Rate of True-Positive Findings of COVID-19 Typical Appearance at Chest CT per RSNA Consensus Guidelines in an Increasingly Vaccinated Population

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

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Background: RSNA consensus guidelines for COVID-19–related chest CT are widely used but, to the knowledge of the authors, their rate of true-positive findings for COVID-19 pneumonia in vaccinated patients has not been assessed.

Purpose: To assess the rate of true-positive findings of typical appearance for COVID-19 at chest CT by using RSNA guidelines in fully vaccinated patients with polymerase chain reaction (PCR)-confirmed COVID-19 infection compared with unvaccinated patients.

Materials and Methods: Included were patients with COVID-19 who had typical appearance on chest CT images and one PCR test for COVID-19 with a positive result or two tests with negative results within 7 days of undergoing chest CT between January 2021 and January 2022 at a quaternary academic medical center. True-positive findings were defined as chest CT images interpreted as COVID-19 typical appearance and PCR-confirmed COVID-19 infection within 7 days. Logistic regression models were constructed to quantify the association between PCR results and vaccination status, vaccination status and COVID-19 variants, and vaccination status and number of months.

Results: Included were 652 patients (median age, 59 years; IQR, 48–72 years; 371 men [57%]) with CT scans classified as typical appearance. Of those patients, 483 (74%) were unvaccinated and 169 (26%) were fully vaccinated. The overall rate of true-positive findings on CT images rated as typical appearance was lower in vaccinated versus unvaccinated patients (70 of 169 [41%; 95% CI: 34, 49] vs 352 of 483 [73%; 95% CI: 69, 77]); odds ratio [OR], 3.8 [95% CI: 2.6, 5.5]; P < .001). Unvaccinated patients were more likely to have true-positive findings on CT images compared with fully vaccinated patients during the peaks of COVID-19 variants Alpha (OR, 16; 95% CI: 6, 42; P < .001) and Delta (OR, 8; 95% CI: 4, 16; P < .001), but no statistical differences were found during the peak of the Omicron variant (OR, 1.7; 95% CI: 0.3, 11; P > .56).

Conclusion: Fully vaccinated patients with confirmed COVID-19 breakthrough infections had lower rates of true-positive findings of COVID-19 typical appearance at chest CT.

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Supplemental material is available for this article

The COVID-19 pandemic continues to cause substantial morbidity and mortality worldwide despite the development of vaccines that are proven to be effective in reducing the risk of severe illness. This partly because of heterogeneity of vaccination in the general population, waning vaccine immunity leading to breakthrough infections, and the rise of highly contagious variants of concern (VOCs) such as Delta and Omicron (1–5).

Nucleic acid amplification testing with the reverse transcription polymerase chain reaction (PCR) has been the reference standard in detecting COVID-19 infections due to the high sensitivity and specificity. However, false-negative rates have been reported from less than 5% to 40% depending on test type and specimen quality (6,7). Radiology, particularly chest CT, has had a central role in this pandemic. CT has been used in diagnosis, triage, and outcomes assessment in patients who present with COVID-19 pneumonia (8). To aid in these efforts, the RSNA released consensus guidelines to standardize reporting of chest CT findings related to COVID-19 pneumonia in patients suspected of having or who have confirmed COVID-19 infection (9). These guidelines classify chest CT findings of COVID-19 pneumonia into four categories and have been widely adopted across radiology practices worldwide (8).

The RSNA guidelines were developed before COVID-19 tests and vaccines were widely available. Since 2021, COVID-19 test results have often been available before the radiologists interpret the CT scan. Our institution continues to use the RSNA COVID-19 classification system in patients with and without COVID-19 PCR results for triage and placement of patients who may have
COVID-19 to prevent spread of the virus in the hospital setting. Although chest CT is an important component in the evaluation of patients to detect occult COVID-19 infections given the rate of false-negative PCR findings, the applicability of the use of chest CT and reporting guidelines in an increasingly vaccinated population has not been well characterized. Therefore, the purpose of our study was to assess whether vaccination influences the true-positive rate of CT in diagnosis of COVID-19 pneumonia by evaluating the performance of typical appearance of COVID-19 at CT per the RSNA consensus guidelines in patients with PCR-confirmed COVID-19 infection.

