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# Transthoracic Echocardiography in Prone Patients With Acute Respiratory Distress Syndrome: A Feasibility Study

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**Objectives:** Patients with acute respiratory distress syndrome are at risk for developing cardiac dysfunction which is independently associated with worse outcomes. Transthoracic echocardiography is an ideal imaging modality for goal-directed assessment and optimization of cardiac function and volume status. Prone positioning, while demonstrated to improve oxygenation, offload the right ventricle, and reduce short-term mortality in acute respiratory distress syndrome, has previously precluded transthoracic echocardiography on these patients. The purpose of this study was to assess the ability to perform focused transthoracic echocardiography examinations on acute respiratory distress syndrome patients in the prone position.

**Design:** We performed a cross-sectional study of critically ill patients hospitalized for acute respiratory distress syndrome due to coronavirus disease 2019.

**Setting:** This study was conducted in medical and surgical intensive units in a tertiary hospital.

**Patients:** We examined 27 mechanically ventilated and prone patients with acute respiratory distress syndrome due to coronavirus disease 2019. Participants were examined at the time of enrollment in an ongoing clinical trial (NCT04306393), and no patients were excluded from echocardiographic analysis.

**Interventions:** None.

**Measurements and Main Results:** We were able to perform transthoracic echocardiography and obtain satisfactory images for quantitative assessment of right ventricular function in 24 out of 27 (88.9%) and left ventricular function in 26 out of 27 (96.3%) of patients in the

prone position, including many who were obese and on high levels of positive end-expiratory pressure ( $\geq 15$  cm H<sub>2</sub>O).

**Conclusions:** Transthoracic echocardiography can be performed at the prone patient's bedside by critical care intensivists. These findings encourage the use of focused transthoracic echocardiography for goal-directed cardiac assessment in acute respiratory distress syndrome patients undergoing prone positioning.

**Key Words:** acute respiratory distress syndrome; coronavirus disease 2019; critical care; prone; transthoracic echocardiography; ultrasound

The coronavirus disease 2019 (COVID-19) pandemic has resulted in a drastic increase in the number of patients with acute respiratory distress syndrome (ARDS), many of whom will require prone positioning to improve oxygenation. Transthoracic echocardiography (TTE) is a noninvasive tool that can provide a rapid assessment of cardiac function and volume status. It is often used to guide management by assessing response to interventions or to perform serial monitoring. Focused TTE assessment in ARDS patients may offer clinical benefits from hemodynamic monitoring and optimization of cardiac function and volume status to facilitate weaning from mechanical ventilation (1, 2). Prone positioning, while demonstrated to increase oxygenation and reduce mortality in ARDS (1), has previously precluded TTE examinations due to the perception that transthoracic windows cannot be obtained in the prone position. In this study, we describe a technique and demonstrate the feasibility of performing focused TTE examinations on mechanically ventilated patients with COVID-19 ARDS in the prone position.

## MATERIALS AND METHODS

We performed TTE on critically ill adults with ARDS secondary to COVID-19 infection admitted to the medical and surgical ICUs at a tertiary hospital. Patients were examined at the time of enrollment in an institutional review board-approved randomized clinical

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trial of nitric oxide versus placebo for the treatment of COVID-19 (NCT04306393). All patients were intubated and receiving mechanical ventilation at the time of examination. Our study population was subject to the exclusion criteria of the trial which included a history of lung malignancy or lung transplant, the presence of severe burns (> 40% body surface area), the presence or presumed presence of severe neurologic deficit, those receiving renal replacement therapy, or the presence of an irreversible condition with 6-month mortality greater than 50%. No patients were excluded from echocardiographic analysis once enrolled in the trial.

