Chest CT Severity Score as an Auxiliary Grading Tool to COVID-19 Pneumonia Imaging Classification: A Tertiary Care Experience in Pakistan

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ABSTRACT

Objective: To identify utility of chest computed tomography severity score (CT-SS) as an additional tool to COVID-19 pneumonia imaging classification in assessing severity of COVID-19.
Study Design: Descriptive analytical study
Place and Duration of Study: Armed Forces Institute of Radiology and Imaging, (AFIRI) Rawalpindi, from April 2020 to June 2020.
Methodology: Five hundred suspected COVID-19 cases referred for high resolution computed tomography – chest were included in the study. Cases were categorised by radiological findings using COVID-19 pneumonia imaging classification, proposed in the radiological society of North America expert consensus statement on reporting chest CT findings related to COVID-19. CT-SS was calculated for all scans. Patients were clinically classified according to disease severity as per 'Diagnosis And Treatment Program of Pneumonia of New Coronavirus Infection' recommended by China's National Health Commission. The relationships between radiological findings, CT-SS, and clinical severity were explored.
Results: Based on the radiological findings, 298 cases were graded as typical, 34 as indeterminate, 15 as atypical, and 153 as negative for pneumonia. The apical and posterior basal segments of lower lobes were most commonly involved. The CT-SS showed higher values in patients of severe group as compared to those in moderate group ($p < 0.05$). CT-SS threshold for recognising severe COVID-19 was 18.5 (area under curve, 0.960), with 84.3% sensitivity and 92.5% specificity.
Conclusion: In coherence with COVID-19 pneumonia imaging classification, CT-SS may provide a comprehensive and objective assessment of COVID-19 severity.

Key Words: *COVID-19, COVID-19 pneumonia, CT-SS, High resolution computed tomography.*

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INTRODUCTION

Severe acute respiratory syndrome coronavirus-2 (*SARS-CoV-2*) was first identified to cause a respiratory illness in Wuhan, Hubei Province, China in December 2019 [1], and was declared a global pandemic on 11 March 2020. [2] The clinical features of COVID-19 are cough, fever, shortness of breath and fatigue.[3] Treatments include combination of antiviral agents, steroids, anticoagulation and oxygen therapy, depending on disease severity.

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The identification of COVID-19 is primarily dependent on real--time reverse transcriptase polymerase chain reaction (RT-PCR).[4] Computed tomography (CT) findings of COVID-19, their progression over time, and the interpretation of radiologists in differentiating COVID-19 from other viral infections has been studied in literature.[5,6] COVID-19 demonstrates CT findings of bilateral and multi-lobar ground-glass opacities (GGO) in peripheral distribution.[7] Additional imaging findings include linear, curvilinear or peri-lobular opacities, diffuse GGO and consolidation.[8-10]

Standardisation of COVID-19 reporting language introduced by Radiological Society of North America (RSNA) was aimed to improve radiologists' communication with physicians and to help in patient management.[11] A CT severity score (CT-SS) less than 19.5 could negate severe or critical disease with high NPV of 96.3%, shown by a study conducted in mainland China. Hence, CT-SS can be used as a tool for triage of patients with COVID-19.[12] No study has been conducted to assess the utility of both reporting systems together.

Table I: Clinical and demographic details of 500 Patients of COVID-19 pneumonia.