Materials and Methods

Study Setting
Our retrospective cohort study, performed at a large quaternary academic medical center, is compliant with the Health Insurance Portability and Accountability Act was approved by the institutional review board with a waiver of informed consent.

Study Cohort
The institutional electronic database was queried for chest CT performed between January 2021 and January 2022 that contained the classification of RSNA typical appearance findings at chest CT for COVID-19 pneumonia (hereafter, COVID-19 typical) included in the radiology report. All COVID-19 typical results were identified with an institutional decision support reporting tool that uses the RSNA COVID-19 consensus guidelines. This tool was used to standardize reporting of chest CT findings, assist in triage of patients with confirmed COVID-19 or who are suspected of having COVID-19, and label each scan using one of four RSNA categories: negative for pneumonia, atypical appearance, indeterminate appearance, and typical appearance.

Study inclusion criteria were patients with chest CT findings that were COVID-19 typical (identified using the decision support reporting tool) and one positive or two negative PCR tests for COVID-19 within 7 days of undergoing chest CT.

For patients who underwent two chest CT examinations with COVID-19 typical results but from separate clinical encounters, only the earliest encounter was considered. Patients with only one negative test or no PCR test result for COVID-19 within 7 days of undergoing CT and patients with non–chest CT studies (ie, abdominal CT) that were COVID-19 typical were excluded.

Data Sources and Independent Variables
Demographic data, medical comorbidities, oxygen requirement (ie, supplemental oxygen use, no supplemental oxygen use, and intubation), and clinical status (ie, hospitalization, intensive care unit admission, emergency department visit, outpatient visit, and deceased at time of analysis) were extracted from the electronic medical record (Epic Hyperspace; Epic Systems Corporation). The following comorbidities were included based on Centers for Disease Control classification as risk factors for severe COVID-19: cancer history, chronic kidney disease, chronic obstrcutive pulmonary disease, diabetes, obesity, heart conditions (eg, heart failure, arrhythmias, and hypertension), and immunocompromised status (10,11).

Vaccination Status and Manifesting Symptoms
Documented vaccination status was obtained by electronic medical record review. Patients were considered fully vaccinated if they were 14 days or longer from a second mRNA-1273 (Moderna) or BNT162b2 (Pfizer-BioNTech) dose, or single Janssen (Johnson and Johnson) vaccine dose. Patients were considered fully boosted if 14 days or longer had passed since administration of their booster shot.

Reported symptoms up to a week before patients’ presentations were obtained by electronic medical record review. The most common symptoms associated with COVID-19 included cough, shortness of breath, fatigue, chills, chest pain, gastrointestinal complaints, myalgias, cognitive change, and fever (12).

COVID-19 Status and True-Positive Findings
By reviewing electronic medical record charts, COVID-19 status was defined as having one positive (COVID-19–positive infection) or two negative (COVID-19–negative infection) PCR tests for COVID-19 within 7 days of undergoing chest CT with a report that was COVID-19 typical. True-positive findings on CT scans were defined as PCR-positive scans with a chest CT report that was COVID-19 typical.

VOC Dominance
A VOC was considered dominant during a period when it represented more than 50% of all sequenced COVID-19 strains in Massachusetts. The VOCs include Alpha (January 1, 2021, to July 2, 2021), Delta (July 3, 2021, to December 24, 2021), and Omicron (December 25, 2021, to present).

Statistical Analysis
A random sample of eligible patients was used for analysis. Because of the previously reported institutional true-positive rate of 85% in unvaccinated patients, 400 unvaccinated and 200 vaccinated patients were needed to detect at least a 10%
decrease in the true-positive rate between vaccination status groups when using a one-sided two-sample test of proportions, type I error (α) of .05, and power (1 − β) of .9 (8).

Descriptive summaries were computed for the entire sample. Continuous variables were summarized as the median, and IQR and categorical variables were summarized as frequencies. Differences in the distributions of categorical and continuous variables by vaccination status were assessed using either the χ² and Fisher exact tests or the Wilcoxon test, respectively. Three logistic regression models were constructed to quantify the association between PCR results and vaccination status, vaccination status and the VOC peak at CT assessment, and vaccination status and calendar month. We considered accounting for patient age, but after adjusting for VOC peak, the inclusion of age did not improve the model fit and it was omitted. A second definition of vaccination status and VOC peak was used to investigate the effect of timings of CT and vaccination relative to the VOC peak. In vaccinated patients, we recoded VOC peak to include the VOC at times of CT imaging and vaccination (eg, the subgroup who were both administered the vaccine and underwent chest CT during the Alpha VOC). For all models, linear combinations of parameter estimates were computed to summarize true-positive rates by vaccination status and period (ie, overall, VOC peak, and calendar month), and vaccination status comparisons. All analyses were performed using statistical software (R version 4.2.0; R Foundation for Statistical Computing).

