high proportion of these participants (12 of 28 [43%]) did not undergo mechanical ventilation therapy (12,17,28,29). Thus, our results suggest that multiple factors contribute to the development of these interstitial lesions and that mechanical ventilation and ARDS are not the only factors.

In a previous study involving 114 participants with severe COVID-19, residual CT abnormalities, including GGO, bronchial dilation, parenchymal bands, and honeycombing, were observed in 62% of recovered participants (71 of 114) after 6 months (17). These CT abnormalities were the typical manifestations of interstitial fibrosis (22,30,31). Our study found a lower rate (25% [53 of 209]) of participants demonstrating CT abnormalities after 1 year (17). Several reasons could explain this difference. First, the previous study included only patients with severe COVID-19, but our participants had COVID-19 of differing severities (17). However, the number of patients...
with severe pneumonia or ARDS was similar between the two studies (83 vs 80 patients and 31 vs 22 patients, respectively) (17). Second, we excluded participants with previous chronic lung disease; their inclusion in the previous study may lead to misjudgments of the lung sequelae not genuinely caused by COVID-19. As a potential indicator of this, predominant reticular lesions, bronchiectasis, and honeycombing were reported in COVID-19 are likely permanent (15,38). Third, systematic radiologic follow-up. However, considering that residual lesions are far from straightforward, and the limited follow-up period is unknown whether these CT abnormalities will regress after a longer follow-up, thereby meritting further clinical and radiologic follow-up. However, considering that residual lesions rarely change after 1 year in SARS, these CT abnormalities in COVID-19 are likely permanent (15,38). Third, systematic

| Table 2: Comparison of Characteristics between Two Groups |
|---------------------------------------------|
| Characteristic                                | Participants with Complete Resolution at 12 Months (n = 156) | Participants with Residual CT Abnormalities at 12 Months (n = 53) | P Value |
| Age (y)*                                      | 46 ± 12 (20–82)                                               | 60 ± 10 (31–82)                                               | <.001   |
| <50                                          | 6 (64)                                                       | 6 (11)                                                       | <.001   |
| ≥50                                          | 57 (37)                                                      | 47 (89)                                                      | <.001   |
| Sex                                          |                                                             |                                                             | .89     |
| Men                                          | 69 (44)                                                      | 24 (45)                                                      | <.001   |
| Women                                        | 87 (56)                                                      | 29 (55)                                                      | .89     |
| Comorbidity                                  | 20 (13)                                                      | 21 (40)                                                      | <.001   |
| COVID-19 severity                            |                                                             |                                                             | .001    |
| Pneumonia                                    | 105 (67)                                                     | 2 (3.8)                                                      | <.001   |
| Severe pneumonia                             | 50 (32)                                                      | 30 (57)                                                      | .001    |
| Acute respiratory distress syndrome          | 1 (0.6)                                                      | 21 (40)                                                      | <.001   |
| Time from admission to symptom onset (d)*    | 6.2 ± 4.3 (1.0–17.0)                                          | 9.1 ± 4.1 (1.0–18.0)                                          | <.001   |
| ≤7                                          | 107 (69)                                                     | 21 (40)                                                      | <.001   |
| >7                                          | 49 (31)                                                      | 32 (60)                                                      | <.001   |
| Length of hospital stay (d)*                 | 21.0 ± 9.1 (5.0–55.0)                                         | 36.1 ± 17.0 (11.0–80.0)                                       | <.001   |
| Laboratory results at admission              |                                                             |                                                             |         |
| Lymphocyte count (×10³/L)*                   | 1.28 ± 0.36 (0.55–3.10)                                       | 0.81 ± 0.37 (0.26–1.89)                                       | <.001   |
| <1.10                                       | 20 (13)                                                      | 38 (72)                                                      | <.001   |
| ≥1.10                                       | 136 (87)                                                     | 15 (28)                                                      | <.001   |
| Lactate dehydrogenase level (U/L)*           | 198 ± 64 (98–480)                                             | 352 ± 247 (119–1633)                                         | <.001   |
| ≤245                                        | 140 (90)                                                     | 27 (51)                                                      | <.001   |
| >245                                        | 16 (10)                                                      | 26 (49)                                                      | <.001   |
| Albumin level (g/L)*                         | 35.6 ± 6.0 (22.0–47.7)                                        | 30.8 ± 6.6 (20.1–49.6)                                       | <.001   |
| <33                                         | 30 (19)                                                      | 32 (60)                                                      | <.001   |
| ≥33                                         | 126 (81)                                                     | 21 (40)                                                      | <.001   |

Note.—Except where indicated, data are numbers of participants, with percentages in parentheses. P values comparing participants with complete resolution and participants with residual CT abnormalities were determined using the Mann-Whitney U test or χ² test.

