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FULL RESEARCH ARTICLE

Computed tomography-quantitative evaluation (CT-QE) score of patients with COVID-19 pneumonia: a simple and practical approach

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ABSTRACT

Introduction: *A simple visual score based on chest computed tomography (CT) findings is desirable for defining prognosis in patients with COVID-19 pneumonia.This study evaluated the diagnostic performance of chest CT using a visual quantification score of lung involvement that predicts the clinical outcome and management area of patients with COVID-19 pneumonia. We also compared the accuracy of this score with clinical severity scores and inflammatory markers.* **Materials and methods:** *A chest CT quantitative evaluation (CT-QE) ranging from 0 to 15 points was created. Scores were found to be correlated with the patient management areas such as home, hospital ward, and intensive care unit (ICU). Receiver operating characteristic (ROC) curves were compared with the diagnostic performance of the CT-QE score with clinical severity scales and inflammatory markers to predict clinical outcomes.* **Results:** *A total of 178 patients with COVID-19 pneumonia were included. The CT-QE score (AUC, 0.78) had a higher accuracy for adverse clinical outcomes than the CURB-65 score (AUC, 0.65) and the P/F ratio (AUC, 0.69) ($p < 0.001$). Furthermore, the CT-QE score (AUC, 0.86) outperformed CRP (AUC, 0.77), D-dimer (AUC, 0.73), and ferritin (AUC, 0.76) ($p < 0.001$) in predicting the clinical outcomes. The CT-QE score was 6-9 points for hospital ward management ($p < 0.001$) and ≥ 10 points for admission to the ICU or death ($p < 0.001$).* **Conclusion:** *The CT-QE score is a simple and practical visual quantification tool based on chest CT findings for prognosis, which predicts the clinical outcome and management area in patients with COVID-19 pneumonia.*

Keywords: *COVID-19. Computed tomography. CT severity score. Acute phase reactants. Chest computed tomography.*

INTRODUCTION

Since the coronavirus disease 2019 (COVID-19) pandemic, fear of a patient with a fatal outcome has prevailed among healthcare workers. Therefore, it is crucial to determine the factors that predict a poor outcome in patients with severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) to provide timely medical care and effective therapeutic decision-making. Chest computed tomography (CT) has proven useful not only for detecting early disease and identifying patients with false-negative results for SARS-CoV-2[1] but also for assessing the progression of infection to predict the clinical outcome[2,3].

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Several tools have been evaluated for appropriate clinical categorization of patients with COVID-19[4-8], such as clinical severity scores like the CURB-65 score[7], the PaO_2/FiO_2 (P/F) ratio[8] and the Quick Sequential Organ Failure Assessment (qSOFA). Laboratory inflammatory markers, such as C-reactive protein (CRP), D-dimer, and ferritin, also provide useful information for reliable clinical prognosis throughout the disease[5-8]. The use of predictive scores to facilitate medical decision-making leads to improvement in clinical decisions that determine whether the patient with COVID-19 can be cared for at home or requires hospitalization[9].

Various methods[10-12] have been developed to quantify pulmonary involvement in chest CT and provide an accurate prognosis. Quantitative assessment of the extent of pulmonary involvement in patients with severe acute respiratory syndrome (SARS) sequelae showed a good correlation with clinical and laboratory parameters[13] and was adopted in patients with COVID-19 with variations. Most methods assign scores to each lobe[10,11,14] or segment[12]. These scores are time-consuming and require training. To date, there is no consensus on which to use. It would be desirable to have a simple visual score based on chest CT findings for prognosis, allowing prediction of clinical outcomes and appropriate management in the hospital setting according to the patient's needs to prevent complications and correctly use resources. This study evaluated the diagnostic performance of chest CT using a visual quantification score of pulmonary involvement to predict the clinical outcome and management area of patients with COVID-19 pneumonia through a retrospective observational analysis. We also compared the score's accuracy with clinical severity scores (CURB-65 and P/F ratio) and inflammatory markers (CRP, D-dimer, and ferritin).

MATERIALS AND METHODS

A retrospective cohort study was conducted from March 15 to July 31, 2020, at the Radiology Department of the Hospital General "Isidro Ayora" in Loja, Ecuador. Patients who tested positive for reverse transcription polymerase chain reaction (RT-PCR) of a nasopharyngeal swab and diagnosed with COVID-19 pneumonia were included. Exclusion criteria were patients without available imaging studies and with decompensated comorbidities requiring complex clinical management, regardless of pulmonary and clinical involvement related to COVID-19 pneumonia. Informed consent was not required for this retrospective study of information collected during routine clinical care. The institutional ethics and research committees approved the study.

Clinical and laboratory variables

The variables recorded were sex, age, chronic diseases such as type 2 diabetes mellitus (T2DM), chronic heart disease (CHD), high blood pressure (HBP), chronic obstructive pulmonary disease (COPD), preexisting lung disease, and chronic kidney disease (CKD).