### Image Acquisition and Review

TTE images were obtained using the Philips CX50 portable ultrasound machine (Philips Healthcare, Andover, MA) and a phased array transducer. A three-lead electrocardiogram was recorded throughout each examination, with lead placement as follows: right arm lead on the patient's right shoulder, left arm lead on the patient's left shoulder, and left leg lead on the patient's left flank. All examinations were performed by Dr. Gibson. All images, including quantitative assessments, were reviewed for adequacy through visual inspection by an intensivist (M.G.C.) certified in critical care echocardiography by the National Board of Echocardiography. Studies were interpreted by discussion between the examiner (L.E.G.) and the certified intensivist (M.G.C.).

### Patient Positioning

We used the "swimmer position" to perform TTE on prone patients (3). To achieve this, the patient's left arm was extended overhead at the shoulder with the elbow bent. A pillow was placed under the left shoulder to slightly elevate the lateral chest from the bed, allowing space for the ultrasound transducer. In order to prevent disruption of the endotracheal tube from the extended left arm, the patient's head was turned to the right (Fig. 1).

### Obtaining the Apical Window

Exams began with the apical window. The ultrasound transducer was placed vertically on the left flank with the indicator directed posteriorly, as shown in Figure 1A. The window was obtained in the traditional apical position, at the point of maximal pulsation

near the midclavicular line in the fourth or fifth intercostal space. Once the apical four-chamber view was achieved, an apical five-chamber was obtained by tilting the probe anteriorly. Views were considered adequate if all four chambers (apical four-chamber) and also addition of the left ventricular (LV) outflow tract (apical five-chamber) could be visualized.

### Obtaining the Lateral Inferior Vena Cava Window

Next, a view of the inferior vena cava (IVC) was obtained by repositioning the transducer at the right flank. The transducer was placed horizontally with the indicator directed toward the patient's head, as shown in Figure 1B. Once the IVC was found, a subcostal short-axis view or four-chamber view was obtained by tilting the probe toward the left shoulder and rotating the probe clockwise. The lateral IVC view was considered adequate if the IVC and right atrium could be visualized.

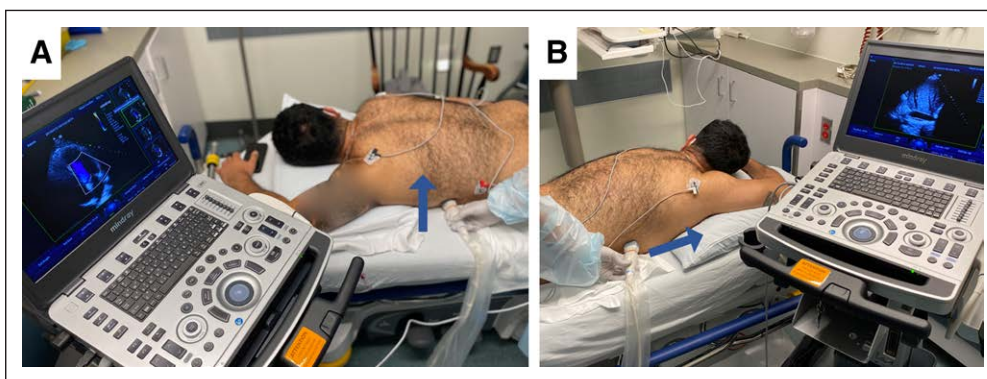
### Assessing Cardiac Function

Quantitative assessments of cardiac function were performed according to the most recent recommendations from the American Society of Echocardiography (4, 5). Representative images of right ventricular (RV) assessment obtained on our patients are shown in Figure 2. From the apical four-chamber view, RV function was assessed by chamber size (Fig. 2A), tricuspid annular plane systolic excursion (TAPSE) in M-mode (Fig. 2B), and RV peak systolic tricuspid annulus velocity (RV S') using tissue Doppler imaging (Fig. 2C). Pulmonary pressures were assessed by tricuspid regurgitation peak gradient (TR PG) using color (Fig. 2D) and continuous-wave Doppler (Fig. 2E). We also performed agitated saline bubble studies when requested by the clinical team to determine the presence of intracardiac shunting. From the lateral subcostal window, we estimated right atrial pressure by the size and collapsibility/distensibility of the IVC (Fig. 2F).