Results

Cohort Characteristics

The initial database query resulted in 2069 results, of which 652 met inclusion criteria (Fig 1) with COVID-19 typical findings at chest CT (Fig 2). The median patient age was 59 years (IQR, 48–72 years); 57% (371 of 652) were men, 65% (422 of 652) were positive for COVID-19 according to PCR test, and 26% (169 of 652) were fully vaccinated against COVID-19 with a median time from vaccination to COVID-19 typical at CT of 119 days (IQR, 55–193 days) (Table 1). The most common symptom (Table 1) was shortness of breath (72%; 469 of 652) and the most common comorbidity was hypertension (56%; 364 of 652). Most patients were hospitalized (58%; 377 of 652) and used supplemental oxygen (60%; 389 of 652; Table 1).

Among fully vaccinated patients, the majority were vaccinated with BNT162b2 (Pfizer-BioNTech; 62%; 104 of 169), whereas fewer were vaccinated with mRNA-1273 (Moderna; 25%; 42 of 169) and Janssen (Johnson and Johnson; 14%; 23 of 169). Compared with unvaccinated patients, fully vaccinated patients were significantly older (median age, 69 years [IQR, 56–79 years] vs 56 years [IQR, 46–68 years], respectively; P < .001), had higher rates of supplemental oxygen use (67% [113 of 169] vs 57% [276 of 483], respectively; P = .03), and had higher rates of hospitalization (68% [115 of 169] vs 54% [262 of 483], respectively; P = .002). Compared with unvaccinated patients, fully vaccinated patients had higher rates of many comorbidities associated with COVID-19 disease severity (10,11) (Table S1). Similarly, fully vaccinated patients with true-positive results compared with unvaccinated patients with true-positive results retained higher rates of most comorbidities and were more likely to be immunocompromised (39% [27 of 70] vs 11% [38 of 352]; P < .001; Table S2). Fully vaccinated patients in the group with true-positive results also had longer time from vaccination to COVID-19 typical CT scan (median, 175 days; IQR, 122–220 days) compared with patients with negative PCR tests (median, 70 days; IQR, 40–150 days; P < .001; Table 1). The most common final diagnoses of patients with negative PCR results from clinical encounters corresponding to their COVID-19 typical CT examinations were pulmonary edema (23%; 70 of 311), interstitial lung disease (13%; 40 of 311), and aspiration (12%; 39 of 311) (Fig S1).
Rates of True-Positive Findings of COVID-19

Overall, the rate of COVID-19 typical true-positive findings (Table 2) was higher in unvaccinated patients (73%; 352 of 483) compared with fully vaccinated patients (41%; 70 of 169; OR, 3.8; 95% CI: 2.6, 5.5; \( P < .001 \)). Rates of true-positive findings also varied with VOCs. Compared with fully vaccinated patients, unvaccinated patients had higher rates of true-positive findings during Alpha variant predominance (67% [95% CI: 62, 72] vs 11% [95% CI: 5, 25], respectively; OR, 16 [95% CI: 6, 42]; \( P < .001 \)) and Delta variant predominance (88% [95% CI: 81, 93] vs 47% [95% CI: 38, 57], respectively; OR, 8 [95% CI: 4, 16]; \( P < .001 \)), whereas differences in rates of true-positive findings were not detected between vaccination status groups during Omicron variant predominance (87% [95% CI: 60, 97] vs 79% [95% CI: 55, 92], respectively; OR, 1.7 [95% CI: 0.3, 11]; \( P = .56 \)).