The laboratory tests were neutrophil ($\times 10^3/\mu l$), lymphocyte ($\times 10^3/\mu l$), and platelet ($\times 10^3/\mu l$) counts, prothrombin time (PT, s), partial prothrombin time (PTT, s), INR (international normalized ratio), neutrophilia (> 65.0%), leukocytosis (> $10.8 \times 10^3/\mu l$), thrombocytopenia (< $130.0 \times 10^3/\mu l$), lymphopenia (< 30.5%), leukopenia (< $4.8 \times 10^3/\mu l$), urea (mg/dl), creatinine (mg/dl), glucose (mg/dl), lactate dehydrogenase (LDH), U/L, and inflammatory markers such as C-reactive protein (CRP), D-dimer, and ferritin.

We assessed two clinical severity scores within 24 hours of examination in the respiratory triage room. The CURB-65 score[7] (confusion, uremia, respiratory rate, blood pressure, and age ≥ 65 years) and the P/F ratio; this was calculated based on the partial pressure of arterial oxygen (PaO_2) and the fraction of inspired oxygen (FiO_2)[8].

Patient management area and clinical outcomes

Clinical records were reviewed, and data were recorded from the patient's arrival at the respiratory triage room. Patients were classified based on the clinical criteria according to the severity of symptoms, pneumonia, respiratory insufficiency, and lung involvement on chest CT for initial treatment. The cases were divided into three categories depending on where the patient was treated: at home, in the hospital ward, or in the intensive care unit (ICU). The treatment area was defined as the place with the highest complexity where the patient was treated for the longest time.

Patients with a CURB-65 score of 0-1 point, a P/F ratio > 300 mmHg, or mild lung involvement on chest CT were treated at home. Patients with a CURB-65 score of 2 points, a P/F ratio of 200-300 mmHg, or moderate lung involvement were treated in the hospital ward, and patients with a CURB-65 score of ≥ 3 points, a P/F ratio < 200 mmHg, or severe lung involvement were treated in the ICU[7,8].

Patients were subclassified into two groups: favorable or adverse clinical outcomes. The latter included

patients who required invasive ventilation or died in the ICU, while those treated at home, in a hospital ward, or in an intermediate care unit without invasive ventilation were classified as having a favorable clinical outcome.

Image acquisition and analysis

All chest CT examinations were performed while the patients were in a supine position with inspiratory apnea and without intravenous contrast medium using the helical technique on a SOMATOM Emotion 16-Slice CT scanner (Siemens Healthineers, Erlangen, Germany). The scanning range was from the base of the neck to the upper third of the abdomen. All images were acquired in full inspiration with a standard-dose protocol (120 kVp, 150 mA) and a detector width of 1.5 mm and reconstructed with a slice thickness of 0.75 mm × 0.75 mm and the kernel U91s ultrasharp. The acquisition direction was from the lung base to the apices. The chest CT was recorded in the picture archiving and communication system (PACS) (Actualpacs, Actualtec Innovacion Tecnologica SL, Castellón de la Plana, Castellón, Spain).

Chest CT images on a workstation with OsiriX MD v.11.0.2 (Pixmeo, Geneva, Switzerland) were read independently by two cardiothoracic radiologists with 8 (MAEB) and 10 (ALS) years of experience. All images were analyzed with orthogonal multiplanar reconstruction (MPR) in the lung window (range WW: 1000-2000 and WL: -700 to -500 HU). Chest CT findings were described based on the term glossary of the Fleischner Society for Thoracic Imaging[15].

Development of the CT-QE score

A visual quantification score of pulmonary involvement was adapted by simplifying the method described by Kazerooni[16], which was also previously used in patients with SARS to describe ground-glass opacity, interstitial opacity, and air trapping[13].

The CT-QE score was created based on visual quantification of the percentage of pulmonary involvement in each of the five lobes and classified as follows: no involvement (0%), 0 points; involvement of 1-29%, 1 point for each affected lobe; involvement of 30-70% scored with 2 points for each affected lobe; and involvement of > 70% scored with 3 points for each affected lobe (Figure 1). The overall extent of pulmonary involvement was determined by the sum of points for each lobe, which ranged from 0 to 15. The CT-QE score was found to be correlated with the patient management area (home, hospital ward, or ICU) and clinical outcome.

Interobserver agreement between the two cardiothoracic radiologists was assessed using the CT-QE score to evaluate pulmonary involvement. The two readers were blinded to the patient's clinical and laboratory data. In cases where the readers disagreed, the score was determined by consensus.

Statistical analysis

Data are presented as frequencies, percentages, or mean ± SD and ranges. The association between the CT-QE score and the patient management area and clinical outcome was determined using the Fisher's exact and chi-square tests. Differences with a p-value < 0.05 were considered significant. The cutoff values of the CT-QE score that accurately determined the patient management area and clinical outcome were defined using the Youden index. The diagnostic performance of the CT-QE score with a 95% confidence interval (CI) was compared with clinical severity scores (CURB-65 and P/F ratio) and inflammatory markers (CRP, D-dimer, and ferritin) to determine the clinical prognosis of patients by constructing receiver operating characteristic (ROC) curves. The intraclass correlation coefficient tested the reproducibility of the CT-QE score between the two readers. The statistical analysis was performed using the IBM SPSS software, version 25.0 (IBM Corp., Armonk, NY, USA).

RESULTS

A total of 184 patients with COVID-19 pneumonia who tested positive for RT-PCR were analyzed. Four patients were excluded because the decision of their treatment in the hospital was based on their comorbidities, and two were excluded because their chest CT was not available. A total of 178 patients were included: 109 (61.2%) men and 69 (38.8%) women aged between 17 and 90 years, with a mean age of 51.11 ± 16.64 years.

