Research Article

COVID-19 Vaccination Effectively Reduces Pneumonia Severity as Assessed by Routine Chest Computed Tomography

Xiaohui Wang*, Xiaotong Xie, Peina Zhang, Wenyan Zeng, Liheng Ma*

Department of Medical Imaging, the First Affiliated Hospital of Guangdong Pharmaceutical University, Guangzhou, China.

*Corresponding Author
Xiaohui Wang, Department of Medical Imaging, the First Affiliated Hospital of Guangdong Pharmaceutical University, Guangzhou, China.

Liheng Ma, Department of Medical Imaging, the First Affiliated Hospital of Guangdong Pharmaceutical University, Guangzhou, China.

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Abstract

Background: *In China, the COVID-19 outbreak infected more than 80% of the population. Few trials have been conducted to assess the effectiveness of the China-manufactured vaccine against COVID-19.*

Purpose: *The purpose of this study was to evaluate the severity of pneumonia in individuals with COVID-19 who were fully vaccinated, partially vaccinated, and unvaccinated, using routine chest computed tomography.*

Materials and Methods: *We analyzed data from patients (aged >18 years) who were hospitalized due to COVID-19 pneumonia between December 2022 and January 2023. Patients who underwent routine chest CT scans were divided into three groups based on their vaccination status. The lobar involvement grading system (0-25) was used to assess the extent of lung injury. The primary outcome was either survival or death. The Pearson chi-square test, Fisher's exact test, and one-way ANOVA were used to compare clinical and imaging features. The receiver operating characteristic (ROC) curve analysis was used to calculate the area under the curve (AUC), sensitivity, and specificity of the CT severity score (CT-SS) in relation to the outcome.*

Results: *Of the 94 patients with COVID-19 pneumonia, 39 patients (41%) were fully vaccinated, 14 (15%) were partially vaccinated, and 41 (44%) were unvaccinated. Among patients with COVID-19 pneumonia, the mean CT severity scores (CT-SS) were 5.9 ± 4.0, 6.5 ± 4.9, and 8.9 ± 4.5 for fully vaccinated individuals, partially vaccinated individuals, and unvaccinated individuals, respectively. The difference was statistically significant ($p<0.05$). CT-SS of 10.5 or higher was associated with severe pneumonia (100% sensitivity, 81.1% specificity, and an area under the curve of 0.92).*

Conclusion: *COVID-19 vaccination leads to less severe pneumonia based on CT. Fully and partially vaccinated patients with COVID-19 pneumonia have less lung involvement compared to unvaccinated patients. Visual observation by CT imaging provides additional evidence to support the clinical effectiveness of vaccination.*

Keywords: Computed tomography, COVID-19 pneumonia, Vaccine, CT pattern

Background

The acute respiratory syndrome corona virus-2 (SARS-COV-2) known as coronavirus disease 2019 (COVID-19) pneumonia was initially identified in Wuhan, China [1]. The World Health Organization (WHO) classified it as a global pandemic since it spread mostly through close contact with respiratory droplets worldwide.The oral mucosa, lungs, heart, blood vessels, colon, kidney, bladder, and brain are among areas where COVID-19

is most commonly seen. Early infection (viral invasion and multiplication), pulmonary phase (host inflammatory response), and hyperinflammatory phase (dysregulated immune response) are the three stages of the infection. Its clinical characteristics, imaging characteristics, and management vary depending on the phase.

One of the primary methods of diagnosis for the quick identification

and treatment of COVID-19 pneumonia is computed tomography (CT) [2]. There are various methods for assessing lung involvement. The chest CT severity score (CT-SS) was shown to be the most straightforward and useful. Each of the five lobes of the lung was visually rated on a scale of 0-5, which was determined based on the degree of lobar involvement. From 0 (no engagement) to 25 (highest involvement), the total CT score was possible.

After the government diminished its zero-COVID policy in early December 2022, the COVID-19 outbreak in China may infect 80% of people in the country. The number of severely ill patients in hospitals reached its high in the first week of January, according to the Center for Disease Control (CDC) of China, and subsequently sharply decreased by more than 70%. According to CDC data, same week also saw a record-high number of mortality. On January 30, 2023, more than 80,000 COVID-19 patients had passed away in hospitals. In China, where the population is aging, some elderly people are hesitant about the effectiveness of the COVID-19 vaccine.