* Numbers are means ± standard deviations, with ranges in parentheses.

with severe pneumonia or ARDS was similar between the two studies (83 vs 80 patients and 31 vs 22 patients, respectively) (17). Second, we excluded participants with previous chronic lung disease; their inclusion in the previous study may lead to misjudgments of the lung sequelae not genuinely caused by COVID-19. As a potential indicator of this, predominant reticular lesions (14%), bronchiectasis (11%), and honeycombing (1.8%) at admission were reported previously, which we did not corroborate (17). Our study also found that focally subpleural reticular or cystic lesions and bronchial dilation could be observed at discharge in 30% of the participants (62 of 209) but resolved in more than half of participants within the first 3 months, indicating remodeling of immature fibrosis (12,23). Reversal of these CT abnormalities has also been observed in SARS, other diffuse alveolar damage, and organizing pneumonia (23,32,33). Similar to the findings in SARS, we observed persistent but very focally reticular or cystic lesions only in a small portion of participants with severe COVID-19 and ARDS (15). However, the differentiation of true, irreversible fibrosis from reversible lesions is far from straightforward, and the limited follow-up period in previous studies might result in the overdiagnosis of fibrosis (13,34,35). For these reasons, we avoided radiologic terms such as “traction bronchiectasis,” “honeycombing,” and “reticular pattern” for their association with genuine lung fibrosis. Instead, we used the terms “bronchial dilation,” “subpleural cystic lesions,” and “reticular lesions,” which were reported to be partially reversible (12,17,22,24).

Our study had limitations. First, there were selection biases. Thousands of discharged participants were excluded because of a lack of chest CT data at admission. The high mortality rate among critically ill participants with COVID-19 had led to the enrollment of only 22 survivors of ARDS (22 of 209 [11%]) (36). Because of the exclusion of participants with previous pulmonary disease, a relatively young cohort (mean age, 49 years) with a low rate of smoking history (1.9%) was reported. Although our approach permitted lung abnormalities to be more definitively attributed to COVID-19, we may have underestimated the long-term effect of COVID-19 on the general population, especially in older patients and patients with a smoking history or previous lung diseases, who probably have more common or more severe lung sequelae (37). Second, it is unknown whether these CT abnormalities will regress after a longer follow-up, thereby meriting further clinical and radiologic follow-up. However, considering that residual lesions rarely change after 1 year in SARS, these CT abnormalities in COVID-19 are likely permanent (15,38). Third, systematic
Table 3: Comparison of CT Findings between Two Groups at Admission and Discharge

| Finding                                           | Participants with Complete Resolution at 12 Months (n = 156) | Participants with Residual CT Abnormalities at 12 Months (n = 53) | P Value |
|---------------------------------------------------|------------------------------------------------------------|---------------------------------------------------------------|---------|
| Chest CT at admission                              |                                                            |                                                               |         |
| Pulmonary involvement                              |                                                            |                                                               |         |
| Unilateral                                        | 31 (20)                                                    | 3 (5.7)                                                       | .02     |
| Bilateral                                         | 125 (80)                                                   | 50 (94)                                                      | .02     |
| Pulmonary lesion distribution                      |                                                            |                                                               |         |
| Subpleural                                        | 127 (81)                                                   | 20 (38)                                                      | <.001   |
| Diffuse                                           | 20 (13)                                                    | 31 (59)                                                      | <.001   |
| Random                                            | 9 (5.8)                                                    | 2 (3.8)                                                      | .733    |
| Chest CT abnormality                               |                                                            |                                                               |         |
| Ground-glass opacity                              | 148 (95)                                                   | 53 (100)                                                     | .21     |
| “Crazy paving” pattern                            | 33 (21)                                                    | 20 (38)                                                      | .02     |
| Consolidation                                     | 81 (52)                                                    | 43 (81)                                                      | <.001   |
| Predominant CT abnormality                         |                                                            |                                                               |         |
| Ground-glass opacity                              | 97 (62)                                                    | 23 (43)                                                      | .02     |
| “Crazy paving” pattern                            | 14 (9.0)                                                   | 8 (15)                                                       | .21     |
| Consolidation                                     | 45 (29)                                                    | 22 (42)                                                      | .09     |
| No. of lobes involved*                             | 3.4 ± 1.6 (1.0–5.0)                                         | 4.7 ± 0.9 (1.0–5.0)                                          | <.001   |
| <5                                                | 93 (60)                                                    | 8 (15)                                                       | <.001   |
| 5                                                 | 63 (40)                                                    | 45 (85)                                                      | <.001   |
| Total CT score*                                   | 7.5 ± 5.8 (1.0–24.0)                                         | 16.0 ± 6.5 (2.0–25.0)                                        | <.001   |
| ≤10                                               | 118 (76)                                                   | 8 (15)                                                       | <.001   |
| >10                                               | 38 (24)                                                    | 45 (85)                                                      | <.001   |
| Chest CT at discharge                              |                                                            |                                                               |         |
| Pulmonary involvement                              |                                                            |                                                               |         |
| Unilateral                                        | 33 (21)                                                    | 0 (0.0)                                                      | <.001   |
| Bilateral                                         | 123 (79)                                                   | 53 (100)                                                     | <.001   |
| Pulmonary lesion distribution                      |                                                            |                                                               |         |
| Subpleural                                        | 135 (87)                                                   | 23 (43)                                                      | <.001   |
| Diffuse                                           | 14 (9.0)                                                   | 29 (55)                                                      | <.001   |
| Random                                            | 7 (4.5)                                                    | 1 (1.9)                                                      | .68     |
| Chest CT abnormality                               |                                                            |                                                               |         |
| Ground-glass opacity                              | 156 (100)                                                  | 52 (98)                                                      | .25     |
| Consolidation                                     | 15 (9.6)                                                   | 22 (42)                                                      | <.001   |
| Parenchymal band                                  | 99 (64)                                                    | 53 (100)                                                     | <.001   |
| Reticular lesion                                  | 21 (14)                                                    | 41 (77)                                                      | <.001   |
| Bronchial dilation                                | 18 (12)                                                    | 39 (74)                                                      | <.001   |
| Volume loss                                       | 11 (7.1)                                                   | 17 (32)                                                      | <.001   |
| Subpleural cystic lesion                          | 2 (1.3)                                                    | 16 (30)                                                      | <.001   |
| No. of lobes involved*                             | 3.3 ± 1.5 (1.0–5.0)                                         | 4.8 ± 0.6 (2.0–5.0)                                          | <.001   |
| <5                                                | 105 (67)                                                   | 9 (17)                                                       | <.001   |
| 5                                                 | 51 (33)                                                    | 44 (83)                                                      | <.001   |
| Total CT score*                                   | 5.9 ± 4.4 (1.0–24.0)                                         | 14.9 ± 5.6 (3.0–25.0)                                        | <.001   |
| ≤10                                               | 139 (89)                                                   | 15 (28)                                                      | <.001   |
| >10                                               | 17 (11)                                                    | 38 (72)                                                      | <.001   |