Patient management area and clinical outcome

Out of 178 patients, 76 (42.7%) were treated at home, 57 (32.0%) required admission to a hospital ward, and 45 (25.3%) required ICU management (Table 1). The length of stay on the ward until discharge from the

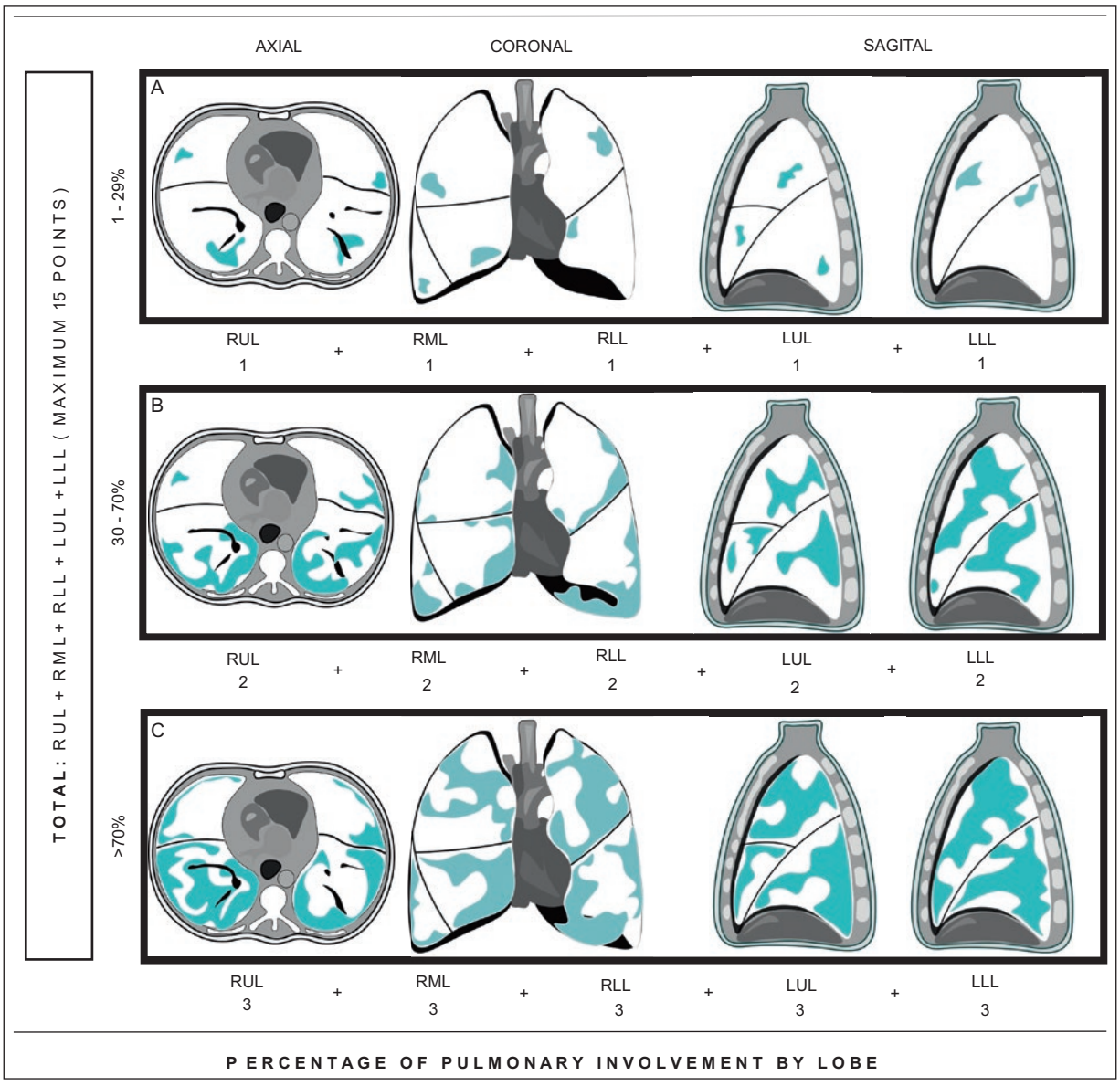

Figure 1. Schematic representation of the CT-QE score based on visual quantification of the percentage of pulmonary involvement in each of the five lung lobes. The overall extent of pulmonary involvement was determined by summing the points for each lobe, which ranged from 0 to 15. **A:** each lung lobe showed between 1% and 29% involvement in the axial, coronal, and sagittal planes and was scored with 1 point each. **B:** each lung lobe showed between 30% and 70% involvement, analyzing the axial, coronal, and sagittal planes, and was scored 2 points each. **C:** each lung lobe showed > 70% involvement, analyzing the axial, coronal, and sagittal planes, and scored 3 points each.

