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Case Series

Pulmonary barotrauma in mechanically ventilated coronavirus disease 2019 patients: A case series

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ABSTRACT

Background: Coronavirus disease 2019 (COVID-19) caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) may result in hypoxic respiratory failure necessitating mechanical ventilation. Barotrauma is a well-documented complication of mechanical ventilation.
Objective: To describe the presentation, characteristics, and management of mechanically ventilated patients with COVID-19 who developed barotrauma.
Methods: Retrospective case series study of 13 adult, mechanically ventilated, laboratory-confirmed COVID-19 positive patients admitted between 3/15/2020 and 4/14/2020 to a community hospital in New York City. Patient demographics, clinical course, ventilatory parameters, and radiographic results were obtained from electronic medical records. Barotrauma was defined as pneumomediastinum, subcutaneous emphysema, and or pneumothorax on chest X-ray. Descriptive analyses and Mann-Whitney *U* test were performed, where appropriate.
Results: Of the 574 COVID-19 positive patients, 139 (24.2%) needed mechanical ventilation and 13 (9.4%) of those developed barotrauma. Majority of patients were Black race (92.3%), older than age 65 (56.8%), male (69.2%), and had comorbidities (76.9%). Most common presenting symptoms were cough (84.6%) and dyspnea (76.9%). Barotrauma presentations included 3/13 pneumothoraces and pneumomediastinum, 12/13 pneumomediastinum and subcutaneous emphysema, and 1/13 pneumothorax alone. The average days on ventilator was 3.4, average positive expiratory-end pressure 15.5 cmH2O, dynamic compliance 33.8 mL/cmH2O, and P/F ratio 165. Interventions were 4/13 chest tubes and 2/13 pigtail catheters.
Conclusions: Barotrauma is a common complication of mechanical ventilation of COVID-19 patients. Despite high ventilatory pressures, tension pneumothorax is rare and barotrauma could potentially be managed conservatively. Further studies are needed to evaluate the indication and outcome of thoracostomies and conservative management.

1. Background

The Coronavirus disease 2019 (COVID-19), caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) is a contagious, mainly pulmonary infection. About 12–26% of COVID-19 patients progress to severe respiratory failure that requires mechanical ventilation and intensive care unit (ICU) admission [1,2].

Pulmonary barotrauma is a complication of positive pressure mechanical ventilation that has been shown to correlate with increased morbidity and mortality [3]. Barotrauma occurs due to alveolar rupture, which leads to an accumulation of air in extra alveolar locations leading to complications such as pneumothorax, pneumomediastinum, and subcutaneous emphysema [4].

Respiratory failure in COVID-19 patients presents as severe hypoxemia, diffuse bilateral radiographic opacities and altered lung compliance, a picture similar to Acute Respiratory Distress Syndrome (ARDS). In mechanically ventilated patients, ARDS is a major risk factor for barotrauma [5,6].

This report is from the Department of Surgery at a COVID-19

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Abbreviations

COVID-19	Coronavirus disease 2019
SARS-CoV-2	severe acute respiratory syndrome (SARS) coronavirus 2
ICU	intensive care unit
ARDS	acute respiratory distress syndrome
CPR	cardiopulmonary resuscitation
EMR	electronic medical record
PEEP	positive end-expiratory pressure
PIP	peak inspiratory pressure
MAP	mean airway pressure
Vt	tidal volume
Vt/kg	tidal volume per kilogram
RR	respiratory rate
MVe	minute ventilation
CT scan	computerized tomography scan
PTX	pneumothorax
PM	pneumomediastinum
SCE	subcutaneous emphysema
CT	chest tube
PT	pigtail
VC-AC	volume-controlled assist-control
PRVC	pressure-regulated volume control
Cdyn	dynamic compliance in ml/cmH2O
P/F =	pO2/FiO2 = arterial oxygen partial pressure/fractional inspired oxygen
SD	standard deviation

designated hospital in New York City. During the COVID-19 pandemic of 2020 we experienced a significant increase in the number of ICU consults secondary to evidence of barotrauma in patients on mechanical ventilation. For many of the patients, barotrauma presented as subcutaneous emphysema or pneumomediastinum but with insignificant or minimal pneumothorax on chest X-ray. The frequent and atypical presentation of a minimal pneumothorax, associated with pneumomediastinum and significant subcutaneous emphysema, prompted our investigation and this case series.