Note.—Except where indicated, data are numbers of participants, with percentages in parentheses. P values comparing participants with complete resolution and participants with residual CT abnormalities were determined using the Mann-Whitney U test, χ² test, or Fisher exact test.
* Numbers are means ± standard deviations, with ranges in parentheses.

use of pulmonary function testing was not performed because of use restrictions during the pandemic. This limits our understanding of the functional consequences of CT findings.

In conclusion, 1 year after COVID-19 diagnosis, three chest CT patterns (ie, complete resolution, residual linear opacities, and multifocal reticular or cystic lesions) could be observed, with complete resolution being the most common. Some of the fibrotic lung changes demonstrated at discharge partially resolved over time, predominantly between discharge and 3 months after symptom onset. Persistent chest CT
abnormalities were more likely to occur in older patients with severe pneumonia, acute respiratory distress syndrome, and lymphopenia. Further studies are needed to determine whether these chest CT findings 1 year after COVID-19 infection are associated with a permanent loss of lung function.

**Table 4: Relationship of Risk Factors with Residual CT Abnormalities after 1 Year**

| Risk Factor                                | Univariable Analysis | Multivariable Analysis |
|--------------------------------------------|----------------------|------------------------|
|                                            | Odds Ratio*          | P Value                |
| Age (y) (≥50 vs <50)                       | 13.6 (5.5, 33.8)     | <.001                  |
| Comorbidity (yes vs none)                  | 4.5 (2.2, 9.2)       | <.001                  |
| COVID-19 severity                          |                      |                        |
| Severe or aggravation of ARDS vs moderate pneumonia | 52.5 (7.2, 137.1)    | <.001                  |
| Lymphocyte count (×10^9/L) (<1.1 vs ≥1.10) | 17.2 (8.1, 36.8)     | <.001                  |
| Lactate dehydrogenase level (U/L) (>245 vs ≤245) | 8.4 (4.0, 17.8)     | <.001                  |
| Albumin level (g/L) (<33 vs ≥33)           | 6.4 (3.2, 12.6)      | <.001                  |
| No. of lobes involved (5 vs <5)            | 8.3 (3.7, 18.8)      | <.001                  |
| Total CT score (>10 vs ≤10)                | 17.5 (7.6, 40.3)     | <.001                  |

*Numbers in parentheses are 95% CIs.

Note.—ARDS = acute respiratory distress syndrome.

**Figure 6:** Graphs depict dynamic CT changes over time between participants with complete resolution and residual CT abnormalities at 12 months. Graphs show (A) significant differences in total CT score, (B) number of involved lung lobes, (C) percentages of reticular lesions, and (D) percentage of bronchial dilation between the two groups at each time point. Standard deviation bar is shown in (A) and (B). Linear mixed model of repeated measures was established to estimate fixed effects of time and grouping on total CT score (A) and number of involved lung lobes (B) using type III tests, and P values of multiple comparisons were obtained using Bonferroni adjustments. Significant decreases of mean total CT score (A) and number of involved lung lobes (B) in both groups were seen at 3 months (P < .001 for each comparison). Over time, total CT score (A) and number of involved lung lobes (B) gradually decreased but were higher in participants with residual CT abnormalities than in participants with complete resolution (P < .001 for both comparisons).

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