In a monthly comparison of the rate of true-positive COVID-19 typical chest CT findings (Table 2), unvaccinated patients were more likely to have true-positive results on CT scans between April 2021 (OR, 20; 95% CI: 4, 94; \( P < .001 \)) and July 2021 (OR, 11; 95% CI: 1, 106; \( P = .04 \)). Between April 1, 2021, and July 1, 2021, the vaccination rate in Massachusetts...
rose from 20% to 60%, whereas COVID-19 cases decreased from 4750 to 61 cases between January 5 and July 1, 2021 (Fig 3). The months with no differences in rates of true-positive findings between fully vaccinated and unvaccinated patients coincided with the rise of dominant VOCs in August to October 2021 (Delta) and January 2022 (Omicron; Table 2).

### Table 1: Characteristics of Patients With COVID-19 Typical Appearance Findings at CT

| Patient Characteristic               | All Patients (n = 652) | COVID-19 PCR-Positive Results (n = 422) | COVID-19 PCR-Negative Results (n = 230) | P Value |
|--------------------------------------|------------------------|----------------------------------------|----------------------------------------|---------|
| **Demographic**                      |                        |                                        |                                        |         |
| Age (y)*                              | 59 (48–72)             | 57 (47–70)                             | 64 (50–75)                             | <.001†  |
| Female sex                           | 281 (43)               | 178 (42)                               | 103 (45)                               | .58     |
| COVID-19 PCR-positive                | 422 (65)               | ...                                    | ...                                    | ...     |
| Time from vaccination to CT (d)*     | 119 (55–193)           | 175 (122–220)                          | 70 (40–150)                            | <.001†  |
| **Presenting symptom**               |                        |                                        |                                        |         |
| Cough                                | 415 (64)               | 307 (73)                               | 108 (47)                               | <.001   |
| Shortness of breath                  | 469 (72)               | 317 (75)                               | 152 (66)                               | .02     |
| Fatigue                              | 223 (34)               | 171 (41)                               | 52 (23)                                | <.001   |
| Chills                               | 134 (21)               | 101 (24)                               | 33 (14)                                | .005    |
| Chest pain                           | 182 (28)               | 142 (34)                               | 40 (17)                                | <.001   |
| GI symptoms                          | 256 (39)               | 182 (43)                               | 74 (32)                                | .008    |
| Myalgia                              | 147 (23)               | 133 (32)                               | 14 (6)                                 | <.001   |
| Cognitive Change                     | 62 (10)                | 27 (6)                                 | 35 (15)                                | <.001   |
| Fever                                | 280 (43)               | 211 (50)                               | 69 (30)                                | <.001   |
| **Comorbidty**                       |                        |                                        |                                        |         |
| Current smoker                       | 70 (11)                | 27 (6)                                 | 43 (19)                                | <.001   |
| Never-smoker                         | 351 (54)               | 260 (62)                               | 91 (40)                                | <.001   |
| Hypertension                         | 364 (56)               | 211 (50)                               | 153 (67)                               | <.001   |
| Diabetes                             | 166 (26)               | 101 (24)                               | 65 (28)                                | .27     |
| Obesity                              | 264 (41)               | 182 (43)                               | 82 (36)                                | .08     |
| Heart failure                        | 83 (13)                | 31 (7)                                 | 52 (23)                                | <.001   |
| COPD                                 | 50 (8)                 | 22 (5)                                 | 28 (12)                                | .002    |
| History of malignancy                | 167 (26)               | 94 (22)                                | 73 (32)                                | .01     |
| Arrhythmias                          | 102 (16)               | 52 (12)                                | 50 (22)                                | .002    |
| Chronic kidney disease               | 91 (14)                | 43 (10)                                | 48 (21)                                | <.001   |
| Vaccination status                   |                        |                                        |                                        |         |
| Fully vaccinated                     | 169 (26)               | 70 (17)                                | 99 (43)                                | <.001   |
| Vaccinated with BNT162b2 (Pfizer-BioNTech)† | 104 (62)           | 38 (54)                                | 66 (67)                                | .18     |
| Vaccinated with mRNA-1273 (Moderna)†  | 42 (25)                | 19 (27)                                | 23 (23)                                | .18     |
| Vaccinated with Janssen (Johnson and Johnson)† | 23 (14)             | 13 (19)                                | 10 (10)                                | .18     |
| Boosted                              | 26 (4)                 | 9 (2)                                  | 17 (7)                                 | .003§   |
| Oxygen requirement                   |                        |                                        |                                        |         |
| No supplemental oxygen               | 158 (24)               | 117 (28)                               | 41 (18)                                | .01     |
| Supplemental oxygen                  | 389 (60)               | 247 (59)                               | 142 (62)                               | .48     |
| Intubation                           | 105 (16)               | 58 (14)                                | 47 (20)                                | .04     |
| Clinical status                      |                        |                                        |                                        |         |
| Hospital admission                   | 377 (58)               | 228 (54)                               | 149 (65)                               | .01     |
| ICU                                  | 169 (26)               | 104 (25)                               | 65 (28)                                | .36     |
| ED visit                             | 98 (15)                | 85 (20)                                | 13 (6)                                 | <.001§  |
| Outpatient visit                     | 8 (1)                  | 5 (1)                                  | 3 (1)                                  | >.99§   |
| Deceased                             | 87 (13)                | 39 (9)                                 | 48 (21)                                | <.001§  |