Here, we have outlined the presentation, characteristics, and management of a series of mechanically ventilated patients with COVID-19 pneumonia who developed barotrauma. Our study's objective is to report on individuals rather than a cohort of patients and to generate further studies that can potentially conserve resources and improve outcomes.

2. Methods

Study Design & Study Population: This is a retrospective case series study done at an academic community hospital in NYC. The study population included laboratory-confirmed COVID-19 intubated ICU patients admitted during a one-month time period (3/15/2020–4/14/2020). Our institution approved IRB exemption for this study because there was less than minimal risk for patients. Consent forms were waived because patient data was deidentified. This study has been reported in line with the PROCESS criteria [7]. We included adult confirmed COVID-19 patients with barotrauma defined as extrapulmonary air on chest radiographic report while on mechanical ventilation. Exclusion criteria included: age <18, patients with pre-existing pneumothorax or chest tube thoracostomy on presentation to the emergency department; barotrauma within 48 hours after insertion of jugular or subclavian central venous catheter; barotrauma on noninvasive ventilation and barotrauma after cardiopulmonary resuscitation (CPR) with chest compressions.

Data Collection: Patient demographics and pre-existing comorbidities were obtained from the electronic medical record (EMR). We documented the ventilatory variables at the time of barotrauma recognition, including positive end-expiratory pressure (PEEP), peak inspiratory pressure (PIP), mean airway pressure (MAP), tidal volume (Vt), tidal volume per kilogram (Vt/Kg), respiratory rate (RR), minute ventilation (MV). Dynamic lung compliance was calculated as Vt/(PIP - PEEP) = Dynamic lung compliance (ml/cmH2O) [8].

Statistical Analysis: Descriptive analysis included proportions, means, and medians where appropriate. Comparisons between patients with pneumothorax and patients with pneumomediastinum and/or subcutaneous emphysema was done using Whitney Mann *U* test with a significant P value < 0.05.

3. Results

3.1. Demographic & clinical characteristics

During the study period, 139 of the 574 COVID-19 positive patients underwent mechanical ventilation. Fifteen of these were diagnosed with barotrauma. Two patients were excluded; the first because of existing pneumothorax on presentation to emergency department and the second because the barotrauma happened while on noninvasive ventilation prior to intubation. In order to avoid potential spreading of COVID-19 and hemodynamic instability on transport, most barotrauma cases were diagnosed by portable chest X-ray and only two additionally underwent a chest Computerized Tomography (CT) scan. In both patients, the CT scan was done to rule out pulmonary embolism (negative in both). Patient demographics and co-morbidities are shown in Table 1. Our patient population consisted of a majority older, black males. Only 3/13 patients had history of chronic pulmonary disease. Cardiovascular disease (76.9%) and diabetes (69.2%) were common comorbidities.

3.2. Radiographic findings & ventilatory parameters

The most common findings on chest X-ray were subcutaneous emphysema (11/13), pneumomediastinum (10/13) and only 4/13 patients developed a pneumothorax (Fig. 1). Pneumothorax was minimal or small despite high respiratory pressures and none of the patients had a tension pneumothorax (or a complete lung collapse) (Table 2).