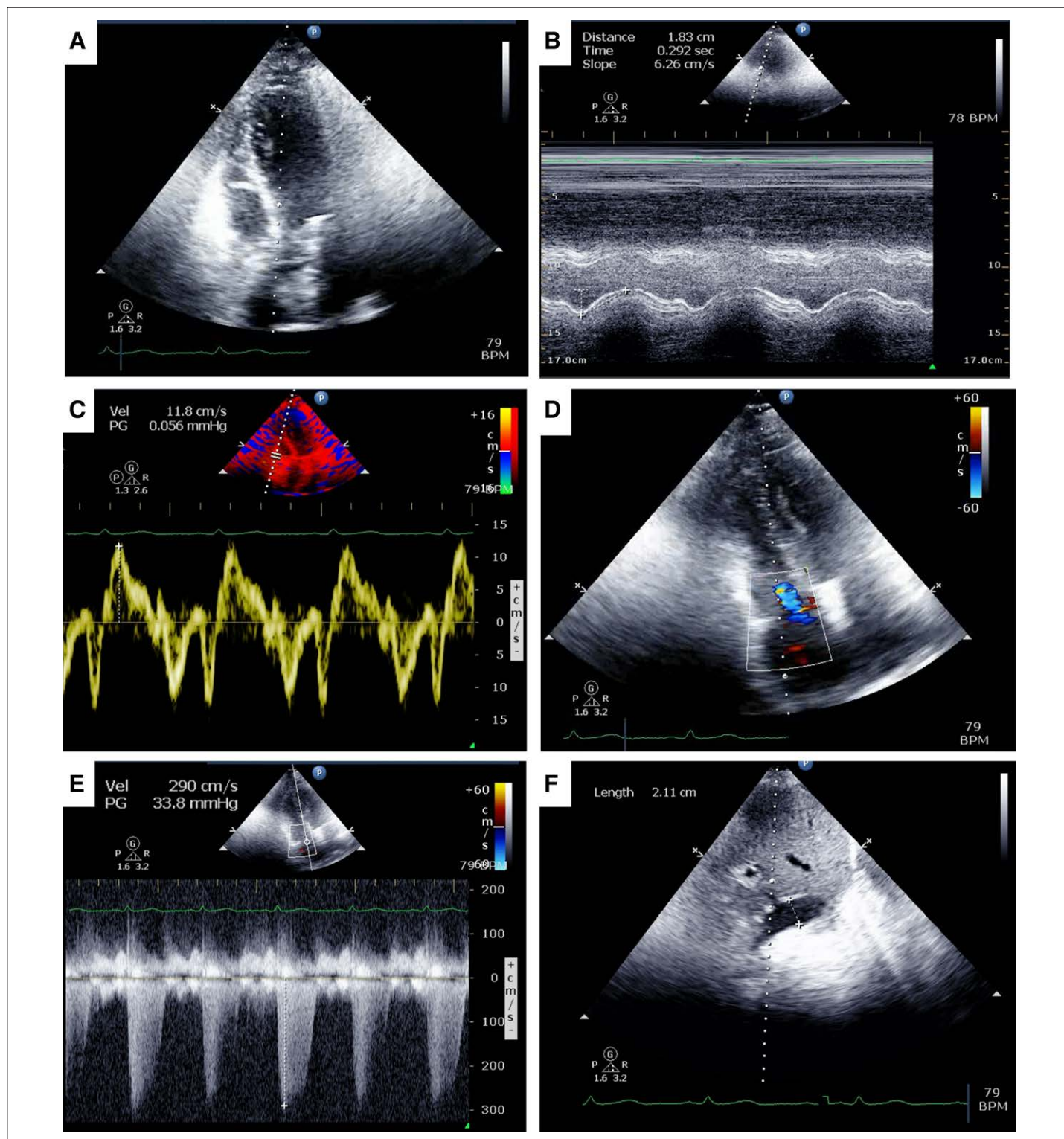
Acknowledging that LV dysfunction may also contribute to elevated pulmonary pressures, we assessed variables of LV systolic and diastolic function. Representative images of LV assessment obtained on our patients are shown in Figure 3. From the apical four-chamber view, we assessed chamber size, mitral annular plane systolic excursion (MAPSE) (Fig. 3A), mitral inflow signal (E and A) by pulsed-wave Doppler (Fig. 3B), and motion of the mitral annulus (e' and a') using tissue Doppler imaging (Fig. 3C). From the apical five-chamber view, we measured the velocity time integral (VTI) of the LV outflow tract and its variation with positive pressure ventilation (Fig. 3D).

