Effects of Patient-Based Imaging Artifacts On CT Diagnosis of COVID-19 and Its Severity

Burcu Akman, MD
Ahmet Turan Kaya, MD

Purpose To investigate the effects of patient-induced artifacts on the diagnostic performance of the COVID-19 Reporting and Data System (CO-RADS) and the computed tomography chest severity score (CT-SS).

Methods A single-center retrospective analysis of patients aged 18 years and older who were admitted to the authors' hospital with laboratory-confirmed COVID-19 and underwent chest CT between July and November 2021 was conducted. Patients' chest CT scans were examined by 3 radiologists for CT-SS and CO-RADS classifications. Patient-based artifacts, including metal artifacts, incomplete projection artifacts, motion artifacts, and insufficient inspiration, were identified by 3 readers who were unaware of each other. For statistical analysis, interreader agreement was investigated using Fleiss kappa (κ) agreement analysis.

Results The study population included 549 patients with a median age of 66 years (IQR, 55-75 years), 321 (58.5%) of whom were men. According to the overall CO-RADS classification, the highest interreader agreement was in patients without CT artifacts ($\kappa = 0.924$), while the lowest interreader agreement was in patients with motion artifacts ($\kappa = 0.613$). For the CO-RADS 1 and 2 patient groups, insufficient inspiration decreased the interreader agreement most ($\kappa = 0.712$ and $\kappa = 0.250$, respectively). For the CO-RADS 3, 4, and 5 patient groups, motion artifacts reduced the interreader agreement most ($\kappa = 0.464$, $\kappa = 0.453$, and $\kappa = 0.705$, respectively). For total CT-SS, the highest kappa value was in patients without artifacts ($\kappa = 0.574$), while the lowest kappa value was in patients with motion artifacts ($\kappa = 0.374$).

Discussion The CT technologist can avoid patient-induced artifacts by placing patients carefully on the CT table, giving patients necessary instructions before CT acquisition, and selecting optimal scanning parameters. The authors are not aware of another study in the literature investigating the effects of patient-based artifacts on interreader agreement of CO-RADS classification and CT-SS for COVID-19.

Conclusion CT artifacts degrade image quality and might lead to interreader disagreement of CO-RADS classification and CT-SS for patients with COVID-19.

Keywords | *COVID-19, computed tomography, artifact, CO-RADS, CT severity score*

In December 2019, a new coronavirus (severe acute respiratory syndrome coronavirus 2 or SARS-CoV-2) was identified in Wuhan, China, and the disease it causes was called *coronavirus disease 2019 (COVID-19)*. COVID-19 often is observed as a lung infection ranging from a mild upper respiratory tract infection to severe pneumonia and acute respiratory distress syndrome. In addition, the multisystemic effects of COVID-19 and accompanying complications might occur in the course of the disease.[1]

Although the definitive diagnosis of COVID-19 occurs through a real-time, reverse transcription polymerase chain reaction (RT-PCR) test, some studies have reported computed tomography (CT) as the most sensitive method for diagnosing COVID-19.[2,3] Chest CT provides useful information in demonstrating the extent of lung involvement and in planning treatment for COVID-19. In COVID-19 pneumonia, typical CT findings are bilateral, multifocal, peripherally located ground-glass opacities (GGOs); consolidation;

linear and reticular opacities; and interlobular and intralobular septal thickenings (crazy-paving pattern).[4] In the advanced stages of the disease, the frequency of consolidation increases.

For standardized reporting, a COVID-19 Reporting and Data System (CO-RADS) based on a 5-point scale of suspicion for pulmonary involvement of COVID-19 on chest CT was defined.[5] CO-RADS classification is performed according to the level of suspicion, ranging from very low (CO-RADS 1) to very high (CO-RADS 5) on nonenhanced chest CT images. A semiquantitative CT severity scoring system (CT-SS) based on the percentage of involvement of each pulmonary lobe also was established; the degree of COVID-19 pulmonary involvement ranges from a score of 0 (no involvement) to 25 (maximum involvement).[6]

An artifact can be defined as an artificial feature, content, or information on the image that is not present in the real object. Artifacts can substantially degrade the image quality of CT and reduce its diagnostic usefulness. Knowing the source of an artifact is necessary to eliminate it and improve image quality. CT artifacts can be classified according to their origin as physics-based artifacts, patient-based artifacts, hardware-based artifacts, and helical and multisection artifacts. With the design features of modern CT devices, many device-induced artifacts can be reduced. Patient-induced artifacts can occur because of patient movement, respiration, and metallic objects on the patient, or when a portion of the patient lies outside the scan field of view.

This study investigated the effects of patient-based artifacts on interreader agreement of CO-RADS classification and CT-SS for patients with COVID-19. The authors evaluated only patient-induced artifacts that might be avoided by the CT technologist placing patients carefully on the CT table, giving necessary instructions to patients before CT acquisition, and selecting optimal scanning parameters.[7,8] The authors are not aware of another study in the literature investigating the effects of patient-based artifacts on interreader agreement of CO-RADS classification and CT-SS for COVID-19.