Note.—Unless otherwise indicated, data are numbers of patients and data in parentheses are percentages; unless otherwise indicated, P values were calculated with a χ² test. COPD = chronic obstructive pulmonary disease, ED = emergency department, GI = gastrointestinal, ICU = intensive care unit, PCR = polymerase chain reaction.

* Data are median; data in parentheses are IQR.
† P values were calculated with a Wilcoxon rank sum test.
‡ Percentages in parentheses are relative to the fully vaccinated group (n = 169).
§ P values were calculated with a Fisher exact test.
A secondary analysis explored the relationship between the true-positive rate based on predominant VOCs and time from vaccination to true-positive findings of COVID-19 typical at CT (Fig 3). The odds of having a true-positive result at chest CT during Delta predominance in unvaccinated patients was higher than in patients who were either vaccinated during the period of Delta predominance (OR, 22; 95% CI: 8, 66) or vaccinated during Alpha predominance (OR, 6; 95% CI: 3, 13). Fully vaccinated patients who were vaccinated during the period of Alpha predominance were more likely to have true-positive findings at CT when imaged during a period of Delta predominance (OR, 9; 95% CI: 3, 25) or Omicron predominance (OR, 39; 95% CI: 4, 405; estimated from values in Table 3) compared with patients who were also imaged during Alpha predominance.

Exploratory analyses of true-positive rates stratified by booster status from November 2021 to January 2022 were performed (Table S3). Unvaccinated patients were more likely to have true-positive results on CT scans compared with fully vaccinated patients in November 2021 (OR, 6.8; 95% CI: 1.1, 43; P = .043) and December 2021 (OR, 13; 95% CI: 2.3, 69; P = .003), and more likely to have true-positive results on CT scans compared with fully boosted patients during November 2021 (OR, 95; 95% CI: 7.7, 1180; P < .001) and December 2021 (fully boosted, zero of six; 0%; 95% CI: 0, 39).

Discussion

The RSNA consensus guidelines, adopted by many institutions, provided a standardized framework for interpreting and reporting findings at CT that are associated with COVID-19 pneumonia (8,9). Our study showed that in an increasingly vaccinated population, these guidelines provide valuable information for triage and disposition of patients who are evaluated for suspected or confirmed COVID-19 infections because unvaccinated patients had a higher overall true-positive rate of COVID-19 typical appearance (hereafter, COVID-19 typical) at chest CT compared with fully vaccinated patients (352 of 483 [73%; 95% CI: 69, 77] vs 70 of 169 [41%; 95% CI: 34, 49], respectively; odds ratio, 3.8 [95% CI: 2.6, 5.5]; P < .001). Additionally, the overall true-positive rate of 65% in all patients who at CT were COVID-19 typical during the study period at our institution represents a substantial decrease from the true-positive rate of 85% during the initial peak of the pandemic in 2020, which is likely because of the decrease in disease severity in vaccinated patients (8).

Breakthrough infections in vaccinated patients have been reported to have distinct imaging characteristics compared with those of unvaccinated patients, including higher rates of CT scans with findings that were negative for pneumonia or with mild severity scores (15–17). In one study (16), most patients were immunosuppressed and all but one patient with immunosuppression (80%) showed abnormalities at imaging.