## RESULTS

A total of 27 mechanically ventilated patients with COVID-19 ARDS were examined by TTE while in the prone position (Table 1). Patients were 37% female and 63% male, with a mean age of  $55 \pm 11$  years, body mass index (BMI)  $31 \pm 5.1$  kg/m<sup>2</sup>, and were on  $13 \pm$

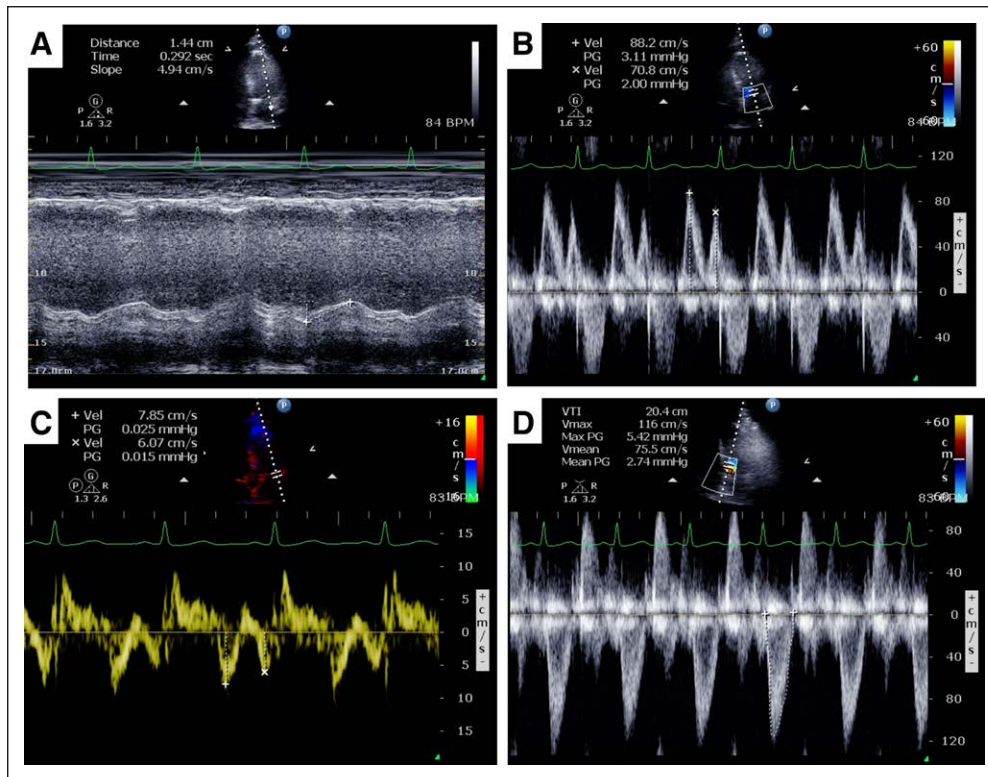


**Figure 1.** Patient positioning for prone transthoracic echocardiography, with the left shoulder slightly elevated by a pillow support. To obtain the apical four-chamber view, the transducer is placed along the left anterior axillary line at the fourth to fifth intercostal space with the indicator directed posteriorly (A; blue arrow). To obtain a lateral inferior vena cava view, the transducer is placed between the right anterior and midaxillary lines at the fifth to sixth intercostal space with the indicator directed toward the patient's head (B; blue arrow).