Methods

This study was approved by the Ethical Committee of Amasya University Faculty of Medicine and was conducted according to the Declaration of Helsinki and Good Clinical Practice (March 3, 2022; number: 33). The present study is retrospective; patient information was obtained from electronic records and censored. Because the study was retrospective, the ethics committee did not require written informed consent from the patients.

Study Population and Data Collection

A single-center retrospective analysis of 705 patients aged 18 years or older who presented to the hospital's emergency department between July and November 2021 and were suspected of having COVID-19 was conducted. Exclusion criteria included 3 negative RT-PCR tests, no chest CT scan, a chest CT scan that used intravenous contrast, or an incomplete chest CT scan. After exclusion criteria were applied, a total of 549 patients were included in the study (see **Figure 1**). Patient data, including demographic information, comorbidities, history of hospitalization or intensive care unit (ICU) admission, and survival, were obtained from the hospital's electronic medical records.

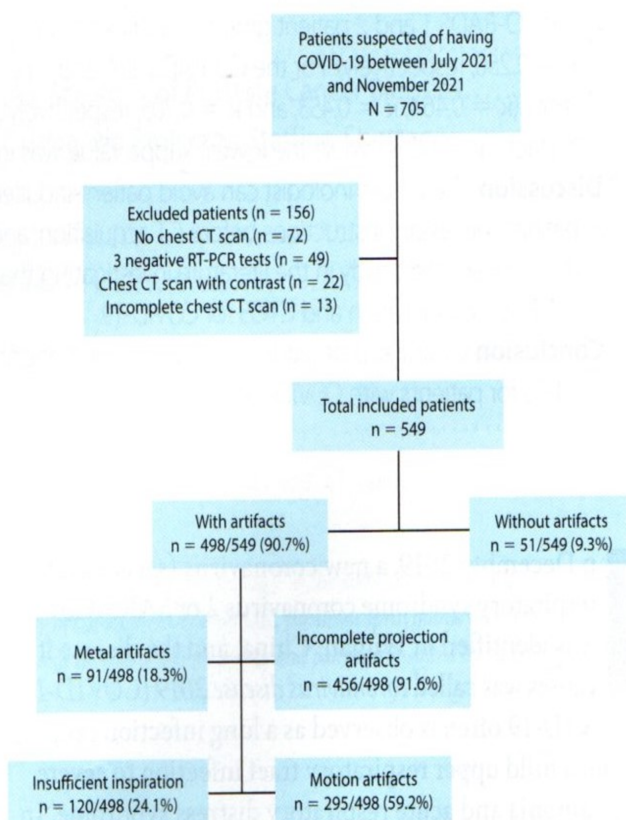

Figure 1. *Flow diagram illustrating sampling procedure of the study. Abbreviations: CT, computed tomography; RT-PCR, reverse transcription polymerase chain reaction. Figure courtesy of the authors.*

Computed Tomography Protocol

Noncontrast chest CT scans were performed using a multidetector CT system, the 128-slice GE Healthcare Revolution EVO CT scanner (GE HealthCare). The settings used were:

- acquisition direction – craniocaudal
- beam collimation – 64 mm × 0.625 mm
- beam pitch – 1.375
- gantry rotation – 0.4 seconds
- reconstruction kernel – standard
- section overlap – 0.625 mm
- slice thickness – 0.625 mm
- tube current – 100 to 450 mA
- tube voltage – 120 kV

Chest CT scans were performed during a single breath-hold in the supine position and evaluated at the lung window (width, 1500 HU; level, −450 HU) and mediastinal window (width, 400 HU; level, 40 HU).

Image Analysis

Three readers with 7, 9, and 15 years of experience in general radiology evaluated CT scans of patients confirmed of having COVID-19 using a standard clinical PACS workstation. Evaluations were made in mediastinal (width, 350 HU; level, 40 HU) and parenchymal (width, 1500 HU; level, −450 HU) windows. All readers were blinded to the patients' clinical examinations, laboratory results, and RT-PCR test results.

Parenchymal chest CT findings were defined according to the Fleischner Society's glossary; findings included[9]:

- consolidation
- crazy-paving pattern
- GGO
- halo and reversed halo signs
- reticular pattern

Nonenhanced chest CT images were assessed using the CO-RADS classification system and graded according to likelihood of a patient having confirmed COVID-19 with lung involvement[5]:

- 1 – very low
- 2 – low
- 3 – uncertain
- 4 – high
- 5 – very high (typical finding)

Five pulmonary lobes were scored individually from 0 to 5 for lung involvement using a semiquantitative CT-SS based on the percentage of involvement of each lobe[6]:

- 0 – no involvement
- 1 – less than 5%
- 2 – 5% to 25%
- 3 – 26% to 49%
- 4 – 50% to 75%
- 5 – more than 75%

The scores for each lobe were summed to obtain the total CT-SS, ranging from 0 (absent) to 25 (maximum).

