Right Ventricle Dilation Detected on Point-of-Care Ultrasound Is a Predictor of Poor Outcomes in Critically Ill Patients With COVID-19

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Background: During the COVID-19 pandemic, the need for judicious use of diagnostic tests and to limit personnel exposure has led to increased use and dependence on point-of-care ultrasound (POCUS) examinations. We reviewed POCUS findings in patients admitted to the intensive care unit (ICU) for acute respiratory failure with COVID-19 and correlated the findings to severity of illness and 30-day outcomes.

Methods: Patients admitted to the ICU in March and April 2020 were reviewed for inclusion (acute hypoxemic respiratory failure secondary to COVID-19 pneumonia; documentation of POCUS findings).

Results: Forty-three patients met inclusion criteria. B lines and pleural thickening were associated with a lower PaO_2/FiO_2 by 71 (P = .005; adjusted R^2 = 0.24). Right ventricle (RV) dilation was more common in patients with 30-day mortality (P = .02) and was a predictor of mortality when adjusted for hypertension, diabetes mellitus, and age (odds ratio,12.0; P = .048). All patients with RV dilation had bilateral B lines with pleural irregularities.

Conclusions: Although lung ultrasound abnormalities are prevalent in patients with severe disease, RV involvement seems to be predictive of outcomes. Further studies are needed to discern the etiology and pathophysiology of RV dilation in COVID-19.

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Point-of-care ultrasound (POCUS) is increasingly being used by critical care physicians to augment the physical examination and guide clinical decision making, and several protocols have been established to standardize the POCUS evaluation.[1] During the COVID-19 pandemic, POCUS has been a valuable tool as standard imaging techniques were used judiciously to minimize exposure of personnel and use of personal protective equipment (PPE).[2]

In the US Department of Veterans Affairs (VA) New York Harbor Healthcare System (VANYHHS) intensive care unit (ICU) on initial clinical examination included POCUS, which was helpful to examine deep vein thromboses, cardiac function, and the presence and extent of pneumonia. An international expert consensus on the use of POCUS for COVID-19 published in December 2020 called for further studies defining the role of lung and cardiac ultrasound in risk stratification, outcomes, and clinical management.[3]

The objective of this study was to review POCUS findings and correlate them with severity of illness and 30-day outcomes in critically ill patients with COVID-19.

METHODS

The study was submitted to and reviewed by the VANYHHS Research and Development committee and study approval and informed consent waiver was granted. The study was a retrospective chart review of patients admitted to the VANYHHS ICU between March and April 2020, a tertiary health care center designated as a COVID-19 hospital.

Patients admitted to the ICU aged > 18 years with a diagnosis of acute hypoxemic respiratory failure, diagnosis of COVID-19, and documentation of POCUS findings in the chart were included in the study. A patient was considered to have a COVID-19 diagnosis following a positive SARS-CoV-2 polymerase chain reaction test documented in the electronic health record (EHR). Acute respiratory failure was defined as hypoxemia < 94% and the need for either supplemental oxygen by nasal cannula > 2 L/min, high flow nasal cannula, noninvasive ventilation, or mechanical ventilation.

To minimize personnel exposure, initial patient evaluations and POCUS examinations were performed by the most senior personnel (ie, fellowship trained, board-certified pulmonary critical care attending physicians or pulmonary and critical care fellowship