CT-QE: computed tomography-quantitative evaluation; COVID-19: coronavirus disease 2019; LLL: left lower lobe; LUL: left upper lobe; RLL: right lower lobe; RML: right middle lobe; RUL: right upper lobe.

hospital was 7.14 ± 4.93 days. The average length of stay in the ICU was 18.80 ± 14.52 days. A significant risk factor for the need for a more complex medical management area was age > 60 years (n = 55 patients, 30.9%), T2DM (n = 32, 17.9%), and CHD or HBP (n = 47, 26.4%). A total of 126 (70.8%) patients had a favorable clinical outcome, while 52 (29.2%) had an adverse clinical outcome. Notably, 38 (21.3%) patients died, 7 (18.4%) were in a hospital ward, and 31 (81.6%) were in the ICU. The mean time from onset of symptoms to death was 24.87 ± 13.15 days.

Clinical severity scores according to the patient management area and clinical outcome

The CURB-65 score and the P/F ratio were assessed in a sub-analysis of 118 and 96 patients,

Table 1. Characteristics of patients with COVID-19 pneumonia according to the management area and clinical outcome

Characteristic	Home (n = 76)	Hospital ward (n = 57)	ICU (n = 45)	*p*-value	Favorable outcome (n = 126)	Adverse outcome (n = 52)	*p*-value
Men, n (%)	38 (50.0)	36 (63.2)	35 (77.8)	< 0.001	67 (53.2)	41 (78.8)	
Women, n (%)	38 (50.0)	21 (36.8)	10 (22.2)		59 (46.8)	11 (21.2)	< 0.001
Age, years, mean ± SD	41.5 ± 14	54.74 ± 16.06	62.71 ± 11.80	< 0.001	45.74 ± 15.29	64.13 ± 11.98	0.002
(range)	(17-84)	(24-90)	(24-85)		(17-84)	(24-90)	
Age > 60 years, n (%)	4 (5.4)	22 (28.9)	29 (64.4)	< 0.001	19 (15.1)	36 (69.2)	< 0.001
T2DM, n (%)	5 (6.6)	15 (26.3)	12 (26.7)	0.003	19 (15.1)	13 (25.0)	0.117
Pre-existing lung disease[a], n (%)	0	3 (5.3)	2 (4.4)	0.143	2 (1.6)	3 (5.8)	0.125
COPD, n (%)	0	0	3 (6.7)	0.011	0	3 (5.8)	0.007
CHD or HBP, n (%)	7 (9.2)	19 (33.3)	21 (46.7)	< 0.001	22 (17.5)	25(48.1)	< 0.001
CKD, n (%)	0	6 (10.5)	6 (13.3)	0.007	4 (3.2)	8 (15.4)	0.003

COVID-19: coronavirus disease 2019; T2DM: type 2 diabetes mellitus; CHD: chronic heart disease; HBP: high blood pressure; COPD: chronic obstructive pulmonary disease; CKD: chronic kidney disease; ICU: intensive care unit; [a]Diffuse interstitial lung disease, pneumoconiosis, and tuberculosis.

respectively (Table 2). A higher CURB-65 score was found in patients who required ICU management (2.02 ± 0.82) and had adverse clinical outcomes (2.04 ± 0.82) ($p < 0.004$ and $p < 0.001$, respectively). The P/F ratio values were also lower in patients who required ICU management (149.25 ± 84.93; $p < 0.001$) and had adverse clinical outcomes (153.50 ± 82.46; $p < 0.001$).

Laboratory values associated with patient management area and clinical outcome

Patients with an adverse clinical course had higher absolute neutrophil counts and urea, glucose, and LDH levels compared with patients with a favorable clinical outcome ($p < 0.001$) (Table 3). In addition, patients with an adverse clinical course were more likely to have neutrophilia (94.1%) and thrombocytopenia (15.6%) ($p < 0.001$).

CRP and ferritin levels were higher in patients with an adverse clinical course than in patients with a favorable prognosis ($p < 0.001$). However, there were no significant differences in leukopenia, creatinine, and D-dimer. The mean interval between the onset of symptoms and sampling for inflammatory markers was 7.92 ± 6.77 days for CRP, 7.63 ± 6.23 days for D-dimer, and 8.09 ± 6.84 days for ferritin.

Chest CT findings according to the patient management area and clinical outcome

Tomographic findings in patients with COVID-19 pneumonia are shown in Table 4. The predominant pattern was ground-glass opacities with a primarily subpleural distribution ($n = 167$, 93.8%). Airspace consolidation ($n = 69$, 38.7%) and crazy paving ($n = 30$, 16.8%) were less common. Only 11 (6.1%), 8 (4.4%), and 5 (2.8%) patients had pleural effusion, unilateral involvement, and subpleural sparing, respectively. Notably, 9 (5.0%) of 178 patients with confirmed COVID-19 pneumonia had no abnormal CT findings. The mean interval between the first visit and the chest CT scan was 1.43 ± 4.16 days, with a CT evaluation within 24 hours. The mean interval between the onset of symptoms and the performance of RT-PCR and chest CT was 7.29 ± 6.03 and 7.88 ± 6.41 days, respectively. The interval between the evaluation of the chest CT and the RT-PCR results was 3.29 ± 4.21 days.

In the initial phase, patients were more frequently treated at home ($n = 37$, 48.7%). In contrast, patients in the progression phase were more frequently treated in the hospital ward ($n = 26$, 45.6%) and in the ICU ($n = 28$, 62.2%), with significant differences between the groups ($p < 0.001$).