Variables	Minimal (n=155)	Moderate (n=230)	Severe (n=115)	p-value
Age Mean ± SD range	 37.90 ± 14.255 15 – 81	 47.77 ± 16.147 2 – 110	 54.76 ± 13.995 11 – 86	<0.001*
Age group 0-20 21-40 41-60 61 and above	 10 (6.5%) 91 (58.7%) 40 (25.8%) 14 (9%)	 6 (2.6%) 77 (33.5%) 103 (44.8%) 44 (19.1%)	 1 (0.9%) 16 (13.9%) 62 (53.9%) 36 (31.3%)	<0.001*
Gender Male Female	 117 (75.5%) 38 (24.5%)	 185 (80.4%) 45 (19.6%)	 105 (91.3%) 10 (8.7%)	0.004*
Cough Yes	68 (43.9%)	137 (59.6%)	83 (72.2%)	<0.001*
Feeling cold Yes	19 (12.3%)	45 (19.6%)	24 (20.9%)	0.105
Diarrhea Yes	8 (5.2%)	20 (8.7%)	10 (8.7%)	0.386
Sore throat Yes	39 (25.2%)	51 (22.2%)	31 (27.0%)	0.586
Body aches Yes	48 (31%)	83 (36.1%)	41 (35.7%)	0.555
Headache Yes	23 (14.8%)	48 (20.9%)	22 (19.1%)	0.324
Fever Yes	56 (36.1%)	115 (50%)	76 (66.1%)	<0.001*
Shortness of breath Yes	24 (15.5%)	80 (34.8%)	66 (57.4%)	<0.001*
Malaise Yes	26 (16.8%)	72 (31.3%)	44 (38.3%)	<0.001*
Travel history Yes	17 (11%)	9 (3.9%)	4 (3.5%)	0.007*
Travel to COVID-19 hit area Yes	18 (11.6%)	20 (8.7%)	3 (2.6%)	0.027*
Contact history with COVID-19 Patient Yes	29 (18.7%)	28 (12.2%)	6 (5.2%)	0.004*
Co-morbid conditions Yes	12 (7.7%)	49 (21.3%)	33 (28.7%)	<0.001*
Diabetes mellitus Yes	6 (3.9%)	25 (10.9%)	20 (17.4%)	0.001*
Hypertension Yes	4 (2.6%)	32 (13.9%)	21 (18.3%)	<0.001*
Ischemic heart disease Yes	5 (3.2%)	18 (7.8%)	18 (15.7%)	0.001*
Asthma Yes	2 (1.3%)	4 (1.7%)	1 (0.9%)	0.803

** p-value <0.05 was taken as statistically significant.*

The aim of this study was to establish a structured reporting system of HRCT chest for COVID-19 by using the defined guidelines of RSNA and using CT-SS to quantify the disease process. A structure focused reporting system was designed with a view to help physicians formulate appropriate management plans for patients and judiciously use limited health resources, especially respiratory support during the pandemic.

METHODOLOGY

The study was approved by Ethical Review Board of AFIRI, Rawalpindi. The first 500 cases admitted at Pak Emirates Miltary Hospital (PEMH) with clinical suspicion of COVID-19 referred to AFIRI for HRCT chest from April 2020 till June 2020 were studied. Patients with tuberculosis, lung neoplasm or history of lung surgery were excluded from the study.

Table II: Score collation of each lung region involved in moderate and severe groups.