Studies have illustrated the effectiveness of the vaccine against COVID-19 [3,4]. COVID-19 pneumonia was shown to be roughly twice as common in unvaccinated patients as in fully vaccinated patients in patients who had chest CT examination [5]. Studies on the relationship between China-made vaccinations and COVID-19 pneumonia are uncommonly documented.

The purpose of this study was to compare the severity of COVID-19 pneumonia by chest CT according to the vaccination status (fully vaccinated, partially vaccinated or unvaccinated) in Guangzhou, during December 2022 and January 2023, when the COVID-19 outbreak in China.

Materials and Methods
In this retrospective study, patients (aged>18 years) confirmed with COVID-19 infection and common chest CT showed pneumonia between December 2022 and January 2023 were enrolled. The protocol was approved by the Ethics Committee of the First Affiliated Hospital of Guangdong Pharmaceutical University. Patients who underwent common chest CT imaging were categorized into three groups based on their vaccination status: fully vaccinated, partially vaccinated, or unvaccinated.

Individuals were considered fully vaccinated if they tested positive for the COVID-19 nucleic acid amplification test (NAAT) at least 14 days after receiving the third dose of the COVID-19 vaccine manufactured in China. People who tested positive for COVID-19 NAAT at least 14 days after receiving the first dose of the vaccination were considered partially immunized. Those who tested positive for COVID-19 NAAT with no record of immunization or who were diagnosed with COVID-19 fewer than 14 days after receiving the first dose of the vaccine were classified as unvaccinated.

The clinical outcomes, comorbidities (hypertension, diabetes, cardiovascular disease, and cancer), and demographic factors (age and sex) were assessed. All individuals who underwent a CT scan had their chest images scrutinized and analyzed. Based on the affected region, a semiquantitative scoring system was employed to estimate the extent of pulmonary involvement in all of these anomalies. The extent of lobar involvement was used to calculate the chest CT severity score (CT-SS). A visual score of 0 to 5 was assigned to each of the five lung lobes, with 0 denoted no engagement, 1 denoted less than 5% involvement, 2 denoted 5-25% involvement, 3 denoted 26-49% involvement, 4 denoted 50 to 75% involvement, and a score of 5 denoted more than 75% involvement [6]. CT findings and severity score (CT-SS) were then assessed using descriptive analysis.

Pneumonia patterns on CT images were categorized as typical, indeterminate, atypical, or negative based on the RSNA Expert Consensus Statement [5,7]. Peripheral bilateral ground glass opacities (GGOs) or multifocal round GGOs, with or without consolidation or intralobular lines, or a reverse halo sign, are considered a typical appearance. An indeterminate appearance was defined as the presence of GGOs with or without consolidation, but without typical features. An atypical appearance is defined as the absence of typical or indeterminate features, with the presence of lobar and/or segmental consolidation without GGOs, discrete centrilobular nodules, lung cavitation, or smooth interlobular septal thickening with pleural effusion.

Statistical Analysis
Statistical analysis was performed using GraphPad Prism 9.0 software. Categorical variables are presented as numbers and percentages, while continuous variables are presented as means and standard deviations (SD). Statistical assessment of differences between groups was determined using the Pearson chi-square test or Fisher exact test for categorical variables such as sex, comorbidities, and clinical outcomes. The CT-SS between different categories was analyzed using the t-test or one-way ANOVA. $P<0.05$ was considered as an indication of a statistically significant difference. The correlation between age and CT-SS was also calculated. The receiver operating characteristic (ROC) curve analysis was used to determine the area under the curve, sensitivity, and specificity for the CT-SS in relation to the outcome.

Results
Ninety-four patients with COVID-19 who met the inclusion criteria are presented in Table 1. The average age of the patients was 74 years, ranging from 27 to 99 years. Out of the 94 patients, 61(64.9%) were men and 3(35.1%) were women. Out of the 46 patients, 48.9% had at least one of the following comorbidities: hypertension, diabetes, cardiovascular disease, or cancer. All patients were symptomatic. Among all patients, 39(41%) were fully vaccinated, 14(15%) were partially vaccinated, and 41 (44%) were unvaccinated. The mean age was higher in the unvaccinated group (80 years ± 12) and the partially vaccinated group (73 years ± 17) compared to the fully vaccinated group (66 years ± 16) (P<0.05). Patients with comorbidities who required oxygen supply were not significantly different among the three groups. However, the death rate in the hospital was higher for unvaccinated patients (3%, 3 out

of 94 patients) compared to fully and partially vaccinated patients
(P<0.05).