On CT images, patient-based artifacts, including incomplete projection artifacts, motion artifacts, metal artifacts, and insufficient inspiration, were identified by the 3 readers, who were unaware of each other's findings. Incomplete projection artifacts can occur when a portion of the patient lies outside the scan field of view, such as when the patient's arms are down, and often appear as streaking or shading artifacts.[7,8] Motion artifacts can occur with voluntary or involuntary movements of a patient's body and usually are seen as shading or streaking in the reconstructed image. The presence of high-attenuation objects, such as prostheses and dental fillings, in the scanning field of view causes metal artifacts, which often are seen as severe streaking artifacts.[10] On inspiratory axial CT scans, the shape of the trachea is round; however, on expiratory axial CT scans, the posterior wall of the trachea flattens or bends slightly forward.[11] Therefore, if the posterior wall of the trachea was curved anteriorly on a CT image, the artifact was defined as insufficient inspiration (see **Figure 2**).

Reference Standard

The RT-PCR test was accepted as the reference standard for the diagnosis of COVID-19. The test was performed on swabs taken from the patient's nasopharynx and oropharynx. The RT-PCR test was repeated in patients with clinical and radiological suspicion of COVID-19.

Statistical Analyses

Statistical analyses were performed by using SPSS Statistics version 25.0 (IBM). The conformity of the variables to the normal distribution was examined

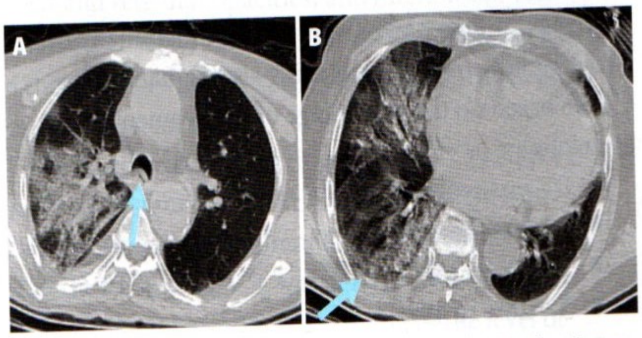

Figure 2. *A 72-year-old man with a history of cardiovascular disease and diabetes had a positive RT-PCR test. He died in the intensive care unit after 11 days of treatment. Because of movement artifacts and insufficient inspiration, distinguishing between the healthy and the involved parenchyma was difficult, which led to disagreements among the readers on the CT severity score (CT-SS). A. Axial lung window of noncontrast chest CT shows the bowing forward of the trachea's posterior wall because of insufficient inspiration (arrow). Extensive consolidations, ground-glass opacities (GGOs), and crazy-paving pattern are seen in the upper lobe of the right lung. B. In lower sections, chest CT shows consolidations, GGOs, and crazy-paving pattern in the middle and lower lobe of the right lung. Shading (arrow) occurred near consolidations and GGOs because of motion artifacts. Images courtesy of the authors.*

using a Kolmogorov-Smirnov test. For descriptive analysis, normally distributed variables were represented as mean and standard deviation, and nonnormally distributed variables were represented as median and interquartile ranges (IQR).

For descriptive statistical analysis, the patients were divided into 2 groups according to the presence of artifacts in their CT images, and continuous and categorical variables were compared. The Student *t* test was used to compare normally distributed continuous variables, and the Mann-Whitney test (ie, *U* test) was used to compare the nonnormally distributed continuous variables. The chi-square test or the Fisher exact test was used to compare categorical variables of the 2 patient groups (ie, with and without CT artifacts) and to investigate the relationship between the presence of CT artifacts and comorbidities; in cases where the values displayed in the cells did not meet the assumptions of the chi-square test, the Fisher exact test was used. Fleiss kappa analysis was performed to evaluate the effect each type of artifact had on the diagnostic success of CO-RADS and CT-SS. Significance was established as $P < .05$ for all statistical tests. Interreader agreement was defined according to the κ value[12]:

- slight – 0.01-0.20
- fair – 0.21-0.40
- moderate – 0.41-0.60
- substantial – 0.61-0.80
- almost perfect – 0.81-1.00

Results

The study population included 549 patients with a median age of 66 years (IQR: 55-75 years), 321 (58.5%) of whom were men. Artifacts were present on chest CT images of 498 patients (90.7%); images for some patients demonstrated multiple types of artifacts. Metal artifacts were observed in 91 patients (16.6%), 456 patients (83.1%) had incomplete projection artifacts, 295 (53.7%) had motion artifacts, and 120 (21.9%) had insufficient inspiration.

There was no significant difference between the presence of CT artifacts and sex ($P = .122$). Among the group with artifacts, 154 (30.9%) of the 498 patients died, whereas 4 (7.8%) of the 51 patients in the group without artifacts died. Forty-four (8.0%) of 549 patients were treated as outpatients, and 505 (92.0%) were treated as inpatients. Among those who received inpatient treatment, 142 (30.7%) of the 462 patients with CT artifacts were treated in the ICU, while 4 (9.3%) of the 43 patients without CT artifacts were treated in ICU. Patients with CT artifacts had higher rates of ICU admission and mortality ($P = .002$ and $P < .001$, respectively) (see **Table 1**).