Treatment with a thoracostomy tube or pigtail catheter was made by an attending surgeon. Four patients who presented with pneumothorax while on positive pressure ventilation were drained to avoid an occult or potential developing tension pneumothorax (Table 2). Out of the remaining nine patients, one patient with extensive subcutaneous emphysema was drained using a pigtail catheter. The other eight patients with pneumomediastinum and/or subcutaneous emphysema were not drained during the time of this study despite positive pressure ventilation. However, they were followed closely and did not demonstrate accumulation of air in the chest cavity or soft tissues necessitating drainage.

Patients had low PaO2/FiO2 ratio and low calculated dynamic lung compliance (Table 3). Because of the similarity to ARDS, some of the principles of mechanical ventilation of ARDS patients like low tidal

Table 1
Clinical characteristics of patients with barotrauma. Asterisk (*) N = 12.

Characteristic N = 13 (Proportion)			
Age-group	18–44	0	(0%)
	45–64	3	(23.1%)
	65–74	5	(38.4%)
	75–Over	5	(38.4%)
Gender	Male	9	(69.2%)
Race	Black	12	(92.3%)
	White	1	(7.7%)
Body Mass Index	Average	28.7 kg/m^2	
	Median	27.7 kg/m^2	
Comorbidities Cardiovascular			
	Hypertension	9	(69.2%)
	Hyperlipidemia	6	(46.1%)
	Cardiovascular disease	10	(76.9%)
	Coronary artery disease	2	(15.4%)
	Congestive heart failure	1	(7.7%)
	Arrhythmias	2	(15.4%)
	Cerebrovascular disease	2	(15.4%)
Endocrine			
	Hypothyroidism	1	(7.7%)
	Diabetes Mellitus	9	(69.2%)
Pulmonary			
	Chronic Obstructive Lung Disease	2	(15.4%)
	Asthma	1	(7.7%)
Other			
	End-Stage Renal Disease	1	(7.7%)
	Cancer	2	(15.4%)
Presenting symptoms	Fever	8*	(66.6%)
		Average: 100.2 °F	
		Median: 100.5 °F	(84.6%)
	Cough	11	(76.9%)
	Dyspnea	10	(23.1%)
	Confusion	3	(15.4%)
	Diarrhea	2	
Presenting Vital Signs	Oxygen saturation	Average: 98%	
	Respiratory Rate	Median: 93%	
	Systolic Blood Pressure	Average: 23 breaths/min	
		Median: 20	
		Average: 136 mmHg	
		Median: 143 mmHg	

volume (Vt), high positive end-expiratory pressure (PEEP), low mean inspiratory pressure and high respiratory rate were used in management of these patients [9]. Table 3 summarizes the ventilator settings at the time of barotrauma.

Interestingly, when comparing ventilation settings between the four patients presenting with pneumothorax to the nine patients who presented with pneumomediastinum and/or subcutaneous emphysema, there was a tendency for a higher mean respiratory pressure (average 25.2 vs. 21.2 cmH2O), higher PEEP (average 17.5 vs. 14.5 cm H2O), higher measured peak-inspiratory pressure (PIP) (37.5 vs.31.2 cm H2O) lower calculated dynamic lung compliance (average 24.9 vs. 37.7 mL/cm H2O) and longer time on mechanical ventilation before barotrauma (average 3.7 vs. 2.7 days). These differences did not reach statistical significance (P value > 0.05). The PaO2/FiO2 ratio was also worse in the pneumothorax patients than in the pneumomediastinum/subcutaneous emphysema patients (average 108 vs. 190, respectively, P = 0.11). The average tidal volume was about 5.5 cc/kg weight in both groups.