Variable	Fully vaccinated (n=39)	Partially Vaccinated (n=14)	Unvaccinated (n=41)	*P* value
Age (Y)	66±16	73±17	80±12	< 0.05§
Sex				
Female	16	6	13	0.62
Male	23	8	28	
Comorbidities				
Hypertension	12	9	18	0.08
Diabetes	11	3	10	0.86
Cardiovascular disease	2	2	7	0.24
History of cancer	5	2	4	0.87
Clinical outcomes				
Requiring oxygen supply	18	9	28	0.06
In-hospital death	0	0	3	< 0.05§

Note:-Except where indicated, the data are numbers of patients, with percentages in parentheses. Data are means ± SDs. The difference between fully vaccinated, partially vaccinated and unvaccinated patients was statistically significant (Pearson's Chi-square test or Fisher exact test, P< 0.05). § Indicates statistical significance

Table 1: Clinical Characteristics and Outcomes of Patients with COVID-19 Pneumonia according to Vaccination Status.

Initial chest CT scans were obtained for all 94 patients. Among patients with COVID-19 pneumonia, the mean severity scores (CT-SS) were 5.9 ± 4.0, 6.5 ± 4.9, and 8.9 ± 4.5 for fully vaccinated individuals, partially vaccinated individuals, and unvaccinated individuals, respectively. The difference was statistically significant (P<0.05) (Figure 1). The CT-SS ranged from 2 to 21, and the average CT-SS was 7.1 ± 4.3. Among all patients, those who had a CT-SS of 21-25 were in the unvaccinated group (Table 2). It was also proven that age was positively correlated with disease severity, with a correlation coefficient of 0.12 (Figure 2).

CT severity score	Patients NO.	Fully vaccinated	Partially Vaccinated	Unvaccinated
1-5	42(44.68%)	23(54.76%)	9(21.43%)	10(23.81%)
6-10	31(32.98%)	10(32.26%)	4(12.90%)	17(54.84%)
11-15	15(15.96%)	4(26.67%)	1(6.67%)	10(66.67%)
16-20	5(5.32%)	2(40.00%)	0	3(60.00%)
21-25	1(1.06%)	0	0	1(100%)

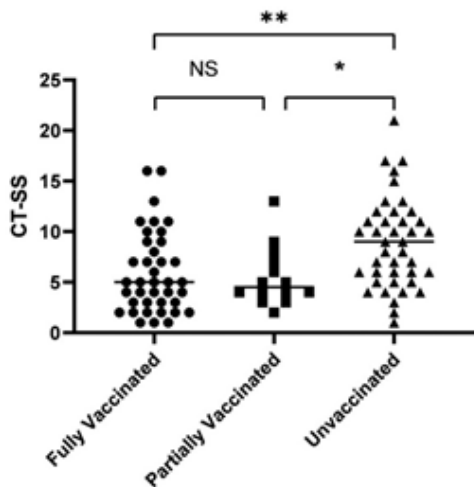**Table 2:** Number and percent of cases in each severity score group.

Figure 1: CT severity scores (CT-SS) of patients with COVID-19 pneumonia based on their vaccination status. CT-SS in fully vaccinated individuals, partially vaccinated individuals, and unvaccinated individuals were 5.9 ± 4.0, 6.5 ± 4.9, and 8.9 ± 4.5, respectively. The difference was statistically significant ($p<0.05$).
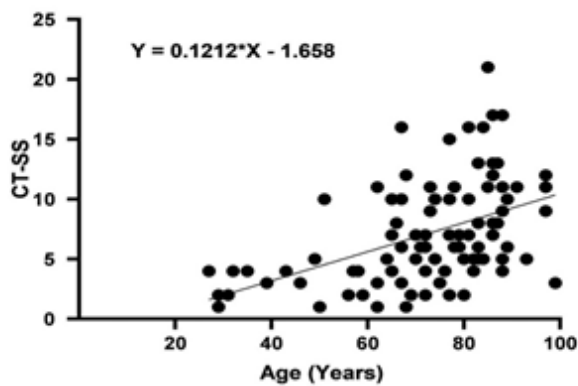

Figure 2: Age has a positive correlation with CT-SS, with a correlation coefficient of 0.12.