The median age of the patient group without CT artifacts was 52 years (IQR: 42-59 years), and the median age of the patient group with CT artifacts was 67 years (IQR: 57-76 years). Thus, there was a statistical relationship between the presence of CT artifacts and older age ($P < .001$). The median CT-SS was 5 (IQR: 0-11) for the patient group without CT artifacts and 10 (IQR: 5-16) for the patient group with CT artifacts. There was a significant association between the presence of artifacts and a high CT-SS ($P = .001$). Also, patients with CT artifacts had high levels of serum inflammatory markers such as C-reactive protein and erythrocyte sedimentation rate ($P = .028$ and $P = .007$, respectively) (see **Table 2**).

Table 1
Comparison of Categorical Variables According to the Presence of CT Artifacts

Categorical variable		Artifact, n (%) Absent	Present	Total	*P* value[a]
Sex	Female	16 (7)	212 (93)	228	.122[b]
	Male	35 (10.9)	286 (89.1)	321	
	Total	51 (9.3)	498 (90.7)	549	
Vital status	Alive	47 (12)	344 (88)	391	< .001[c]
	Dead	4 (2.5)	154 (97.5)	158	
	Total	51 (9.3)	498 (90.7)	549	
Type of care	Outpatient	8 (9.3)	36 (9.3)	44	.034[b]
	Inpatient	43 (9.3)	462 (9.3)	505	
	Total	51 (9.3)	498 (9.3)	549	
Inpatient ICU status	Non-ICU	39 (10.9)	320 (89.1)	359	.002[c]
	ICU	4 (2.7)	142 (97.3)	146	
	Total	43 (8.5)	462 (91.5)	505	

[a] *Significant at the P < .05 level.*
[b] *Chi-square test used for comparison.*
[c] *Fisher exact test used for comparison.*
Abbreviations: CT, computed tomography; ICU, intensive care unit.

When the relationship between CT artifacts and comorbidities was investigated, there was a statistical relationship between incomplete projection artifacts and a history of cardiovascular disease ($P = .014$) and between motion artifacts and a history of cardiovascular disease ($P < .001$) and chronic lung disease ($P = .034$). Insufficient inspiration was associated with chronic lung disease ($P < .001$), cardiovascular disease ($P < .001$), and neurological disease ($P = .015$). There was no association between metal artifacts and comorbidities.

Interreader Agreement on CO-RADS Classification

Three readers evaluated a total of 1647 chest CT images. There was a substantial level of agreement for overall CO-RADS classification (95% CI: 0.720-0.722; $\kappa = 0.721$). According to the overall CO-RADS classification, the highest interreader agreement was for images without CT artifacts (95% CI: 0.920-0.928; $\kappa = 0.924$), while the lowest interreader agreement was for images with motion artifacts (95% CI: 0.612-0.615; $\kappa = 0.613$).

There was a perfect level of agreement for CO-RADS 1 (95% CI: 0.995-1.005; $\kappa = 1.000$) and an almost perfect level of agreement for CO-RADS 5 (95% CI: 0.939-0.949; $\kappa = 0.944$) in images without CT artifacts. Interreader kappa agreement for CO-RADS 1 was almost perfect (95% CI: 0.839-0.842; $\kappa = 0.840$) and for CO-RADS 5 was substantial (95% CI: 0.797-0.800; $\kappa = 0.799$). The lowest kappa agreement was found for CO-RADS 2 (95% CI: 0.308-0.311; $\kappa = 0.310$).

For CO-RADS 1 (95% CI: 0.708-0.715; $\kappa = 0.712$) and 2 (95% CI: 0.246-0.253; $\kappa = 0.250$) classification, insufficient inspiration most decreased interreader agreement. For CO-RADS 3 (95% CI: 0.462-0.466; $\kappa = 0.464$), 4 (95% CI: 0.451-0.455; $\kappa = 0.453$), and 5 (95% CI: 0.702-0.707; $\kappa = 0.705$), motion artifacts most reduced interreader agreement (see **Table 3** and **Figure 3**).

Interreader Agreement on CT-SS

For the calculation of CT-SS, each pulmonary lobe was scored by 3 readers on a scale of 0 to 5. In the