3.3. Outcomes

By the end of the research period, 6/13 (46%) patients expired and 1 was discharged. During the peak of the pandemic at our institution, routine chest CT scans were not performed on all COVID-19 positive patients who were deemed to be too hemodynamically unstable for transport. Follow-up did not extend beyond 30-days, with discharge

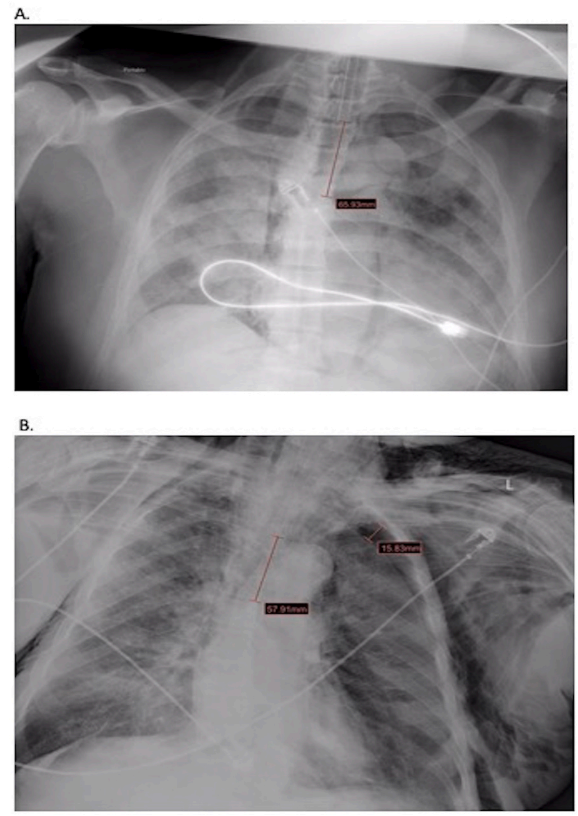

Fig. 1. Chest X-ray images intubated COVID-19 patients with barotrauma. A. Pneumomediastinum B. Pneumothorax and extensive subcutaneous emphysema

Table 2
Type of Barotrauma and Intervention. PTX = pneumothorax. PM = pneumomediastinum. SCE= subcutaneous emphysema. CT = chest tube. PT = pigtail. Check mark (✓) = pneumomediastinum is present. For subcutaneous emphysema: + = mild, ++ = mild to moderate, +++ = moderate, ++++ = severe. mm = millimeters. - = none.

Patient #	PTX Size in mm.		PM	SCE	Intervention	Outcome
	Right	Left				
1		16	✓	++++	CT	Expired
2			✓		–	Expired
3		<5	✓	++++	CT	Expired
4			✓	+	–	
5		23			PT	Discharged
6			✓	+++	–	
7		<5		++++	PT	Expired
8			✓	+	–	Expired
9			✓	++	–	Expired
10			✓	+	CT	
11			✓	+	CT	
12			✓	+	–	
13				++	–	

Table 3
Ventilation Settings, Lung Compliance, P/F Ratios, and Days on Ventilator at Time of Pulmonary Barotrauma. Pt # = patient number. VC-AC= volume-controlled assist-aontrol. PRVC = pressure-regulated volume control. PEEP = positive end-expiratory pressure in cmH2O. FiO2 = fractional inspiratory pressure in percentage. Vt = tidal volume in milliliters. Kg = kilograms. RR = respiratory rate in breaths per minute. Pmean = mean airway pressure. MVe = minute ventilation in liters per minute. Cdyn = dynamic compliance in ml/cmH2O. P/F = blood gas pO2/FiO2. Avg. = average and SD = standard deviation.