**Figure 2.** Assessments of right ventricular (RV) function performed on a patient in the prone position including apical four-chamber view (**A**; **Supplemental Video 1**, Supplemental Digital Content 1, <http://links.lww.com/CCX/A256>; **legend**, Supplemental Digital Content 6, <http://links.lww.com/CCX/A261>) for comparison of chamber sizes (**A**), tricuspid annular plane systolic excursion (**B**), RV peak systolic tricuspid annulus velocity (**C**), color Doppler across the tricuspid valve showing a regurgitant jet (**D**; **Supplemental Video 2**, Supplemental Digital Content 2, <http://links.lww.com/CCX/A257>; **legend**, Supplemental Digital Content 6, <http://links.lww.com/CCX/A261>), continuous-wave Doppler of the same regurgitant jet to obtain the tricuspid regurgitant peak gradient (**E**), and lateral inferior vena cava (IVC) view for measurement of IVC diameter and distensibility/collapsibility index (**F**). BPM = beats per minute, PG = peak gradient, Vel = velocity.





**Figure 3.** Assessments of left ventricular (LV) function performed on a patient in the prone position including mitral annular plane systolic excursion (A), pulsed-wave Doppler of the mitral inflow (E and A waves) (B), pulsed-wave tissue Doppler of the mitral annular velocities (e' and a') (C), and pulsed-wave Doppler of the LV outflow tract velocity time integral (D). BPM = beats per minute, max PG = maximum peak gradient, mean PG = mean peak gradient, PG = peak gradient, Vel = velocity, Vmax = maximum velocity, Vmean = mean velocity, VTI = velocity time integral.

3.1 cm H<sub>2</sub>O of positive end-expiratory pressure (PEEP) at the time of examination (range, 4–19 cm H<sub>2</sub>O).

Adequate apical four-chamber views were obtained in all patients, and adequate five-chamber views were obtained in 26 out of 27 patients (96.3%). Adequate lateral IVC windows were obtained in 25 out of 27 patients (92.6%). In the first two patients studied, the lateral IVC window was not attempted as this was not part of our initial protocol for TTE examination.

Adequate quantitative assessment of RV function, which included TAPSE, RV S', and TR PG, was performed in 24 out of 27 patients (88.9%). Adequate quantitative assessment of LV function, which included mitral inflow velocities, mitral annulus peak velocities, MAPSE, and LV outflow tract VTI, was performed in 26 out of 27 patients (96.3%).

At the request of the clinical team, we performed an agitated saline bubble study in one patient to determine the presence of intracardiac shunting that may be exacerbated by high levels of PEEP (Fig. 4).

## DISCUSSION

### TTE Can Be Reliably Performed on Obese Patients in the Prone Position on High PEEP

Obesity and high levels of PEEP ( $\geq 15$  cm H<sub>2</sub>O) have been shown to have a high failure rate in critically ill patients, and transesophageal echocardiography (TEE) has been suggested as the modality

of choice (6, 7). In this study, we were unable to obtain an adequate TR PG on three patients, all of whom were on greater than or equal to 10 cm H<sub>2</sub>O PEEP. However, we found that prone positioning permitted focused TTE examination to assess RV and LV function in the vast majority (> 85%) of ARDS patients including many who were obese and on high levels of PEEP. We were also able to detect valvular abnormalities in three prone patients that had not been previously documented.