Table 2

Comparison of Continuous Variables According to the Presence of CT Artifacts

Continuous variable[a]	Artifacts	Mean (SD)[b]	Median[c]	IQR	P value[d]
Age, y	Absent	-	52	42 - 59	< .001
	Present	-	67	57 - 76	
	Total	-	66	55 - 75	
CT-SS[e]	Absent	-	5	0 - 11	.001
	Present	-	10	5 - 16	
	Total	-	10	4 - 16	
Length of hospital stay, d	Absent	-	11	6.75 - 17	.058
	Present	-	13	8 - 19	
	Total	-	12	8 - 19	
Length of ICU stay, d	Absent	-	24	11.25 - 28.5	.073
	Present	-	9	6 - 18.25	
	Total	-	9.5	6 - 19	
C-reactive protein (0-5; mg/L)	Absent	39.63 (48.02)	-	0.5 - 175	.028
	Present	58.51 (59.07)	-	0.06 - 391.33	
	Total	56.76 (58.36)	-	0.06 - 391.33	
Ferritin (22-322; µg/L)	Absent	216.4 (276.28)	-	9.7 - 1656.6	.129
	Present	376.3 (745.36)	-	5.5 - 12 021	
	Total	361.5 (716.22)	-	5.5 - 12 021	
Erythrocyte sedimentation rate (0-30; mm/h)	Absent	35.55 (27.7)	-	8 - 137	.007
	Present	54.96 (50.01)	-	5 - 979	
	Total	53.15 (48.68)	-	5 - 979	
White blood cell count (3.39–8.86; 10^9/L)	Absent	7.42 (3.24)	-	2.72 - 17.86	.698
	Present	7.71 (5.39)	-	1.42 - 66.65	
	Total	7.69 (5.23)	-	1.42 - 66.65	
Neutrophil count (1.65-4.97; 10^9/L)	Absent	5.29 (2.97)	-	1.12 - 14.99	.556
	Present	5.7 (4.85)	-	0.34 - 69	
	Total	5.66 (4.7)	-	0.34 - 69	
Lymphocyte count (1.17-3.17; 10^9/L)	Absent	1.37 (0.61)	-	0.4 - 3.39	.761
	Present	1.34 (0.75)	-	0.14 - 5.6	
	Total	1.34 (0.73)	-	0.14 - 5.6	

[a] *Length of hospital stay: Absent, n = 42; present, n = 462; total, n = 504. Length of ICU stay: Absent, n = 4; present, n = 142; total, n = 146. All other variables: Absent, n = 51; present, n = 498; total, N = 549.*

[b] *Normally distributed variables are represented using mean and standard deviation.*

[c] *Nonnormally distributed variables are represented using median.*

[d] *Significant at the P < .05 level.*

[e] *Total CT-SS ranges from 0 (no involvement) to 25 (maximum involvement).*

Abbreviation: CT-SS, CT severity score; IQR, interquartile range.

Table 3

Fleiss Kappa Results of Reader Agreement on CO-RADS by Classification and Type of CT Artifact[a]

CO-RADS classification	Type of artifact	κ value	95% CI
1	No artifacts	1.000	0.995 - 1.005
	Metal artifacts	0.826	0.822 - 0.830
	Incomplete projection artifacts	0.797	0.796 - 0.799
	Insufficient inspiration	0.712	0.708 - 0.715
	Motion artifacts	0.745	0.743 - 0.747
	Total	0.840	0.839 - 0.842
2	Metal artifacts	0.377	0.373 - 0.381
	Incomplete projection artifacts	0.320	0.318 - 0.322
	Insufficient inspiration	0.250	0.246 - 0.253
	Motion artifacts	0.284	0.282 - 0.286
	Total	0.310	0.308 - 0.311
3	No artifacts	0.743	0.738 - 0.748
	Metal artifacts	0.498	0.495 - 0.502
	Incomplete projection artifacts	0.533	0.531 - 0.534
	Insufficient inspiration	0.543	0.540 - 0.547
	Motion artifacts	0.464	0.462 - 0.466
	Total	0.564	0.562 - 0.565
4	No artifacts	0.679	0.674 - 0.684
	Metal artifacts	0.525	0.521 - 0.529
	Incomplete projection artifacts	0.507	0.506 - 0.509
	Insufficient inspiration	0.527	0.524 - 0.531
	Motion artifacts	0.453	0.451 - 0.455
	Total	0.534	0.533 - 0.536
5	No artifacts	0.944	0.939 - 0.949
	Metal artifacts	0.818	0.814 - 0.822
	Incomplete projection artifacts	0.778	0.776 - 0.780
	Insufficient inspiration	0.717	0.714 - 0.720
	Motion artifacts	0.705	0.702 - 0.707
	Total	0.799	0.797 - 0.800
Overall	No artifacts	0.924	0.920 - 0.928
	Metal artifacts	0.705	0.703 - 0.707
	Incomplete projection artifacts	0.689	0.688 - 0.690
	Insufficient inspiration	0.631	0.629 - 0.634
	Motion artifacts	0.613	0.612 - 0.615
	Total	0.721	0.720 - 0.722

[a] *Significance was at the $P < .05$ level. All types of artifacts were $P < .001$.*
Abbreviation: CO-RADS, COVID-19 reporting and data system.

CT-SS evaluation of all pulmonary lobes (ie, right upper lobe, right middle lobe, right lower lobe, left upper lobe, and left lower lobe), the artifact that most reduced the agreement among the readers was the motion artifact (κ = 0.619, κ = 0.559, κ = 0.588, κ = 0.632, and κ = 0.605, respectively). In addition, for CT-SS evaluation of all pulmonary lobes, the κ values were highest in the patient group without artifacts (κ = 0.752, κ = 0.745, κ = 0.757, κ = 0.857, κ = 0.732, respectively).

The total CT-SS was calculated by 3 readers on a scale of 0 to 25 by summing the scores of all 5 lobes. The kappa value was highest in patients without artifacts (κ = 0.574, 95% 95% CI: 0.572-0.575), while the kappa value was lowest in patients with motion artifacts (κ = 0.374, 95% CI: 0.374-0.374) for total CT-SS (see **Table 4** and **Figure 4**).