All patients tested positive for pneumonia on CT scans, and the CT imaging features were classified according to the RSNA Expert Consensus Statement. These features were typical in 71.8% (28 out of 39) of fully vaccinated patients, 57.2% (8 out of 14) of partially vaccinated patients, and 90.2% (37 out of 41) of unvaccinated patients (Figures 3,4). The most common CT patterns observed in the fully, partially, and unvaccinated groups were typical, and intergroup differences were observed (P<.03) (Figure 7).

CT-SS of 10.5 or higher was associated with severe pneumonia (100% sensitivity; 81.1% specificity; area under the curve of 0.92) (Figure 8).
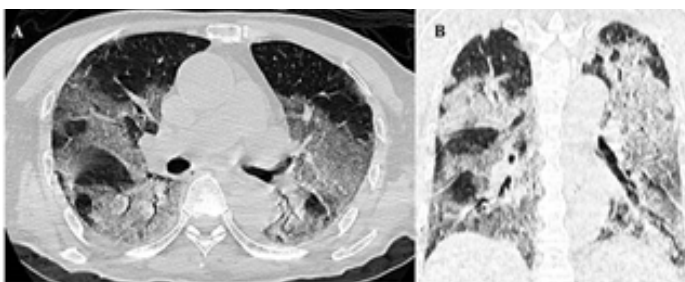

Figure 3: Images of an 85-year-old man with no history of COVID-19 vaccination, but with a history of hypertension. He complained of recurrent fever for five days, with the highest temperature reaching 39.5°C. (A-B) The chest CT scan reveals bilateral ground-glass opacity with consolidation, the extent of pneumonia was assessed as 21, with involvement in all five lobes. This case was classified as a typical manifestation of COVID-19, according to the RSNA chest CT classification system.
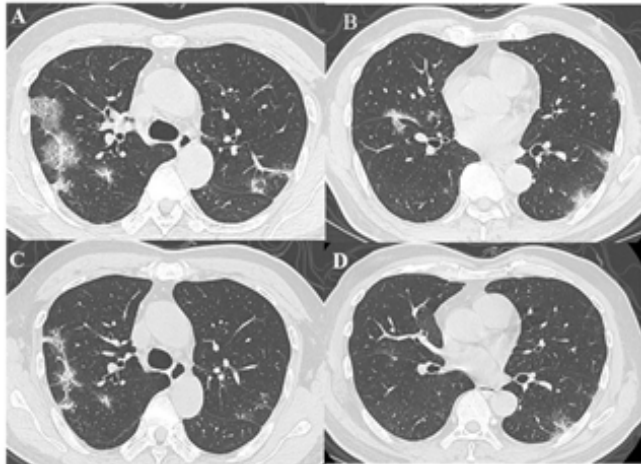
Figure 4: Images of a 63-year-old man with a history of full vaccination for COVID-19 and no comorbidities. He complained of recurrent fever and cough for a week. The highest temperature recorded was 38.5°C. (A-B) The initial chest CT scan reveals bilateral multifocal ground-glass opacity without consolidation. The CT severity score (CT-SS) was 6, indicating a typical appearance of COVID-19 based on the RSNA chest CT classification system. Transverse non-enhanced CT scan (C-D), obtained a week after infection, demonstrates residual reticulations.
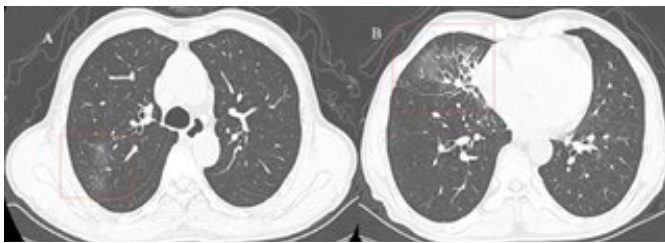