Variables	Sample	Moderate (n=230)	Severe (n=115)	p-value	KAPPA

Apical segment upper lobe (R)				<0.001	0.881
0	239	190 (82.6%)	49 (42.6%)		
1	78	35 (15.2%)	43 (37.4%)		
2	28	5 (2.2%)	23 (20%)		
Anterior segment (R)				<0.001	0.914
0	134	125 (54.4%)	9 (7.8%)		
1	171	95 (41.3%)	76 (66.1%)		
2	40	10 (4.3%)	30 (26.1%)		
Posterior segment (R)				<0.001	0.918
0	125	116 (50.4%)	9 (7.8%)		
1	134	89 (38.7%)	45 (39.1%)		
2	86	25 (10.9%)	61 (53.0%)		
Medial segment (R)				<0.001	0.889
0	152	138 (60%)	14 (12.2%)		
1	154	83 (36.1%)	71 (61.7%)		
2	39	9 (3.9%)	30 (26.1%)		
Lateral segment (R)				<0.001	0.880
0	153	145 (63%)	8 (7.0%)		
1	124	71 (30.9%)	53 (46.0%)		
2	68	14 (6.1%)	54 (47%)		
Apical segment lower lobe (R)				<0.001	0.939
0	81	81 (35.2%)	0		
1	134	104 (45.2%)	30 (26.1%)		
2	130	45 (19.6%)	85 (73.9%)		
Anterior basal segment (R)				<0.001	0.892
0	155	148 (64.3%)	7 (6.1%)		
1	150	77 (33.5%)	73 (63.5%)		
2	40	5 (2.2%)	35 (30.4%)		
Medial basal segment (R)				<0.001	0.885
0	155	145 (63%)	10 (8.7%)		
1	142	77 (33.5%)	65 (56.5%)		
2	48	8 (3.5%)	40 (34.8%)		
Lateral basal segment (R)				<0.001	0.928
0	125	122 (53%)	3 (2.6%)		
1	121	79 (34.4%)	42 (36.5%)		
2	99	29 (12.6%)	70 (60.9%)		
Posterior basal segment (R)				<0.001	0.900
0	68	68 (29.6%)	0		
1	158	122 (53%)	36 (31.3%)		
2	119	40 (17.4%)	79 (68.7%)		
Apical segment upper lobe (L)				<0.001	0.799
0	246	194 (84.3%)	52 (45.2%)		
1	90	34 (14.8%)	56 (48.7%)		
2	9	2 (0.9%)	7 (6.1%)		
Anterior segment (L)				<0.001	0.884
0	157	145 (63%)	12 (10.4%)		
1	165	80 (34.8%)	85 (73.9%)		
2	23	5 (2.2%)	18 (15.7%)		
Posterior segment (L)				<0.001	0.916
0	149	142 (61.7%)	7 (6.1%)		
1	136	79 (34.4%)	57 (49.5%)		
2	60	9 (3.9%)	51 (44.4%)		
Superior lingular segment (L)				<0.001	0.839
0	171	153 (66.5%)	18 (15.7%)		
1	125	68 (29.6%)	57 (49.5%)		
2	49	9 (3.9%)	40 (34.8%)		
Inferior-lingular segment (L)				<0.001	0.852
0	157	143 (62.2%)	14 (12.2%)		
1	136	76 (33%)	60 (52.2%)		
2	52	11 (4.8%)	41 (35.6%)		
Apical segment lower lobe (L)				<0.001	0.936
0	102	97 (42.2%)	5 (4.3%)		
1	132	96 (41.7%)	36 (31.3%)		
2	111	37 (16.1%)	74 (64.4%)		

Anterior basal segment (L) 0 1 2	169 126 50	150 (65.2%) 72 (31.3%) 8 (3.5%)	19 (16.5%) 54 (47%) 42 (36.5%)	<0.001	0.896
Medial basal segment (L) 0 1 2	200 104 41	172 (74.8%) 55 (23.9%) 3 (1.3%)	28 (24.4%) 49 (42.6%) 38 (33%)	<0.001	0.866
Lateral basal segment (L) 0 1 2	143 134 68	132 (57.4%) 85 (36.9%) 13 (5.7%)	11 (9.6%) 49 (42.6%) 55 (47.8%)	<0.001	0.882
Posterior basal segment (L) 0 1 2	100 156 89	95 (41.3%) 110 (47.8%) 25 (10.9%)	5 (4.3%) 46 (40%) 64 (55.7%)	<0.001	0.902
Score of right lung	345	5.27 ± 4.024 (0 - 18)	13.45 ± 3.606 (6 - 20)	<0.001	0.979#
Score of left lung	345	4.33 ± 3.627 (0 - 13)	12.20 ± 4.288 (2 - 20)	<0.001	0.979#
Total score	345	9.61 ± 7.096 (1 - 29)	25.67 ± 7.419 (10 - 40)	<0.001	0.986#

 # ICC: Intraclass correlation coefficient, R: Right lung, L: Left lung.

Table III: Radiological findings in moderate and severe groups of covid-19 patients as per covid-19 pneumonia imaging classification.

Variables	**Sample (n=345)**	**Moderate (n=230)**	**Severe (n=115)**	**P-value**
GGOs	328	213 (92.6%)	115 (100%)	0.003*
Consolidation	258	149 (64.8%)	109 (94.8%)	<0.001*
Typical appearance				
Crazy paving	271	161 (70%)	110 (95.7%)	<0.001*
Reverse halo sign	209	112 (48.7%)	97 (84.3%)	<0.001*
Peripheral distribution	297	187 (81.3%)	110 (95.7%)	<0.001*
Bilateral involvement	298	184 (80%)	114 (99.1%)	<0.001*
Indetereminate appearance				
Unilateral distribution	37	36 (15.7%)	1 (0.9%)	<0.001*
Non-specific distribution	25	23 (10%)	2 (1.7%)	0.005*
Non-rounded distribution	19	18 (7.8%)	1 (0.9%)	0.008*
Non-peripheral distribution	10	10 (4.3%)	0	0.034*
Atypical appearance				
Isolated consolidation	11	10 (4.3%)	1 (0.9%)	0.108
Pulmonary nodules	11	9 (3.9%)	2 (1.7%)	0.348
Lung cavitation	4	3 (1.3%)	1 (0.9%)	>0.999
Inter lobular septal thickening	4	3 (1.3%)	1 (0.9%)	>0.999
Pleural effusion	18	10 (4.3%)	8 (7.0%)	0.304