Discussion

This study investigated the effects of patient-based CT artifacts on the diagnostic performance of CO-RADS and CT-SS among readers using Fleiss kappa agreement analysis. There was a substantial level of agreement for CO-RADS classification and a moderate level of agreement for CT-SS among the 3 readers. According to data from the comparison of CO-RADS

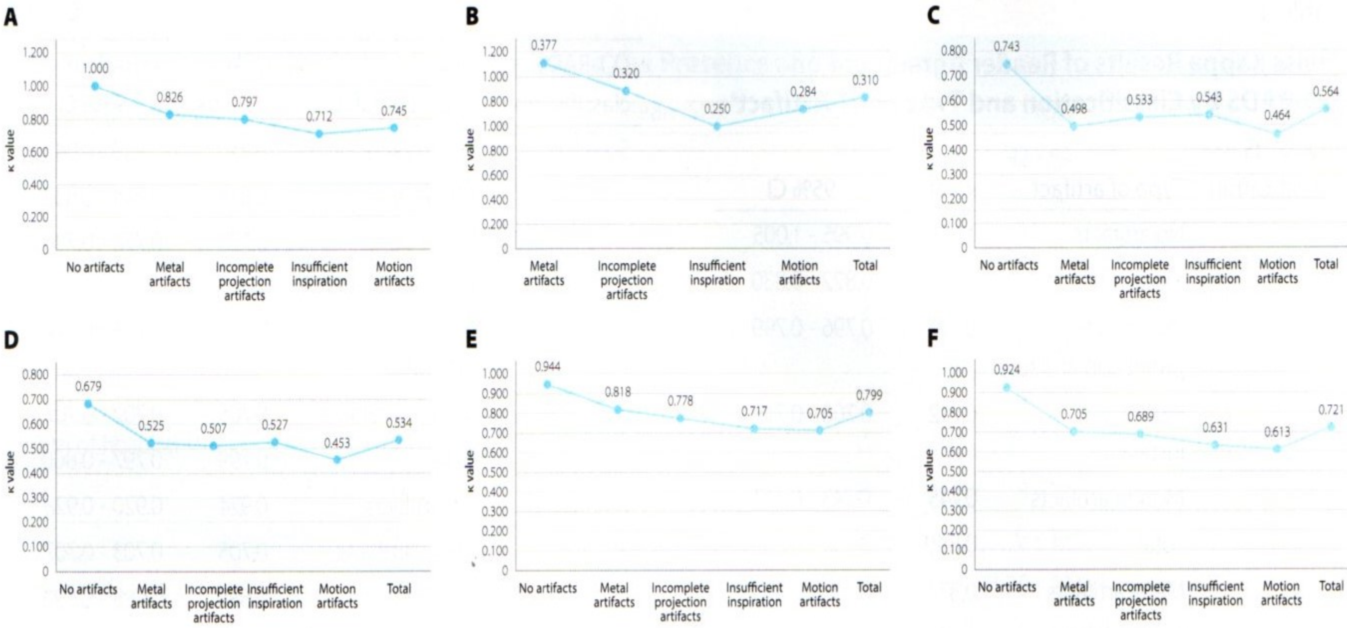

Figure 3. *Line graphs demonstrating the level of reader agreement (κ value) on coronavirus disease 2019 reporting and data system (CO-RADS) classification by type of CT artifact. A. CO-RADS 1. B. CO-RADS 2. C. CO-RADS 3. D. CO-RADS 4. E. CO-RADS 5. F. All CO-RADS classifications. Graphs courtesy of the authors.*

classification by type of article, the highest interreader agreement was for CT images with no artifacts, and the lowest was for CT images with motion artifacts. For CO-RADS 1 and 2 classifications, insufficient inspiration most reduced interreader agreement. For CO-RADS 3, 4, and 5 classifications, motion artifacts most reduced interreader agreement. In addition, the Fleiss kappa value for total CT-SS was highest in the CT images without artifacts and lowest in the CT images with motion artifacts.

A statistical relationship was found between the presence of CT artifacts and older age, but no association was found between the presence of CT artifacts and sex. In a study by Veikutis et al, neither age nor sex of patients affected the frequency and number of artifacts on CT images.[8] In their study, participants were selected randomly from a group of patients who had undergone CT imaging, whereas the present study consisted of patients who had undergone CT imaging and had been diagnosed with COVID-19. Older patients have been shown to be more prone to severe forms of COVID-19 pneumonia, and older patients with comorbidities who have been diagnosed with COVID-19 have been shown to have severe pneumonia and poor clinical outcomes.[13-16] In the current study, patients with a history of chronic lung disease, cardiovascular disease, and neurological disease had more artifacts on CT images. Motion artifacts were more frequent on the CT scans of patients with cardiovascular disease and chronic lung disease. These patients might not have been able to hold their breath easily because of respiratory distress caused by chronic lung disease or conditions secondary to cardiovascular disease such as pleural or pericardial effusion and pulmonary edema. Insufficient inspiration artifacts also were more frequent on CT scans of patients with cardiovascular disease, chronic lung disease, and neurological disease because of respiratory distress and unconsciousness. There were more artifacts on the CT scans of patients who received treatment in the ICU with a high degree of CT severity or a fatal outcome.