TABLE 1 Baseline Characteristics

Characteristics	Discharged Within 30 d	Mortality Within 30 d	*P* value
No.	14	24	
Age, mean (SD), y	64 (11)	71 (9)	.03
Female, No. (%)	1 (7)	1 (4)	.99
Hypertension, No. (%)	11 (77)	20 (83)	.99
Chronic obstructive pulmonary disease, No. (%)	0 (0)	6 (25)	.12
Diabetes mellitus, No. (%)	5 (36)	16 (67)	.13
Smoking history, No. (%)	6 (43)	11 (46)	.10
White blood cells, mean (SD), K/uL	14.5 (6)	31 (10)	.02
C-reactive protein, mean (SD), mg/dL	10 (7)	23 (10)	< .001
Lactate, mean (SD), mmol/L	1.96 (0.35)	2.76 (1.97)	.21
Interleuken-6, mean (SD), pg/mL	265 (225)	354 (294)	.46
Ferritin, mean (SD), ng/mL	1062 (574)	1302 (508)	.19
Troponin, mean (SD), ng/mL	0.12 (0.11)	3.17 (11)	.31
D-dimer mean (SD), ng/mL	7576 (13,173)	11,464 (15,342)	.44
PaO_2/FiO_2, mean (SD)	135.6 (64)	88 (41)	.02
B lines with irregular pleura (B'), No. (%)	7 (50)	18 (75)	.16
Reduced left ventricular function, No. (%)	3 (21)	3 (12.5)	.79
B lines without irregular pleura (B), No. (%)	12 (86)	20 (83)	.99
Right ventricular dilation, No. (%)	0 (0)	10 (42)	.02
Mechanical ventilation, No. (%)	6 (43)	23 (96)	.001

trainees). Three members of the team had certification in advanced critical care echocardiography by the National Board of Echocardiography and oversaw POCUS imaging. POCUS examinations were performed with a GE Heathcare Venue POCUS or handheld unit. After use, ultrasound probes and ultrasound units were disinfected with wipes designated by the manufacturer and US Environmental Protection Agency for use during the COVID-19 pandemic.

The POCUS protocol used by members of the team was as follows: POCUS lung—at least 2 anterior fields and 1 posterior/lateral field looking at the costophrenic angle on each hemithorax with a phased array or curvilinear probe. A linear probe was used to look for subpleural changes per physician discretion.[4,5] Lung ultrasound findings in anterior lung fields were documented as A lines, B lines (as defined by the bedside lung ultrasound in emergency [BLUE] protocol) anterior pleural abnormalities or consolidations.[4,5] The costophrenic point findings were documented as presence of consolidation or pleural effusion.

The POCUS cardiac examination consisted of parasternal long and short axis views, apical 4 chamber view, subcostal and inferior vena cava (IVC) view. Left ventricular (LV) ejection fraction was visually estimated as reduced or normal. Right ventricular (RV) dilation was considered present if RV size approached or exceeded LV size in the apical 4 chamber view. RV dysfunction was considered present if in addition there was flattening of interventricular septum, RV free wall hypokinesis or reduced tricuspid annular plane systolic excursion (TAPSE).[6] IVC was documented

TABLE 2 POCUS Findings by Mechanical Ventilation Need

Characteristics	Noninvasive O_2 Therapy, No. (%)	Mechanical Ventilation, No. (%)	*P* value
No.	9	20	
A lines bilaterally/A profile	1 (11)	3 (10)	.99
B lines bilaterally/B profile	3 (33)	7 (24)	.91
B lines + pleural irregularities/B'	5 (56)	19 (66)	.88
Consolidation	0 (0)	1 (3)	.99
Left ventricular ejection fraction reduced	2 (22)	4 (14)	.93
Right ventricular dilation	0 (0)	10 (35)	.11
30-day mortality	1 (11)	23 (80)	.001

as collapsible or plethoric by size and respirophasic variability (2 cm and 50%). Other POCUS examinations including venous compression were done at the discretion of the treating physician.[7] POCUS was also used for the placement of central and arterial lines and to guide fluid management.[8]

The VA EHR and Venue image local archives were reviewed for patient demographics, laboratory findings, imaging studies and outcomes. All ICU attending physician and fellow notes were reviewed for POCUS lung, cardiac and vascular findings. The chart was also reviewed for management changes as a result of POCUS findings. Patients who had at minimum a POCUS lung or cardiac examination documented in the EHR were included in the study. For patients with serial POCUS the most severe findings were included.

Patients were divided into 2 groups based on 30-day outcome: discharge home vs mortality for comparison. POCUS findings were also compared by need for mechanical ventilation. Patients still hospitalized or transferred to other facilities were excluded from the analysis. A Student *t* test was used for comparison between the groups for continuous normally distributed variables. Linear and stepwise regression models were used to evaluate univariate and multivariate associations of baseline characteristics, biomarker, and ultrasound findings with patient outcomes. Analyses were performed using R 4.0.2 statistical software.