### Prone Positioning May Enhance Image Quality by Anterior Cardiac Displacement

Chino and Marks (8) previously found that the lateral and superior aspects of the heart were displaced anteriorly by 2 cm in the prone position, and the volume of interposed lung between the heart and chest wall when lying prone is markedly reduced (3 vs 25 mL). This could translate to less acoustic barrier and superior image quality in the prone versus supine position. Particularly in ARDS, high levels of PEEP and diffuse B lines from interstitial edema

in overlying lung fields can further obscure echocardiographic images. Interestingly, we noted improved image quality in the prone position for multiple examined patients including many who were obese and on high levels of PEEP. Apical views obtained from the same patient taken in the supine (Fig. 5A) and prone (Fig. 5B) positions are shown, demonstrating a case in which better delineation of the cardiac chambers was obtained in the prone position. Although we found that the “swimmer position” (3) allowed for the best visualization of cardiac chambers in the prone position, others (9) have recently described image acquisition in prone patients without the need to adopt this position.

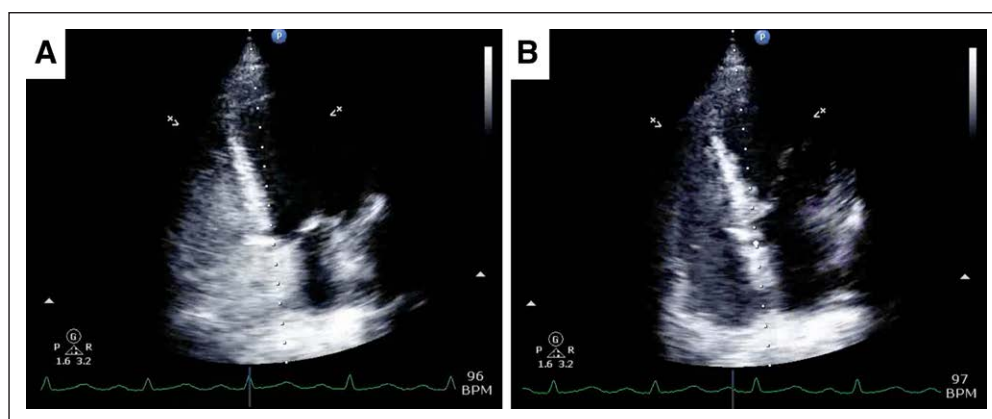
### TTE Is the Optimal Imaging Modality in Prone ARDS Patients

Experts have historically considered TEE to be preferred over TTE for assessing prone patients due to superior image quality (10, 11). Although TEE may provide higher image quality, the images we obtained by TTE were adequate for focused assessment of RV and LV function. TTE is less labor intensive, poses far fewer risks to the patient, and can be readily performed by critical care physicians at the bedside of prone ARDS patients. Furthermore, TEE presents a rare but potentially catastrophic risk of esophageal perforation (12–14). TEE probe insertion and manipulation can be cumbersome and technically challenging in the prone position, further increasing risk for mechanical complications (15). Given that many patients with ARDS will have underlying respiratory