Although the standard diagnostic tool for COVID-19 is RT-PCR testing, chest CT provides useful information in demonstrating the extent of lung involvement and in planning treatment for COVID-19. The CO-RADS classification is based on the suspicion of COVID-19 pneumonia and provides a common reporting system for readers.[5] CT-SS determines the severity of pneumonia by calculating the percentage of pulmonary involvement for all lobes.[6] However, patient-based artifacts can

Table 4

Fleiss Kappa Results of Reader Agreement on CT-SS by Pulmonary Lobe and Type of CT Artifact[a]

Pulmonary lobe	Artifacts	κ value	95% CI
Right upper	No artifacts	0.752	0.750 - 0.755
	Metal artifacts	0.637	0.635 - 0.639
	Incomplete projection artifacts	0.629	0.628 - 0.630
	Motion artifacts	0.619	0.618 - 0.620
	Insufficient inspiration	0.624	0.622 - 0.625
	Total	0.644	0.644 - 0.645
Right middle	No artifacts	0.745	0.742 - 0.748
	Metal artifacts	0.669	0.667 - 0.671
	Incomplete projection artifacts	0.584	0.583 - 0.585
	Motion artifacts	0.559	0.558 - 0.560
	Insufficient inspiration	0.580	0.578 - 0.582
	Total	0.607	0.606 - 0.608
Right lower	No artifacts	0.757	0.754 - 0.759
	Metal artifacts	0.642	0.641 - 0.644
	Incomplete projection artifacts	0.626	0.626 - 0.627
	Motion artifacts	0.588	0.587 - 0.589
	Insufficient inspiration	0.595	0.594 - 0.597
	Total	0.637	0.636 - 0.638
Left upper	No artifacts	0.857	0.855 - 0.860
	Metal artifacts	0.693	0.692 - 0.695
	Incomplete projection artifacts	0.646	0.645 - 0.647
	Motion artifacts	0.632	0.631 - 0.633
	Insufficient inspiration	0.635	0.633 - 0.636
	Total	0.676	0.675 - 0.676
Left lower	No artifacts	0.732	0.730 - 0.735
	Metal artifacts	0.637	0.635 - 0.638
	Incomplete projection artifacts	0.638	0.637 - 0.639
	Motion artifacts	0.603	0.602 - 0.604
	Insufficient inspiration	0.605	0.603 - 0.606
	Total	0.650	0.649 - 0.651

[a] *Significance was at the P < .05 level. All types of artifacts were P < .001.*

greatly degrade CT image quality. Artifacts might cause false-negative results by preventing the evaluation of parenchymal GGOs and consolidation areas, which are typical CT findings in the diagnosis of COVID-19 pneumonia. In addition, mosaic attenuation areas that might occur because of insufficient inspiration can create false GGO areas and cause false-positive results. Therefore, avoiding patient-based artifacts when imaging patients with COVID-19 is crucial.

This study focused on patient-based artifacts because they can be avoided by the CT technologist. To avoid incomplete projection artifacts, the radiologic technologist must position the patient correctly so that no parts remain outside the scan area.[7] To reduce motion artifacts, the technologist should instruct patients to hold their breath during scanning. For pediatric patients or patients with trauma or dementia, positioning aids or sedation can be used to avoid or minimize voluntary movements. Also, using short scan times, overscan and underscan modes, software correction, and cardiac gating can reduce motion artifacts.[7,8] Some metal artifacts can be avoided if the CT technologists ask patients to remove metal materials before the scan. To avoid metal artifacts caused by nonremovable material objects, the gantry angle can be changed to remove the objects from required anatomy region scans, kilovoltage can be increased, sections can be thinned, or special software corrections can be used. Insufficient inspiration during CT examination in dyspneic COVID-19 patients can lead to false-positive GGOs.[17] In this study, false GGOs occurred because of the inability to inhale deeply, especially in COVID-19 patients with respiratory distress, leading to disagreements among the readers.