RESULTS

Eighty-two patients were admitted to the VANYHHS ICU in March and April 2020, including 12 nonveterans. Sixty-four had COVID-19 and acute respiratory failure. POCUS findings were documented in 43 (67%) patients. Thirty-nine patients had documented lung examinations, and 25 patients had documented cardiac examinations. Patients were divided into 2 groups by 30-day outcome (discharge home vs mortality) for statistical analysis. Five patients who were either still hospitalized or had been transferred to another facility were excluded.

Baseline characteristics of patients included in the study stratified by 30-day outcomes are shown in Table 1. The study group was predominantly male (95%). Patients with poor 30-day outcomes were older, had higher white blood cell counts, more severe hypoxemia, higher rates of mechanical ventilation and RV dilation (Figures 1, 2, 3, 4, and 5). RV dilation was an independent predictor of mortality (odds ratio [OR], 12.0; $P = .048$).

Serial POCUS documented development or progression of RV dilation and dysfunction from the time of ICU admission in 4 of the patients. The presence of B lines with irregular pleura was predictive of a lower arterial pressure of oxygen to fraction of inspired oxygen ratio (PaO_2/FiO_2) by a value of 71 compared with those without B lines with irregular pleura ($P = .005$, adjusted $R^2 = 0.238$). All patients with RV dilation had bilateral B lines with pleural irregularities on lung ultrasound. Vascular POCUS detected 4 deep vein thromboses (DVT).[7] An arterial thrombus was also detected on focused examination. There was a higher mortality in patients who required mechanical ventilation; however, there was no difference in POCUS characteristics between the groups (Table 2).

Two severely hypoxemic patients received systemic tissue plasminogen activator (TPA) after findings of massive RV dilation with signs of volume and pressure overload and clinical suspicion of pulmonary embolism (PE). One of these patients also had a popliteal DVT. Both patients were too unstable to transport for additional imaging or therapies. Therapeutic anticoagulation was initiated on 4 patients with positive DVT examinations.

In a fifth case an arterial thrombectomy and anticoagulation was required after diminished pulses led to the finding of an occlusive brachial artery thrombus on vascular POCUS.

DISCUSSION

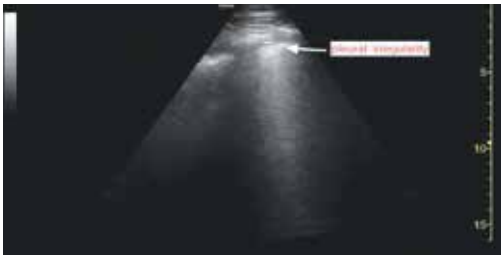
POCUS identified both lung and cardiac features that were associated with worse outcomes. While lung ultrasound abnormalities were very prevalent and associated with worse PaO_2 to FiO_2 ratios, the presence of RV dilation was associated most clearly with mortality and poor 30-day outcomes in the critical care setting.

Lung ultrasound abnormalities were pervasive in patients with acute respiratory failure and COVID-19. On linear regression we found that presence with bilateral B lines and pleural thickening was predictive of a lower PaO_2/FiO_2 (coefficient, -70; $P = .005$). Our study found that B lines with pleural irregularities, otherwise known as a B' profile per the BLUE protocol, was seen in patients with severe COVID-19. Thus severe acute respiratory failure secondary to COVID-19 has similar lung ultrasound findings as non-COVID-19 acute respiratory distress syndrome (ARDS).[4,5] Based on prior lung ultrasound studies in ARDS, lung ultrasound findings can be used as an alternate to chest radiography for the diagnosis of ARDS in COVID-19 and predict the severity of ARDS.[9] This has particular implications in overwhelmed and resource poor health care settings.