CT-QE score for predicting the patient management area and clinical outcome

The interobserver agreement of the CT-QE score was almost perfect, with a mean of 0.86 ($p < 0.001$). Figure 2 shows the CT-QE score according to a visual quantification of pulmonary involvement in three patients with COVID-19 pneumonia. The CT-QE score was obtained by adding the points of each lobe according to the percentage of pulmonary involvement. In the first

Table 2. Clinical severity scores related to patient management area and clinical outcome in patients with COVID-19 pneumonia

Description	n	Home	n	Hospital ward	n	ICU	*p*-value	n	Favorable outcome	n	Adverse outcome	*p*-value
CURB-65 score, mean ± SD	20	1.25 ± 0.85	54	1.43 ± 0.82	44	2.02 ± 0.82	0.004	67	1.30 ± 0.78	51	2.04 ± 0.82	< 0.001
P/F ratio, mean ± SD	5	390.40 ± 98.37	50	221.92 ± 79.76	41	149.25 ± 84.93	< 0.001	49	243.94 ± 95.84	47	153.50 ± 82.46	< 0.001

COVID-19: coronavirus disease 2019; ICU: Intensive Care Unit; CURB-65: confusion, uremia, respiratory rate, blood pressure, and age ≥ 65 years; P/F ratio: partial pressure of arterial oxygen in blood (PaO_2) divided by the fraction of inspired oxygen (FiO_2).

Table 3. Laboratory values and inflammatory markers according to patient management area and clinical outcome in patients with COVID-19 pneumonia

Parameter	n	Home	n	Hospital ward	n	ICU	*p*-value	n	Favorable outcome	n	Adverse outcome	*p*-value
Neutrophils, $x10^3$/µl	62	4.61 ± 3.05	57	7.98 ± 4.0	44	9.79 ± 5.11	< 0.001	112	6.19 ± 4.46	51	9.39 ± 5.01	< 0.001
Lymphocytes, $x10^3$/µl	62	1.61 ± 0.72	57	1.19 ± 0.54	44	1.18 ± 0.73	< 0.001	112	1.45 ± 0.664	51	1.13 ± 0.712	< 0.001
Platelets, $x10^3$/µl	62	238.19 ± 67.14	57	267.42 ± 103.80	44	223.00 ± 94.41	0.545	112	257.42 ± 85.26	51	215.53 ± 94.43	0.008
PT, sec	46	12.45 ± 1.10	49	13.91 ± 6.44	44	13.89 ± 2.26	0.240	88	12.98 ± 4.69	51	14.17 ± 2.72	0.265
PTT, sec	46	35.37 ± 8.24	48	39.10 ± 12.61	44	40.34 ±12.45	0.038	87	36.61 ± 9.56	51	41.06 ± 13.64	0.026
INR	46	1.15 ± 0.12	49	1.30 ± 0.64	44	1.30 ± 0.22	0.078	88	1.21 ± 0.47	51	1.33 ± 0.27	0.098
Neutrophilia, %	30	48.3	45	78.9	41	93.1	< 0.001	68	60.7	48	94.1	< 0.001
Leukocytosis, %	57	91.9	41	71.9	24	55.8	< 0.001	92	82.1	30	60.0	0.002
Thrombocytopenia, %	1	1.6	3	5.2	6	13.6	0.012	2	1.7	8	15.6	< 0.001
Lymphopenia, %	15	24.2	26	45.6	23	52.3	0.002	36	32.1	28	54.9	0.006
Leukopenia, %	16	25.8	3	5.3	3	6.9	0.003	18	16.0	4	8.0	0.168
Urea, mg/dl	60	25.87 ± 12.82	55	55.16 ± 51.31	45	98.21 ± 49.24	< 0.001	108	35.39 ± 30.34	52	73.72 ± 55.84	< 0.001
Creatinine, mg/dl	60	0.87 ± 0.21	55	2.08 ± 3.99	45	1.99 ± 2.51	0.027	108	1.43 ± 2.90	52	1.96 ± 2.36	0.250
Glucose, mg/dl	55	113.50 ± 47.82	55	139.05 ± 63.11	45	168.51 ± 62.68	< 0.001	103	125.69 ± 57.64	52	163.98 ± 62.13	< 0.001
LDH, U/L	34	278.88 ± 206.2	39	368.21 ± 160.0	35	510.03 ± 181.0	< 0.001	67	314.10 ± 175.77	41	503.61 ± 192.39	< 0.001
CRP, mg/l	58	9.36 ± 35.3	57	11.99 ± 10.08	44	18.61 ± 10.40	0.048	98	10.40 ± 26.65	51	18.07 ± 10.54	0.050
D-dimer, ug/ml	56	0.81 ± 2.94	55	2.18 ± 8.15	42	1.81 ± 2.31	0.315	98	1.35 ± 6.23	49	2.06 ± 2.58	0.442
Ferritin, ng/ml	53	405.26 ± 425.6	51	976.52 ± 668.05	41	1191.8 ± 605.9	< 0.001	98	650.94 ± 595.23	47	1199.05 ± 634.87	< 0.001

COVID-19: coronavirus disease 2019; ICU: Intensive Care Unit; PT: prothrombin time; PTT: partial prothrombin time; INR: international normalized ratio; LDH: lactate dehydrogenase; CRP: C-reactive protein. Values refer to mean ± SD unless otherwise stated.