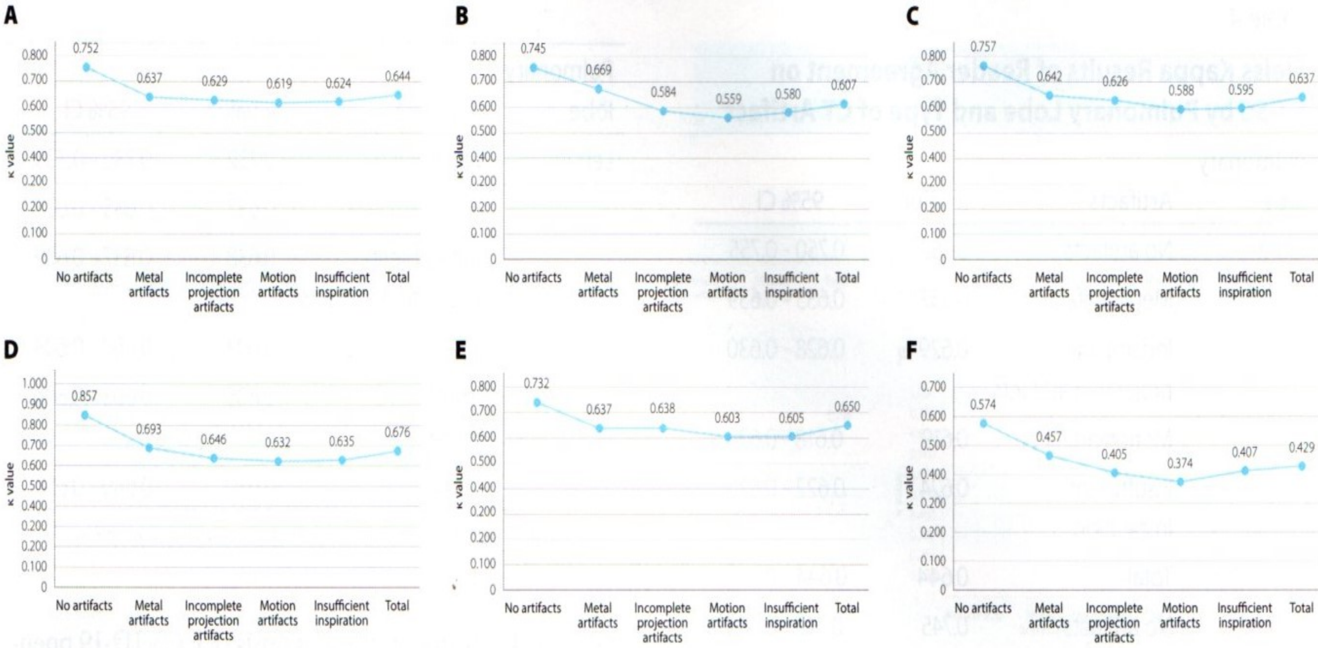

Figure 4. *Line graphs demonstrating the level of reader agreement (κ value) on the CT-SS score assigned to each pulmonary lobe by type of CT artifact. A. Right upper lobe B. Right middle lobe C. Right left lobe. D. Left upper lobe. E. Left lower lobe. F. All pulmonary lobes. Graphs courtesy of the authors.*

The number of CT artifacts in this study was higher than in the literature.[8,18] This might be because most patients had respiratory distress caused by COVID-19 and had less capacity to hold their breath or inhale deeply during CT image acquisition. In addition, COVID-19 was highly contagious, which required social distancing and protective face coverings; therefore, CT technologists might have been unable to adequately instruct patients (eg, raise your arms or hold your breath) or clearly communicate instructions before the scan, for example, the removal of metal items such as dentures.

During the COVID-19 pandemic, many CT technologists in the authors' hospital had COVID-19, so CT technologists with less experience had to perform CT scans. The CT scans were performed in the emergency CT unit under emergency conditions. Study results were shared with the CT technologists in the authors' radiology department, and training was provided to the technologists on the formation of artifacts and how to prevent artifacts if the patient is compliant. Veikutis et al reported that most artifacts (92%) were detected on CT images performed in the emergency CT unit.[8] In the literature on CO-RADS, the Fleiss kappa value of interreader agreement ranged from 0.43 to 0.876, which agrees with the findings of this study.[19-21]

To the authors' knowledge, this study is the first in the literature to investigate the effect of patient-induced artifacts on interreader agreement on CT scans of patients confirmed of having COVID-19. Although the CO-RADS and CT-SS agreement among readers was high for images without artifacts, the level of agreement was reduced for CT images with artifacts, especially motion artifacts and insufficient inspiration. Severe CT artifacts might lead to loss of diagnostic quality of CT scans and require repeat scanning, increasing the radiation dose to patients. CT technologists must take care to reduce artifacts before and during acquisition to help avoid misdiagnosis and prevent patients from receiving unnecessary radiation doses.

Limitations

There are a few limitations in this study. First, it was a single-center retrospective analysis; a multicenter study is needed for further validation. Second, readers evaluated only patient-based artifacts. Future studies that evaluate reader agreement for all types of CT artifacts will provide useful information. This study evaluated the effects of patient-induced artifacts on the diagnostic value of CT scans because patient-based effects can be prevented by CT technologists' guidance of patients. Therefore, CT device-induced artifacts were not identified or included in the study. Third, the number of patients who required repeat CT scans because of artifacts and the additional radiation dose received because of CT repetition was not calculated. Future studies could calculate the additional radiation dose in patients who required repeat CT imaging because of artifacts.

Conclusion

This study found that CT artifacts degraded the diagnostic quality of chest CT scans of patients confirmed of having COVID-19 and significantly reduced the agreement on CO-RADS and CT-SS among readers. Because most patient-based artifacts, except for those in noncooperative, breathless patients and patients with nonremovable metal objects, can be avoided by CT technologists before and during CT acquisition, technologists must take care when obtaining a quality image.

Burcu Akman, MD, and Ahmet Turan Kaya, MD, are assistant professors for the Department of Radiology at Amasya University in Turkey.

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Reprint requests can be mailed to the American Society of Radiologic Technologists, Publications Department, 15000 Central Ave SE, Albuquerque, NM 87123-3909, or emailed to publications@asrt.org.

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