** p-value 0.05 was taken as statistically significant.*

Based on the "Diagnosis and Treatment Program of Pneumonia of New Coronavirus Infection," endorsed by China's National Health Commission to clinically classify COVID-19[13] patients were categorised as minimal, common, severe and -critical. Minimal disease showed mild clinical changes with normal imaging. Patients classified as common had clinical symptoms and changes on chest imaging. Severe cases had Respiratory Rate more than 30 breaths per minute or resting oxygen saturation less than 93%. Critical cases were those with Respiratory failure/Shock or any organ failure. Patients with minimal disease were classified as minimal, common case group as moderate, and patients with severe and critical status in severe group.

HRCT chest was conducted on a 16-slice CT scan machine (Alexion; Toshiba) in supine position in a single breath-holding period in craniocaudal direction from lung apex to dome of diaphragm. HRCT specifications included X-ray tube settings of 120 kVp and 300mAs; rotation time of 0.75 seconds; section thickness-1 mm; and intersection space interval of five mm. Reconstruction in coronal/sagittal planes and 3D reconstruction was performed.

All scans were reported by two consultant radiologists, having more than five years of expertise, on a standard picture archiving and diagnostic system (PACS) station at a predetermined window width of 800-1600 HU and window level of -800 to -500HU for lung parenchyma.

Radiological features were graded as per RSNA expert consensus statement on reporting chest CT findings related to COVID-19,[11] as typical, indeterminate, atypical, and negative for COVID-19 pneumonia. CT-SS is a modification of criterion employed to report ground-glass opacity, air trapping and interstitial opacity in patients of *SARS* in 2003.[13,14] Both lungs contain a total of 18 bronchopulmonary segments, which are split into 20 regions. The apicoposterior segment of left upper lobe was split into apical and posterior, and anteromedial basal segment of left lower lobe was divided into anterior basal and medial basal regions. Changes in each region had specified scores of 0, 1, and 2 for 0%, less than 50% and more than 50% parenchymal opacification, respectively. The CT-SS was calculated by adding all scores, with a range of 0-40 for both lungs.

IBM SPSS version 25.0 programme was employed for statistical analysis. Mean ± standard deviation values were used for continuous variables like age, right, left and total lung scores along with comparative analysis by one-way ANOVA and independent sample t-test and percentages were used for nominal variables like gender and clinical symptoms. Patterns and scores of HRCT findings in moderate and severe groups were compared using Chi-square test and Fisher's exact test. Weighted Kappa coefficient was utilised to assess the uniformity of lung region scoring by the two observers (values ≤ 0 showing no consistency, 0.01–0.20 as slight, 0.21–0.40 as mild, 0.41– 0.60 as moderate, 0.61–0.80 as significant, and 0.81–1.00 as near perfect consistency). Inter-observer reliability for individual and total lung CT-SS scores was calculated using intraclass correlation coefficient [ICC] (graded as acceptable=0.70-0.80, good=0.80-0.90, excellent=0.90-1.0). A p-value less than 0.05 was taken as statistically significant. ROC curve analysis was conducted to assess area under the curve (AUC); and calculate sensitivity, specificity and threshold for discrimination of moderate from severe group.