Table 4. Tomographic findings in patients with COVID-19 pneumonia in relation to patient management area and clinical outcome

Description	Home	Hospital ward	ICU	*p*-value	Favorable outcome	Adverse outcome	*p*-value
Typical pattern, n (%)	61 (80.3)	52 (91.2)	42 (93.3)	0.020	108 (85.7)	48 (92.3)	0.221
Ground-glass opacity, n (%)	65 (85.5)	57 (100)	45 (100)	< 0.001	115 (91.3)	52 (100)	0.046
Crazy paving, n (%)	5 (6.6)	7 (12.3)	16 (35.6)	< 0.001	10 (7.9)	18 (34.6)	< 0.001
Airspace consolidation, n (%)	19 (25)	24 (42.1)	26 (57.8)	0.002	42 (33.3)	27 (51.9)	0.025
Peribronchovascular thickening, n (%)	28 (36.8)	47 (61.8)	44 (97.8)	< 0.001	70 (55.6)	49 (94.2)	< 0.001
Nonspecific pattern, n (%)	5 (6.6)	5 (8.8)	2 (4.4)	0.020	8 (6.4)	4 (7.7)	0.221
Subpleural sparing, n (%)	0	2 (3.5)	3 (6.7)	0.098	2 (1.6)	3 (5.8)	0.130
Pleural effusion, n (%)	3 (3.9)	5 (8.7)	3 (6.7)	0.538	7 (5.6)	4 (7.7)	0.609
Unilateral involvement, n (%)	7 (9.2)	1 (1.8)	0	0.026	8 (6.4)	0	0.061
No lung involvement, n (%)	9 (11.8)	0	0	0.020	9 (7.1)	0	0.221

COVID-19: coronavirus disease 2019; ICU: Intensive Care Unit.