**TABLE 1. Characteristics of Patients Examined in the Prone Position**

n	Age	Sex	Body Mass Index (kg/m <sup>2</sup> )	Positive End-Expiratory Pressure (cm H <sub>2</sub> O)	Views			Quantitative Assessment	
					Apical Four-Chamber	Apical Five-Chamber	Lateral Inferior Vena Cava	Right Ventricular	Left Ventricular
1	66	Male	26	10	✓	✓		✓	✓
2	35	Male	41	16	✓	✓		✓	✓
3	51	Male	37	13	✓		✓	✓	
4	51	Male	27	10	✓	✓	✓		✓
5	43	Male	32	14	✓	✓	✓	✓	✓
6	56	Female	24	15	✓	✓	✓	✓	✓
7	69	Female	34	14	✓	✓	✓	✓	✓
8	56	Male	30	12	✓	✓	✓	✓	✓
9	65	Male	26	19	✓	✓	✓	✓	✓
10	63	Female	31	12	✓	✓	✓	✓	✓
11	55	Female	30	15	✓	✓	✓	✓	✓
12	60	Male	28	14	✓	✓	✓	✓	✓
13	40	Female	29	14	✓	✓	✓	✓	✓
14	42	Female	43	14	✓	✓	✓	✓	✓
15	60	Female	36	16	✓	✓	✓	✓	✓
16	66	Male	26	10	✓	✓	✓	✓	✓
17	65	Male	26	12	✓	✓	✓	✓	✓
18	53	Male	29	14	✓	✓	✓		✓
19	72	Female	33	14	✓	✓	✓	✓	✓
20	64	Female	34	15	✓	✓	✓	✓	✓
21	63	Male	23	19	✓	✓	✓		✓
22	45	Male	24	4	✓	✓	✓	✓	✓
23	37	Male	27	12	✓	✓	✓	✓	✓
24	72	Female	33	14	✓	✓	✓	✓	✓
25	39	Male	31	8	✓	✓	✓	✓	✓
26	38	Male	31	12	✓	✓	✓	✓	✓
27	55	Male	36	12	✓	✓	✓	✓	✓

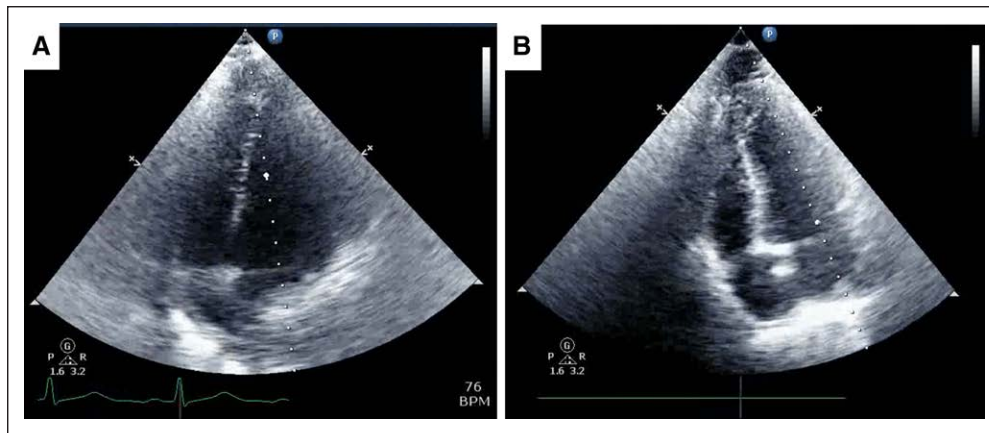
✓ indicates that the view could be adequately imaged or the structure could be quantitatively assessed.



**Figure 4.** Agitated saline bubble echocardiography study performed on a patient in the prone position (**Supplemental Video 3**, Supplemental Digital Content 3, <http://links.lww.com/CCX/A258>; legend, Supplemental Digital Content 6, <http://links.lww.com/CCX/A261>). Injection of agitated saline caused opacification of the right ventricular (**A**) without the appearance of bubbles in the left heart (**B**), indicating absence of intracardiac shunting. BPM = beats per minute.

infections, instrumentation of the oral cavity for TEE also carries the risk of aerosolization of infectious particles, thus presenting a hazard to staff particularly in COVID-19 era. We believe that TTE has the potential to offer the greatest benefits relative to risk in terms of monitoring disease progression and response to therapies in patients with ARDS.