RESULTS

Out of 500 patients, 155 (31%) were placed in the minimal, 230 (46%) in the moderate, and 115 (23%) in the severe group (Table I) with respective mean ages of 37.90, 47.77 and 54.76 years ($p<0.001$). The commonest clinical symptoms were cough (288/500, 57.6%, $p<0.001$) and fever (247/500, 49.4%, $p<0.001$). Significant association of COVID-19 patients with diabetes mellitus (51/500, 10.2%, $p=0.001$), hypertension (57/500, 11.4%, $p<0.001$), and ischemic heart disease (41/500, 8.2%, $p=0.001$) was noted.

The ICC for CT-SS of both lungs was found to be excellent in this study (n=500, ICC median=0.986, ICC mean=0.993). Excellent agreement was also noticed in scoring of right and left lungs (ICC median=0.979, ICC mean=0.989). The weighted Kappa for scoring of individual lung regions also demonstrated near perfect agreement between the two observers (Values ranging between 0.80-1.00). The scores calculated by one of the readers was then selected randomly for further investigation.

Overall, posterior basal segments of both lower lobes [right, 277/345 (80.3%); left, 245/345 (71.0%)], apical segments of both lower lobes [right, 264/345 (76.5%); left, 243/345 (70.4%)], lateral basal segments of both lower lobes [right, 220/345(63.8%); left, 202/345 (58.5%)], and anterior and posterior segments of right upper lobe [anterior, 211/345 (61.1%); posterior, 220/345 (63.8%)] were found to be the sites most frequently involved in COVID-19 (Table II).

Statistically significant differences were noted between CT-SS of moderate and severe groups in each lung segment with p-value less than 0.05. Mean right lung score was 5.27 ± 4.024, left lung score 4.33 ± 3.627, and total CT-SS of both lungs was 9.61 ± 7.096 in the moderate group. The average right lung score was 13.45 ± 3.606, left lung score was 12.20 ± 4.288, and the total CT-SS of both lungs was found to be 25.67 ± 7.419 in the severe group.

Out of the total 500 cases, 298 cases were graded as typical, 34 as indeterminate, 15 as atypical, and 153 cases were negative for pneumonia. GGO was the most common radiological appearance in patients with imaging findings (328/345, 95.1%, $p=0.003$), followed by consolidation (258/345, 74.8%, $p<0.001$, Table III). All findings, associated with typical appearance, demonstrated statistical significance with clinical severity ($p<0.05$). Findings in indeterminate appearances also showed statistical significance ($p<0.05$).

Four hundred and twenty-seven (85.4%) cases were PCR positive, while 73 (14.6%) were PCR negative. In terms of radiological criteria, 263/298 cases with typical appearance were PCR positive and 35 cases were PCR negative ($p<0.001$). In cases with indeterminate appearance, 25 were PCR positive and 9 were PCR negative. Seven cases with atypical appearance were PCR positive and eight were negative. In cases negative with pneumonia, 132 were PCR positive and 21 PCR negative. However, all PCR negative cases with typical appearance later came out PCR positive on repeat RT-PCR testing.

In correlating with clinical criteria, 134 (86.5%) cases from minimal, 190 (82.6%) from moderate, and 103 (89.6%) cases out of severe group were PCR positive, while 21 (13.5%), 40 (17.4%) and 12 (10.4%) cases from minimal, moderate and severe groups, respectively, were PCR negative.

ROC curve analysis was performed for severity scoring to assess its ability to differentiate severe from minimal and moderate groups. AUC for identifying clinical severity was found to be 0.960 (95%CI, 0.945-0.974). The ideal CT-SS cut off for recognising cases in severe group was 18.5, showing 84.3% sensitivity and 92.5% specificity. Cases having CT-SS more than 18.5 were 97 in severe group and 29 in moderate group. Cases having CT-SS lower than 18.5 were 18, 201 and 155 in severe, moderate and minimal groups, respectively. It showed a positive predictive value (PPV) of 77% and a negative predictive value (NPV) of 95.2% for severe group.