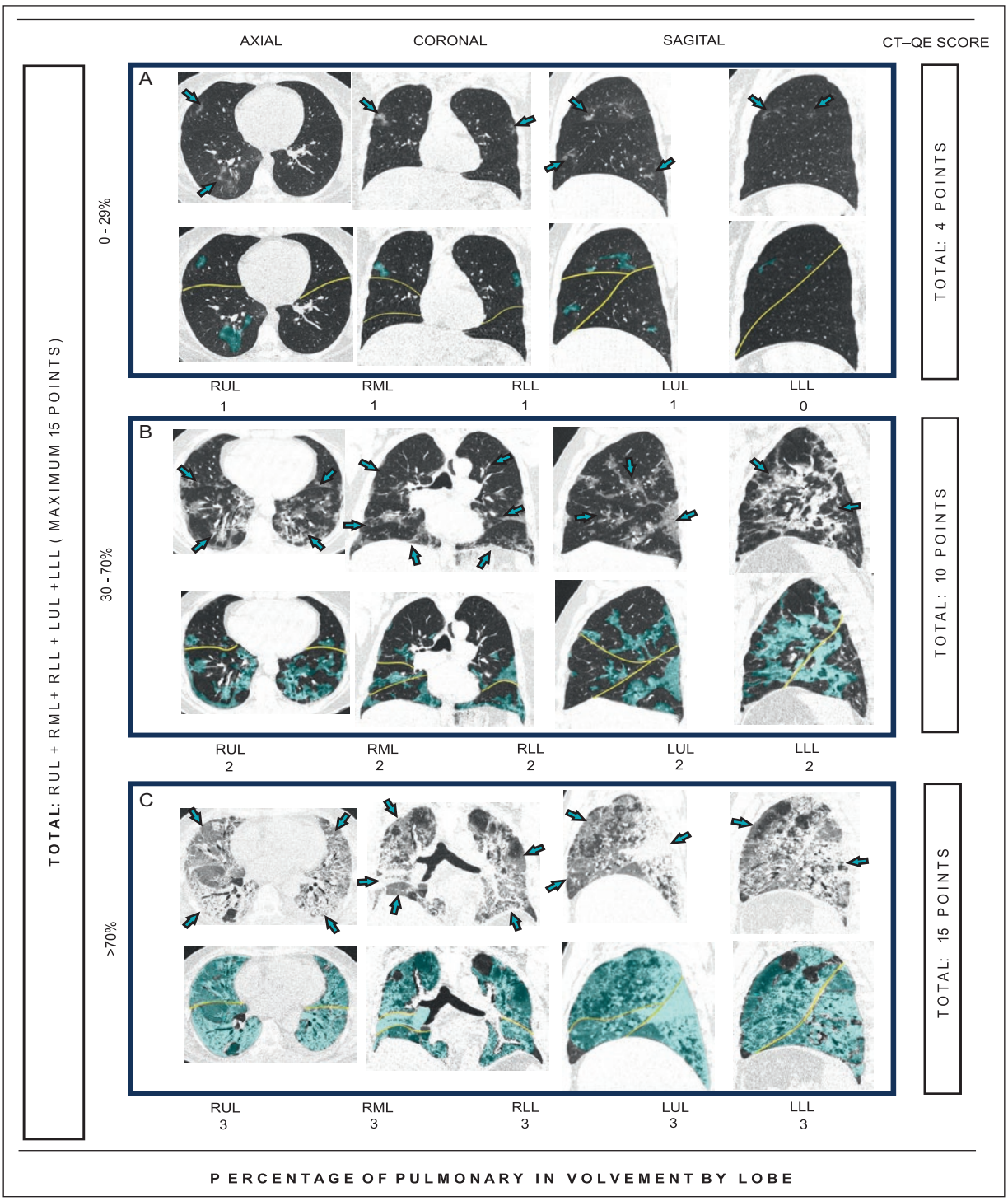

Figure 2. CT-QE score to define pulmonary involvement in three clinical cases. **A:** chest CT of a 37-year-old woman diagnosed with COVID-19 pneumonia. In the upper panel, the presence of ground glass opacity (blue arrows) was scored 0-29% in all lobes (one point each), except the LLL (0 points). In the lower panel, the areas with ground-glass opacity are shown in blue, and the lung fissures are shown in yellow. The CT-QE was scored with a total of 4 points. **B:** chest CT of a 49-year-old man diagnosed with COVID-19 pneumonia. The upper panel shows ground-glass opacity and airspace consolidation (blue arrows) with 30-70% impairment, scored as 2 points per lung lobe. In the lower panel, the areas with ground-glass opacity are shown in blue, and the lung fissures are shown in yellow. The CT-QE score was a total of 10 points. **C:** chest CT of a 57-year-old woman diagnosed with COVID-19 pneumonia. The upper panel shows areas of ground glass opacity, airspace consolidation, and crazy paving (blue arrows) > 70% involvement, scored with 3 points per lung lobe. In the lower panel, the areas with ground glass opacity are shown in blue, and the lung fissures are shown in yellow. The CT-QE score was a total of 15 points.

CT-QE: computed tomography-quantitative evaluation; COVID-19: coronavirus disease 2019; LLL: left lower lobe; LUL: left upper lobe; RLL: right lower lobe; RML: right middle lobe; RUL: right upper lobe.

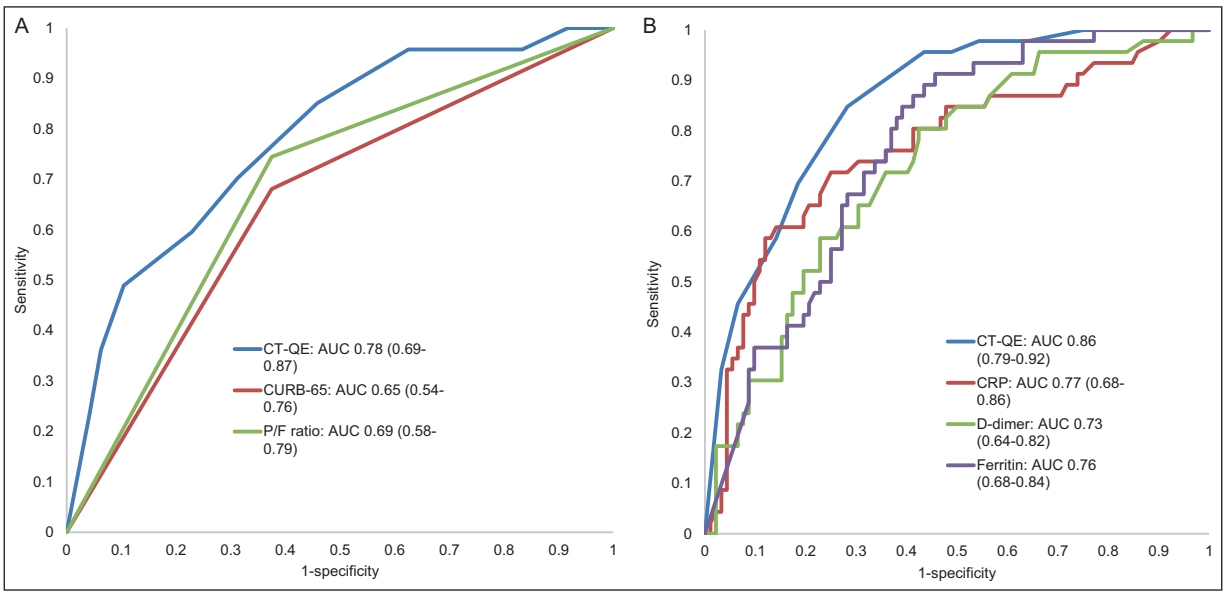

Figure 3. ROC analysis of CT-QE score compared with clinical severity scores and inflammatory markers in patients with COVID-19 pneumonia. **A:** the CT-QE score was compared with CURB-65 (> 1 point) and P/F ratio (< 200) for predicting an adverse clinical outcome. The CT-QE (AUC, 0.78) has a higher accuracy for predicting an adverse clinical outcome than CURB-65 (AUC, 0.65) and the P/F ratio (AUC, 0.69). **B:** the CT-QE score (AUC, 0.86) outperformed CRP (AUC: 0.77), D-dimer (AUC, 0.73), and ferritin (AUC, 0.76) in determining the prognosis of adverse clinical outcome in patients with COVID-19 pneumonia.

AUC: area under the curve; COVID-19: coronavirus disease 2019; CRP: C-reactive protein; CT-QE: computed tomography-quantitative evaluation; P/F Ratio: ratio of the partial pressure of arterial oxygen (PaO_2) to the fraction of inspired oxygen (FiO_2).

case, 1 point was assigned to each lung lobe as the observed involvement was between 0% and 29% of the total volume of the affected lung lobe, giving a cumulative total of 4 points. In the second case, pulmonary involvement in each lobe was between 50% and 70% of the total volume per lobe and was assigned 2 points, giving a cumulative total of 10 points. In the third case, the pulmonary involvement in each lobe was > 70% and scored 3 points per lobe, giving a CT-QE score of 15.