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### Table 2: Rate of True-Positive Findings by Vaccination Status

| Parameter                      | Unvaccinated Patients with True-Positive Findings at CT | Fully Vaccinated Patients with True-Positive Findings at CT | Odds Ratio | P Value |
|-------------------------------|--------------------------------------------------------|------------------------------------------------------------|------------|---------|
| All variants                  | 352 (69, 77)                                            | 70 (169)                                                   | 3.8 (2.6, 5.5) | <.001   |
| Dominant VOC*                 |                                                        |                                                            |            |         |
| Alpha                         | 67 (62, 72)                                            | 11 (4.8, 25)                                               | 3.8 (2.6, 5.5) | <.001   |
| Delta                         | 88 (81, 93)                                            | 47 (38, 57)                                                | 16 (6.1, 42) | <.001   |
| Omicron                       | 87 (60, 97)                                            | 79 (55, 92)                                                | 8.3 (4.2, 16) | <.001   |
| Calendar month                |                                                        |                                                            |            |         |
| January 2021                  | 73 (54, 72)                                            | 25 (1, 70)                                                 | 16 (6.1, 42) | <.001   |
| February 2021                 | 65 (53, 75)                                            | 13 (4, 36)                                                 | 20 (4.1, 94) | <.001   |
| March 2021                    | 69 (57, 78)                                            | 25 (1, 70)                                                 | 6.6 (0.64, 67) | .11     |
| April 2021                    | 74 (62, 82)                                            | 13 (4, 36)                                                 | 20 (4.1, 94) | <.001   |
| May 2021                      | 73 (56, 86)                                            | 13 (4, 38)                                                 | 18 (3.3, 97) | .001    |
| June 2021                     | 50 (19, 81)                                            | 0 (0, 32)                                                  | 11 (1, 106) | .04     |
| July 2021                     | 67 (30, 90)                                            | 15 (4, 42)                                                 | 6.6 (0.64, 67) | .11     |
| August 2021                   | 84 (68, 93)                                            | 60 (39, 78)                                                | 3.8 (0.97, 13) | .06     |
| September 2021                | 94 (72, 100)                                           | 75 (47, 91)                                                | 5.0 (0.45, 56) | .19     |
| October 2021                  | 79 (52, 92)                                            | 59 (36, 78)                                                | 2.6 (0.52, 13) | .25     |
| November 2021                 | 91 (71, 97)                                            | 35 (19, 55)                                                | 18 (3.3, 97) | .001    |
| December 2021                 | 93 (79, 98)                                            | 40 (23, 59)                                                | 21 (4.1, 109) | <.001   |
| January 2022                  | 87 (62, 96)                                            | 88 (64, 97)                                                | 0.93 (0.11, 7.6) | .95     |

Note.—Unless otherwise indicated, data are percentages; data in parentheses are 95% CIs. Odds ratios indicate comparisons. All estimates were obtained via separate logistic regression models (all: COVID-19 polymerase chain reaction [PCR] status by vaccine status; dominant VOC: COVID-19 PCR status by vaccine status × phase; calendar month: COVID-19 PCR status by vaccine × month). Calendar periods were defined according to the dominant COVID-19 variant of concern (VOC) identified in Massachusetts (the dates are as follows: Alpha, January 1 to July 2, 2021; Delta, July 3 to December 24, 2021; Omicron, December 25 to present; and all variants, January 1, 2021, to January 31, 2022).

* Refers to dominant VOC at the time of imaging.
was concordant with previously published literature (16,18), showing that fully vaccinated patients were less likely to have COVID-19 typical true-positive findings at chest CT and were more likely to be immunocompromised compared with true-positive findings in unvaccinated patients. The increasing vaccination rates and evolving data may result in a decreased proportion of patients who present with COVID-19 typical true-positive findings at chest CT and may result in an update in RSNA COVID-19 reporting guidelines.

Rates of true-positive findings are influenced by disease prevalence in the population and are expected to fluctuate with factors that decrease or increase COVID-19 prevalence, such as vaccination rates or increased transmissibility of COVID-19 variants (19,20). For example, the Delta variant arose as the dominant-state VOC in mid-2021 and was more transmissible than the Alpha variant (4). This rise in the Delta VOC coincided with the increasing rate of true-positive findings in fully vaccinated patients between July and September 2021 (21). Omicron became the dominant-state VOC on December 25, 2021, and its mutations caused increased transmissibility, leading to more breakthrough cases in vaccinated patients (22–24). This may explain why there was no difference in the likelihood of COVID-19 typical true-positive findings at chest CT between fully vaccinated and unvaccinated patients during January 2022.