We found no difference in 30-day mortality based on lung ultrasound findings or profile, probably because of small sample size or because the findings were tabulated as profiles and not differentiated further with lung ultrasound scores.[10,11] However, there was a significant difference in RV dilation between the 2 groups by 30 days and its presence was found to be a predictor of mortality even when controlled for hypertension and diabetes mellitus ($P = .048$) with an OR of 12. RV dysfunction in patients with ARDS on mechanical ventilation ranges from 22 to 25% and is typically associated with high driving pressures.[12-14] The mechanism is thought to be multifactorial including hypoxemic vasoconstriction in the pulmonary vasculature in addition to the increased transpulmonary pressure.[15] While all of the above are at play in COVID-19 infection, there is reported damage to the pulmonary vascular endothelium and resultant hypercoagulability and thrombosis that further increases the RV afterload.[16]

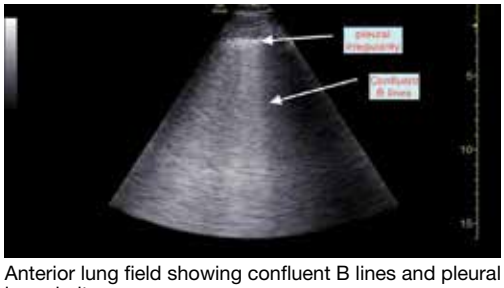
While RV strain and dysfunction indices done by an echocardiographer would be ideal, given the surge in infections and hospitalizations and strain on health care resources, POCUS by the treating or examining clinician was considered the only feasible way to screen a large number of patients.[17] Identification of RV dilation could influence clinical management in-

FIGURE 1 Lung Ultrasound, Phased Array Probe With Tissue Harmonics On



Anterior right lung showing pleural irregularity and thickening.

FIGURE 2 Lung Ultrasound, Phased Array Probe, Anterior Lung Field, Tissue Harmonics Off



Anterior lung field showing confluent B lines and pleural irregularity.

FIGURE 3 Lung Ultrasound, Linear Probe

Anterior lung field showing subpleural consolidation.

FIGURE 4 Phased Array Probe, Lateral Lung Field, Irregular Pleura With B Lines

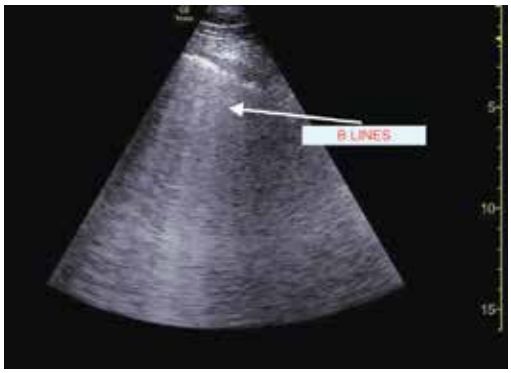


FIGURE 5 Right Ventricular Dilation With Volume and Pressure Overload

cluding workup for venous thromboembolic disease and optimization of lung protective strategies. Further studies are needed to understand the particular etiology and pathophysiology of COVID-19 associated RV dilation. Given increased thrombosis events in COVID-19 infection we believe a POCUS vascular examination should be included as part of evaluation especially in the presence of increased D-dimers and has been discussed above for its important role in working up RV dilation.[18]

Limitations

Our study has several limitations. It was retrospective in nature and involved a small group of individuals. There was some variation in POCUS examinations done at the discretion of the examining physician. We did not have a blinded observer independently review all images. Since RV dilation was documented only when RV size approached or exceeded LV size in the apical 4 chamber view representing moderate or severe dilation, we may be underreporting the prevalence in critically ill patients.

CONCLUSIONS

POCUS is an invaluable adjunct to clinical evaluation and procedures in patients with severe COVID-19 with the ability to identity patients at risk for worse outcomes. B lines with pleural thickening is a sign of severe ARDS and RV dilatation is predictive of mortality. POCUS should be made available to the treating physician for monitoring and risk stratification and can be incorporated into management algorithms.

Visit mdedge.com/fedprac or doi:10.12788/fp.0177 for additional point-of-care ultrasound videos.

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