The Youden index showed that the best cutoff of the CT-QE score was 6-9 points for management in the hospital ward ($p < 0.001$) and ≥ 10 points for ICU admission with adverse clinical outcomes or death ($p < 0.001$). In a ROC curve, the CT-QE score (AUC, 0.78) showed higher accuracy for adverse clinical outcomes than the CURB-65 score (AUC, 0.65) and the P/F ratio (AUC, 0.69) (Figure 3). In addition, the CT-QE score (AUC, 0.86) outperformed CRP (AUC, 0.77), D-dimer (AUC, 0.73), and ferritin (AUC, 0.76) in determining the prognosis of adverse clinical outcomes in patients with COVID-19 pneumonia.

DISCUSSION

This study proposed a simplified and easy-to-use CT-QE score based on visual quantification of tomographic pulmonary involvement in Ecuadorian patients with COVID-19 pneumonia. The proposed CT-QE score based on tomographic findings had a higher diagnostic performance than two clinical severity scores (CURB-65 and P/F ratio) and inflammatory markers for predicting clinical outcomes. This CT-QE score can guide optimized management and resource use in the care of patients with COVID-19 pneumonia.

Chest CT is a widely used tool for assessing pulmonary infections. In an environment of limited resources and high pre-test probability, its use has been established for diagnosing COVID-19 pneumonia in patients with moderate or severe infection[17]. These advantages are complemented by the simultaneous use of clinical severity scores and inflammatory markers that allow clinicians to select the optimal management area[9]. Some scores use a complex system that assigns 0-5 points to each lobe[18] or scores of 0-5 in each of the 20 lung segments[12]. Based on the results of our study in the proposed CT-QE score, only 0-3 points are assigned to the visual quantification of each lung lobe, making the evaluation of tomographic pulmonary involvement simple and practical. The CT-QE score showed high diagnostic performance with an AUC of 0.78 for predicting the clinical outcome and classifying the management area of patients with COVID-19 pneumonia.

It was superior to the CURB-65 score (AUC, 0.65) and the P/F ratio (AUC, 0.68). The CT-QE score has a higher diagnostic performance based on visual quantification of tomographic pulmonary involvement.

The CURB-65 score is routinely used in patients with respiratory symptoms for clinical prognosis and to guide treatment[19]. We found a significant difference in the CURB-65 score between patients with favorable and adverse clinical prognoses (1.30 ± 0.78 vs. 2.04 ± 0.82, respectively; $p < 0.001$). The cutoff points for predicting mortality (> 2.04) were comparable with the Guo's study[20]. On the other hand, the CURB-65 score in our study allowed patients to be adequately classified according to the area of management at home (1.25 ± 0.85), in the hospital ward (1.43 ± 0.82), and in the ICU (2.02 ± 0.82) ($p = 0.004$). In contrast, in the study by Nguyen[7], the accuracy of the CURB-65 score in guiding the decision for inpatient or outpatient care was low. The CT-QE score was found to be correlated with the CURB-65 score in predicting a favorable or adverse clinical outcome.

Laboratory inflammatory markers, such as CRP, D-dimer, and ferritin, provide useful information for reliable clinical prognosis in patients with COVID-19[5-8]. In this study, patients with an adverse clinical course had elevated levels of inflammatory markers, which is consistent with previous findings[19,21]. The CT-QE score (AUC, 0.86) outperformed CRP (AUC, 0.77), D-dimer (AUC, 0.73), and ferritin (AUC, 0.76) in determining the prognosis of adverse clinical outcomes in patients with COVID-19 pneumonia.

The strengths of this study were the population, which included patients with COVID-19 pneumonia with favorable and adverse outcomes, and the fact that the CT-QE score is a simple and practical visual quantification of chest CT findings. The interobserver agreement between readers was almost perfect. The limitations of the study include its retrospective design performed at a single center. In addition, visual quantification of tomographic pulmonary involvement is subjective and may need validation to achieve reproducible and comparable results for radiologists with initial and intermediate experience in chest CT assessment. The CT-QE score must be validated before it can be widely used in clinical practice.

CONCLUSION

This study showed that the proposed CT-QE score is simple and easy to use, with high diagnostic performance for patients with COVID-19 pneumonia, and provides an even more accurate prognosis than some clinical severity scores and inflammatory markers in predicting adverse clinical outcomes and classification for outpatient and inpatient management. There is a need to validate the clinical application of the CT-QE score in prospective cohort studies and larger populations.

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Conflicts of interest

The authors declare no conflicts of interest.

Ethical disclosures

Protection of individuals. This study complied with the Declaration of Helsinki (1964) and its amendments.

Confidentiality of data. The authors declare that they followed their center's protocol for sharing patient data.

Right to privacy and informed consent. Informed consent was not required for this observational study of information collected during routine clinical care.

Use of artificial intelligence. The authors state that they did not use generative artificial intelligence to prepare this manuscript and/or create tables, figures, or figure legends.

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