Figure 5: Images of a 70-year-old man with a history of full COVID-19 vaccination and no comorbidities. He complained of a cough for five days and hemoptysis for one day. Chest CT shows unilateral multifocal ground-glass opacity with bronchiectasis. The CT severity score (CT-SS) was 5. This case was classified as having an indeterminate appearance of COVID-19 according to the RSNA chest CT classification system.
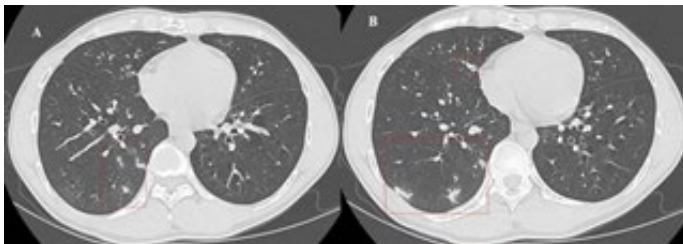

Figure 6: Images in a 39-year-old male who is partially vaccinated and has no comorbidities. He complained of fever for one day and cough for more than a week with a sore throat and muscle pain. The highest temperature was 39°C. (A-B) The chest CT scan reveals bilateral multifocal nodules without consolidation. The CT-SS score was 2, and this case was classified as an atypical appearance of COVID-19 based on the RSNA chest CT classification system.
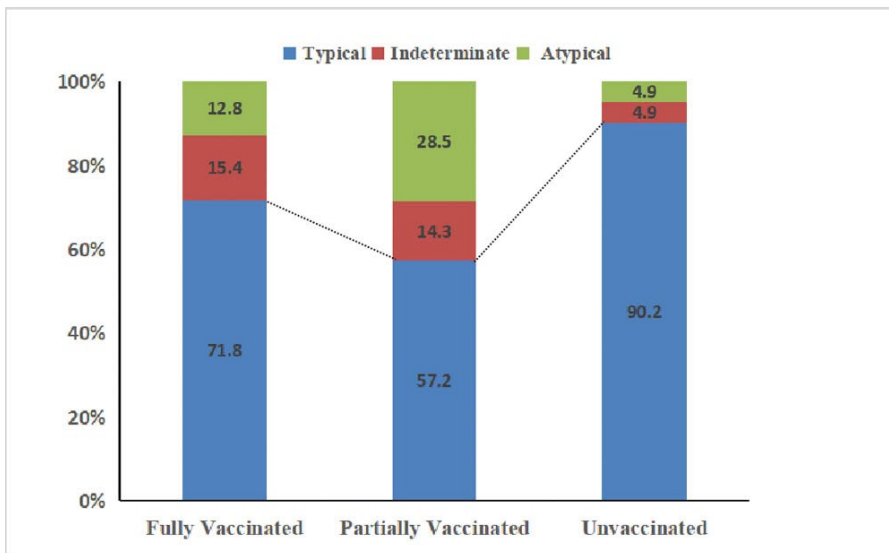
Figure 7: Bar graph shows among patients with pneumonia, the most common CT patterns observed in the fully, partially, and unvaccinated groups were typical, and intergroup difference was observed (P ,.03).
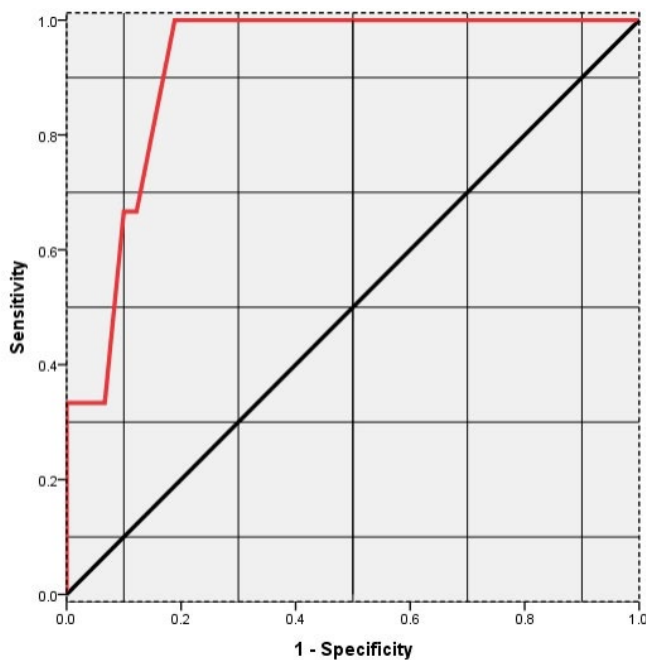

Figure 8: Receiver Operating Characteristic (ROC) curve of CT-SS model performance with the primary outcome. CT-SS, which stands for Chest CT Severity Score.