The ability to monitor cardiac function and optimize ventilatory and hemodynamic variables to best support the RV may improve outcomes in ARDS (16). Pulmonary artery catheterization is considered



**Figure 5.** Comparison of apical four-chamber views obtained on the same patient while positioned supine (**A; Supplemental Video 4**, Supplemental Digital Content 4, <http://links.lww.com/CCX/A259>; legend, Supplemental Digital Content 6, <http://links.lww.com/CCX/A261>) and prone (**B; Supplemental Video 5**, Supplemental Digital Content 5, <http://links.lww.com/CCX/A260>; legend, Supplemental Digital Content 6, <http://links.lww.com/CCX/A261>). Images were acquired within a 24-hr period. BPM = beats per minute.

the gold standard for monitoring pulmonary artery pressures and the transpulmonary gradient and may be indicated for some patients. Although pulmonary artery catheters are able to provide an estimate of RV afterload, they do not allow for direct assessment of RV function (17). TTE is an alternative tool that is noninvasive, poses very little risk to the patient, and can provide direct information regarding RV and LV function to make clinical decisions (18). For example, failure to wean from mechanical ventilation may be cardiac rather than respiratory in etiology, and LV diastolic dysfunction and volume status can be readily assessed

and optimized by echocardiography to facilitate weaning from mechanical ventilation (2). **Table 2** describes several indications for performing TTE in the management of critically ill patients with ARDS.

**Limitations**

Our study has several limitations. Ultrasound studies performed consecutively in the supine and prone positions, without alterations in other clinical variables, would have provided the most direct comparison of image quality but would have disrupted patient care. Efforts were made to examine patients in both positions within close temporal proximity whenever possible; however, some exams were performed up to 48 hours apart and following changes in ventilation variables and hemodynamics. The highest BMI encountered in our study was 41, and whether patients at more extreme upper limits of BMI (> 50) may be more challenging to image in the prone position warrants further investigation. Another limitation of performing TTE in the prone position is the inability to obtain parasternal long- and short-axis views to compute E-point septal separation and fractional shortening as additional variables to assess LV function. Despite these limitations, our findings suggest that TTE in the prone position is feasible

## TABLE 2. Indications for Performing Transthoracic Echocardiography in the Management of Critically Ill Patients With Acute Respiratory Distress Syndrome

### Potential Indications for Transthoracic Echocardiography in Critically Ill Patients With Acute Respiratory Distress Syndrome

- Optimize fluid management (e.g., left ventricular outflow tract velocity time integral variation and inferior vena cava collapsibility/distensibility index)
- Determine the presence of intracardiac shunting as a cause of hypoxemia and need for intervention (i.e., patent foramen ovale closure device)
- Guide positive end-expiratory pressure optimization while monitoring RV function
- Quantitative assessment of RV function to guide titration and weaning of pulmonary vasodilators, inotropic support, and mechanical circulatory support
- Assess for the presence of pulmonary hypertension and response to interventions
- Workup for pulmonary embolus and guide resource utilization (i.e., CT scan)
- Determine the presence of other cardiac causes of hypoxemia (e.g., ruptured papillary muscle, post-myocardial infarction ventricular septal defect)
- Assess for left ventricular diastolic dysfunction as an etiology of difficulty weaning from mechanical ventilation
- Guide the need for diuresis using diastolic markers to assess left atrial pressures
- Assist in determining the cause of undifferentiated shock
- Assess for major valvular abnormalities in order to guide hemodynamic optimization and potential need for valve repair
- Workup for consideration of mechanical circulatory support including the need for venoarterial ECMO vs venovenous ECMO, ventricular assist devices, and to exclude contraindications to mechanical circulatory support (i.e., severe aortic insufficiency)

ECMO = extracorporeal membrane oxygenation, RV = right ventricular.

in many patients and its use should be recognized as means to enhance clinical care.

## CONCLUSIONS

We have demonstrated that focused TTE examinations can be performed in the prone patient with ARDS, including in morbidly obese patients and patients on high levels of PEEP that was previously thought to be technically challenging. We hope that our findings will encourage the use of TTE to facilitate the diagnostic workup and optimization of prone patients with ARDS.

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Drs. Gibson and Chang performed data collection and analysis; both had access to all data and assumed responsibility for the submitted work. All authors wrote and reviewed the article.

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