DISCUSSION

COVID-19 manifests with respiratory symptoms of variable severity, depending on which patients may require variable degrees and types of organ supports. The pandemic took heavy tolls on the healthcare systems worldwide, asking for accurate assessment of disease severity so that physicians can do the maximum for the most patients. Imaging has been considered to complement clinical evaluation and laboratory parameters in therapeutic care of COVID-19. Reduced availability of the diagnostic nucleic acid kits[15] and the relative insensitivity of chest radiographs in early disease led to chest CT becoming the primary radiological modality for diagnosis, at least in China.[12] Initially, the diagnostic accuracy of CT scan was found to vary substantially between studies secondary to bias in reporting which affected generalisation of the results.[16]

This study was conducted to add more value to the role of radiology, especially to that of HRCT scan in COVID-19. The COVID-19 imaging classification was used to diagnose COVID-19; and applied the CT-SS to explore a relationship between HRCT findings and clinical severity of the disease. Out of 500 cases, is 298 cases (59.6%) were graded as typical followed by 153 cases (30.6%) negative for pneumonia, 34 (6.8%) as indeterminate, and 15 (3%) as atypical. A study in Italy also showed typical pattern to be the commonest CT finding (37.4% cases), followed by negative cases (26.7%).[17] Atypical patterns were also found to be the least common in a study at Netherlands.[18] In cases with typical appearance, the commonest pattern was GGO (98.6%), followed by consolidation in (83.5%) and crazy paving (89.9%) in congruence with known imaging manifestations of COVID-19.[19] The lesions were multiple and distributed symmetrically and peripherally, like findings in previous studies.[5,20] The lower lobes were most frequently involved in disease process, which was congruent with previous studies.[21] Another finding was disease predilection for posterior lung segments consistent with cases of *SARS-CoV* and *MERS-CoV* infections.[22-24]

Two hundred and sixty-three (88.3%) cases with typical HRCT appearance were PCR positive, and 35 (11.7%) cases were PCR negative (p<0.001). In another study, percentage of RT-PCR positive cases of COVID-19 showing typical, indeterminate, atypical, and negative appearances for three readers were found to be 76.9%-96.6%, 51.2%-64.1%, 2.8%-5.3%, and 20-25%, respectively.[18] In another study, typical pattern demonstrated a PPV of 87.8% for COVID-19. Atypical and negative patterns showed a PPV of 89.6% and 86.2%, respectively for patients not having COVID-19.[17]

The ideal CT-SS cut-off for recognising cases in severe group was 18.5, having sensitivity of 84.3% and specificity of 92.5%. Cases having CT-SS more than 18.5 were 97 in severe group and 29 in moderate group. Cases having CT-SS less than 18.5 were 18, 201 and 155 in severe, moderate and minimal groups respectively, demonstrating a PPV of 77% and NPV for severe disease of 95.2%. This study results were comparable to Yang *et al.,* who established higher CT-SS in severe cases in contrast to mild cases; but used a CT-SS cut-off of 19.5 having 83.3% sensitivity and 94% specificity with NPV of 96.3%.[12] The ICC for CT-SS of both lungs was also found to be excellent in this study (n=500, ICC median=0.986, ICC mean=0.993) similar to findings by Yang *et al*. However, this study has an added advantage of studying a significantly larger sample population (500 cases compared to 102).

This study has many limitations. First, the HRCT chest was obtained on patient's first contact with healthcare setup analysed, not directed by the duration of symptoms, which may have affected the findings. Second, it was assumed that CT-SS is a representative of the pulmonary burden of COVID-19 without any histologic confirmation. However, this data does depict that patients with higher CT-SS belonged mostly to the clinically labelled severe group. Third, CT-SS calculation of only two radiologists was assessed. Further multi-centre research is suggested to assess the effectiveness of combination of COVID-19 radiological classification with CT-SS.

CONCLUSION

CT-SS and COVID-19 imaging classification, when used together, may contribute significantly more than just the detection of COVID-19. By quantifying the pulmonary involvement, these two radiological tools may help identify patients likely to have a precarious clinical trajectory.

ETHICAL APPROVAL:
This study was conducted with the approval from the Ethics Committee of AFIRI, Rawalpindi (IERB Certificate No 13).

PATIENTS' CONSENT:
Informed consents were obtained from all patients

CONFLICT OF INTEREST:
Authors declared no conflict of interest.

AUTHORS' CONTRIBUTION:
ARP: Conception or design of the work, acquisition, analysis, interpretation of work, radiological diagnosis and drafting the work.
ARS, BN, HA, SR, UZ, ZIM: Fulfill ICJME criteria.

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