Discussion

A pandemic known as COVID-19 has broken out, resulting in a severe public health disaster worldwide [8-10]. COVID-19 immunization has been shown to reduce pneumonia on chest CT [11,12]. In order to further investigate the evidence supporting the prevention of COVID-19-related lung disease, the study examined the correlation between COVID-19 pneumonia and vaccines manufactured in China. The study examined the severity of COVID-19 pneumonia by chest CT between December 2022 and January 2023, based on vaccination status (fully vaccinated, partially vaccinated, or not vaccinated).

During the aforementioned peak period, we investigated 94 individuals with COVID-19 pneumonia. Because of the unique composition of the Chinese population, elderly individuals (over 60 years old) accounted for 89.4% (84 out of 94) of all patients. 39(41%) were fully vaccinated, 14(15%) were partially vaccinated, and 41(44%) were unvaccinated. The mean severity scores (CT-SS) and the lobar involvement scoring system (0-25) were utilized in this study because they were feasible and time-saving [13]. CT-

SS in fully vaccinated individuals, partially vaccinated individuals, and unvaccinated individuals were 5.9 ± 4.0, 6.5 ± 4.9, and 8.9 ± 4.5, respectively. The difference was statistically significant (P<0.05) (Figure 1). Hospital death (3/94, 4%) occurred only in the unvaccinated group (Table 1), which shows that COVID-19 vaccination is effective in reducing the severity of pneumonia as observed in common chest CT scans. These results are consistent with other studies [5,14-18].

Notably, age is a vital indicator of severe disease in patients with COVID-19 [19]. The angiotensin-converting enzyme 2 receptor (ACE2), which is extensively expressed in epithelial cells of the oral mucosa and lungs, is believed to be the target of SARS-CoV-2.Additionally, it has been found that ACE2 expression and affinity rise with age, which could account for the high severity of COVID-19 in older patients [9,20-25]. Age and pneumonia severity have a favorable correlation, according to our study (Figure 2).

The CT imaging features were classified into typical, indeterminate, and atypical patterns in each group in accordance with the RSNA Expert Consensus Statement (Figures 3-6). Which were typical 71.8% (28 of 39) of fully vaccinated, 57.2% (8 of 14) of partially vaccinated and 90.2% (37 of 41) of unvaccinated patients. The most common CT patterns seen in each group were typical, and the majority of research supported the conclusions [5,26,27]. Early infectious, pulmonary, and hyperinflammatory phases make up the progression of COVID-19. Peripheral ground glass opacities are the most common CT findings in the early stages, and treatment that specifically targets SARS-CoV-2 is efficient [5,9,26-28]. CT-SS of 10.5 or higher was associated with severe pneumonia (100% sensitivity; 81.1% specificity; area under the curve of 0.92) (Figure 7).

The study includes the following limitations: the number of patients enrolled was small, especially among those who had only received partial vaccinations. This may have been because they were hesitant to receive vaccinations. In the future, more patients will be enrolled in studies.

In conclusion, our data indicate that receiving the COVID-19 vaccine reduces the severity of pneumonia, as determined by routine chest computed tomography. Patients who have received either a full or partial COVID-19 vaccination show less lung involvement than patients who have not been vaccinated. Additional evidence of the clinical efficacy of immunization is provided by visual observation through CT imaging.

Author Contributions
Xiaohui Wang contributed to the literature search, data analysis and writing of the manuscript. Xiaotong Xie and Peina Zhang contributed to data collection, Wenyan Zeng and Liheng Ma contributed to data interpretation. All authors contributed to the study conception, design, article, and approved the submitted version.

Conflict of Interest
The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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