Pt #	Ventilator Mode	PEEP	Vt/kg	PIP	Pmean	FiO2	Vt	MVe	RR	Cdyn	P/F Ratio	Days on vent
1	VC-AC	20	5.75	34	26	60	460	12	18	32.8	300	2
2	VC-AC	14	4.63	32	23	100	500	13.3	14	27.7	92.9	0
3	VC-AC	15	5.71	37	22	100	400	7.3	20	18.1	221	1
4	PRVC	12	6.67	24	15	50	400	11.3	15	33.3	360	2
5	VC-AC	10	6.25	39	20	70	450	8.5	20	15.5	151.4	11
6	VC-AC	10	6.08	14	11	40	450	7.6	18	112.5	141.3	7
7	VC-AC	25	4.42	40	33	100	500	11.2	28	33.3	68	5
8	VC-AC	15	4.17	29	19	50	400	8.62	20	28.5	260	4
9	VC-AC	10	6.25	31	22	70	450	13.5	20	21.4	82.1	4
10	VC-AC	15	6.08	34	26	80	450	14.6	20	23.6	200	1
11	VC-AC	20	4.43	55	32	100	350	10.5	35	10	49.3	4
12	VC-AC	15	5.56	23	17	60	450	11.3	12	56.2	101.2	2
13	VC-AC	20	5.15	39	26	50	500	11.2	20	26.3	117.4	1
Avg.		15.5	5.5	33.15	22.5	71.5	443	10.8	20	33.8	165	3.4
SD.		4.6	0.8	9.9	6.3	22.3	45	2.23	5.9	26.2	96	0.8

from ICU, mortality, and survival being end-points. Additionally, autopsies were not routinely performed because the morgue was overwhelmed, potential safety risks to pathologists, and or family refusal.

4. Discussion

Patients with decreased lung compliance on positive pressure ventilation are at risk of over insufflation of the relatively preserved parts of the lungs. These more compliant alveoli may stretch and rupture developing pulmonary barotrauma that further compromises ventilation. COVID-19 lungs present with similar radiologic and physiologic characteristics to ARDS, and similarly may be susceptible to barotrauma [5]. Currently, there is scarce literature focusing on the characteristics of barotrauma in COVID-19 pneumonia patients. As a result, the incidence of barotrauma in mechanically ventilated COVID-19 patients is unclear. There are few reports of barotrauma in COVID-19 patients from China; Yang F. et al. reported that 1/91 (1.1%) COVID-19 ventilated patients, Yang X. et al. reported of 2/52 (3.8%) of ventilated patients, and Yeo et al. reported that 12/202 (5.9%) urgently intubated COVID-19 patients [10–12]. None of these publications, to our knowledge, performed a case series of barotrauma with detailed reports about its presentation, treatment or ventilatory settings.

In our institution, we report an incidence of 10.7% (15/139) of barotrauma in severely ill intubated COVID-19 pneumonia patients. As detailed data concerning barotrauma is not mentioned in the previous reports, we are unable to explain the potential reasons to the difference in the observed incidence of barotrauma in our patient population. Two Cochrane Database systematic reviews [13,14], one focusing on lung protective ventilation and the other on pressure-controlled versus volume-controlled ventilation in ARDS, report the rates of barotrauma to be in the range of 8.6–11.7%. Our rate of about 11% is consistent with the Cochrane reports of barotrauma in ARDS patients on mechanical ventilation. In 2005, Kaoet al. reported rates of barotrauma in mechanically ventilated patients due to SARS (Severe Acute Respiratory Syndrome) virus infection in Taiwan to be 12%, again much closer to what we experienced [15].

The presentation of barotrauma in our patients was mostly as an air accumulation in the subcutaneous tissue and or mediastinum. It was less likely to be pneumothorax visible on a portable chest X-Ray. The pleural cavity in all four patients with pneumothorax were drained. It is reasonable to speculate that with positive pressure ventilation patients may have developed tension pneumothorax otherwise. Most of the patients did not present with large pneumothorax as expected despite the positive pressure ventilation, but there is potential for occult pneumothorax [16]. We observed a trend of higher ventilatory pressures in the patients presenting with pneumothorax as compared to isolated pneumomediastinum or subcutaneous emphysema, however due to the small number of barotrauma patients (low power) there was no statistically significant difference in average PIP. It is unknown whether the tears in alveoli of the non-pneumothorax patients were less severe causing a slow air leak resulting in air traveling along the major vessels. On the other hand, even when presenting with pneumothorax and high ventilatory pressures there was no tension pneumothorax created. Menter et al. reported that in an autopsy of 21 COVID-19 patients that in all cases lung parenchyma was heavy and firm [17]. Perhaps, COVID-19 lung is too stiff to completely collapse which may explain the lack of collapsed lung and pneumothorax in our study [18]. This data suggests that ventilated COVID-19 patients who develop barotrauma may be managed conservatively.