The monthly rate of true-positive findings in fully vaccinated patients was likely influenced by the time from vaccination, and fully vaccinated patients with true-positive results had a longer time from vaccination to CT scan compared with fully vaccinated patients with COVID-19 typical appearance at CT and negative PCR test results. The patients in our study were more likely to have true-positive findings at CT with longer intervals between vaccination and CT, suggesting an attenuation in vaccine effectiveness with time. Recent studies have shown that the effect of time from undergoing vaccination and booster was noted to be particularly striking with the Omicron variant, with vaccine efficacy against symptomatic disease after two doses of BNT162b2 reported to be 65% at 2–4 weeks postvaccine and dropping to 9% after 25 or more weeks. Similar waning immunity has been observed with other vaccines and VOCs (25–27). Our study also showed that unvaccinated patients were more likely to have true-positive findings on a scan compared with fully vaccinated patients who were administered a booster, thus underscoring the role of vaccine boosters in COVID-19 severity (28–30).

Our study had several limitations. Although previous studies showed concordance among radiologists interpreting chest CT images using the RSNA guidelines, our study was limited by the lack of a formal re-read of the included studies (8). COVID-19 variant information was not available at the patient level, which
Table 3: Rate of True-Positive Findings by Vaccination Status and Dominant COVID-19 Variant of Concern and By Time from Vaccination to CT

| Predominant COVID-19 Variant | Proportion of True-Positive Findings at CT in Unvaccinated Patients | Proportion of True-Positive Findings at CT in Vaccinated Patients | Odds Ratio | P Value |
|------------------------------|---------------------------------------------------------------------|------------------------------------------------------------------|------------|---------|
| Alpha at time of CT          | 67 (62, 72)                                                         | 11 (5, 25)                                                       | 16 (6.1, 42) | <.001   |
| Alpha at time of vaccination | ...                                                                 | ...                                                              | ...         | ...     |
| Delta at time of CT          | 88 (81, 93)                                                        | 54 (43, 64)                                                      | 6.4 (3.2, 13) | <.001   |
| Delta at time of vaccination | ...                                                                 | ...                                                              | ...         | ...     |
| Omicron at time of CT        | 87 (60, 97)                                                        | 83 (37, 98)                                                      | 1.3 (0.10, 18) | .84     |
| Omicron at time of vaccination| ...                                                                | ...                                                              | ...         | ...     |

Note.—Unless otherwise indicated, data are percentages; data in parentheses are 95% CIs. Variants of concern are those identified in Massachusetts. Row headings summarize the predominant COVID-19 variant at the time of CT; rows below each row heading summarize the predominant COVID-19 variant at time of vaccination (eg, Alpha at time of vaccination).

limited our ability to assess the contribution of different VOCs to the observed rates of true-positive findings. The greater availability and quicker processing of COVID-19 PCR tests may have influenced interpretation, but this was not captured in our study. The decreased severity of breakthrough infections noted in recent literature (15–17) may have influenced the rate of true-positive findings.

In summary, the overall rate of true-positive findings of COVID-19 typical appearance at chest CT was lower in fully vaccinated patients compared with unvaccinated patients. Our study and previous literature showed that several mechanisms likely contributed to the lower rate of true-positive findings observed in fully vaccinated patients, including proportion of the population that was vaccinated. Thus, the use of CT in depicting COVID-19 pneumonia in a vaccinated population should be considered in this context. Whereas fully vaccinated patients with confirmed COVID-19 infections had lower rates of true-positive findings of COVID-19 typical appearance at chest CT in our study, chest CT and the RSNA consensus guidelines have an important role in assisting radiologists and referring clinicians in the triage and evaluation of patients with suspected or confirmed COVID-19 infection in an increasingly vaccinated patient population.

Author contributions: Guarantor of integrity of entire study, N.J.P.; study concepts/study design or data acquisition or data analysis/interpretation, all authors; manuscript drafting or manuscript revision for important intellectual content, all authors; approval of final version of submitted manuscript, all authors; agrees to any questions related to the work are appropriately resolved, all authors; literature research, N.J.P., A.S., J.D.C.; clinical studies, N.J.P., A.S.; experimental studies, J.D.C.; statistical analysis, N.J.P., N.D.M., J.D.C.; and manuscript editing, all authors

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