Additionally, a case-report by Udi et al. reported 8 patients (40%) developed severe barotrauma during mechanical ventilation. Of the 8 patients, one had tension pneumothorax and four had pneumothorax not causing hemodynamic compromise [19]. All patients received chest tubes. In our study, 4/13 had pneumothorax without documentation of hemodynamic compromise. Additionally, two of these patients received chest tubes and the other two received chest pigtail catheter placement. Because none of our patients developed a tension pneumothorax, perhaps they could have been managed conservatively.

Limitations: The study population was 92% Black, which is reflective of the overall hospital demographic (89%) and not generalizable to more diverse hospitals. This study used retrospective review of the EMR which creates potential for information bias and misclassification bias. Patients that were deemed unstable for transport by clinicians received only portable chest X-ray rather than more specific chest CT scans so there are potential barotrauma patients that may have been reported as without barotrauma. In addition, patients imaged by chest X-ray supine with overlying subcutaneous emphysema could possibly had pneumothorax identifiable by CT scan. Also, since routine CT scans and autopsies were not performed, we are unable to identify potential thromboembolic events such as pulmonary embolism. In seven patients, despite free air at the mediastinum and or subcutaneous tissue, the surgeon involved decided to follow the patient without thoracostomy tube despite the positive pressure intubation. None of these patients developed life threatening complications of tension pneumothorax or tension pneumomediastinum. The number of patients is too small to make conclusions or recommendations about the necessity of drainage in similar patients. However, we recommend studies analyzing whether there are differences in outcomes when comparing conservative management to thoracostomy tube placement. Patients that did not have intervention also expired, so there is potential that there was undiagnosed pneumothorax missed where follow-up chest X-rays were not performed. Also, dynamic compliance was calculated instead of static compliance because all charts did not have required components (i.e. plateau pressure).

5. Conclusion

In conclusion, barotrauma is a common complication in mechanically ventilated COVID-19 patients but has minor clinical consequences. This is possibly due to stiff lungs that do not easily collapse. Our data suggests that close observation of mechanically ventilated COVID-19 patients with barotrauma may be sufficient and chest thoracostomy is not mandatory. However, we recommend further studies with a larger patient population to potentially guide management of mechanically ventilated patients with COVID-19.

Declaration of competing interest

The authors declare that there is no conflicts of interest or financial disclosures

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.amsu.2020.11.054.

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Ethical approval

The SUNY Downstate Health Sciences University Institutional Review Board approved exemption (IRB #11521) for the study because there was less than minimal risk for patients. Consent forms were waived because patient data was deidentified.

Consent

The SUNY Downstate Health Sciences University Institutional Review Board approved exemption (IRB #11521) for the study because there was less than minimal risk for patients. Consent forms were waived because patient data was deidentified.

Author contribution

GROUP 1: Jodi-Ann Edwards, Igal Breitman.

Conception of the work, design of the work, acquisition of data, analysis of data, interpretation of data, drafting the work, revising the work critically for important intellectual content, final approval of the version to be published, and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

GROUP 2: Abbasali Badami, Jared Bienstock

Acquisition of data, drafting the work, revising the work critically for important intellectual content, final approval of the version to be published, and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

GROUP 3: Alexander Schwartzman, Irina Kovatch, Lisa Dresner.

Drafting the work, revising the work critically for important intellectual content, final approval of the version to be published, and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Registration of research studies

1. Name of the registry: Research Registry.
2. Unique Identifying number or registration ID: researchregistry6119.
3. Hyperlink to your specific registration (must be publicly accessible and will be checked): https://www.researchregistry.com/register-now#home/registrationdetails/5f8870e2c7f02a0015d9879d/

Guarantor

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