RESEARCH ARTICLE

Pulmonary barotrauma as a complication of mechanical ventilation for management of COVID-19 associated acute respiratory distress syndrome (CARDS)

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Abstract

Objective: To identify that incidence of pulmonary barotrauma secondary to mechanical ventilation for the management of acute respiratory distress syndrome associated with coronavirus-disease-2019, and to compare it with the incidence of pulmonary barotrauma trauma secondary to mechanical ventilation associated with all the other causes.

Method: The retrospective case-control study was conducted at the Aga Khan University Hospital, Karachi, and comprised data from October 2020 to March 2021 of patients who underwent mechanical ventilation. The data was divided into two groups. Data of acute respiratory distress syndrome associated with coronavirus-disease-2019 was in group 1, and that of acute respiratory distress syndrome associated with any other cause in control group 2. Medical records were reviewed to obtain demographic and clinical data, while the institutional picture archiving and communication system was used to review radiological images. Data was analysed using SPSS 24.

Results: Of the 261 cases, 115(44%) were in group 1; 87(75.6%) males and 28(24.3%) females. There were 146(56%) controls in group 2; 96(65.7%) males and 50(34.2%) females. There were 142(54.4%) subjects aged >60 years; 61(43%) in group 1 and 81(57%) in group 2. The incidence of pulmonary barotrauma in group 1 was 39(34%) and 8(5.5%) in group 2 ($p<0.0001$).

Conclusion: Mechanical ventilation in the management of acute respiratory distress syndrome associated with coronavirus-disease-2019 was found to be associated with a significantly higher incidence of pulmonary barotrauma than acute respiratory distress syndrome associated with any other cause.

Keywords: COVID-19, Respiratory distress syndrome, Barotrauma, Pulmonary ventilation, Mediastinal emphysema.

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Introduction

Acute respiratory distress syndrome (ARDS) is a critical condition characterised by acute hypoxaemia accompanied by reduced compliance and non-cardiogenic pulmonary oedema.[1] Since the beginning of the coronavirus disease-2019 (COVID-19) pandemic, a rapid surge of ARDS cases was reported in healthcare centres across the globe, and the condition was labelled as COVID-19-related ARDS (CARDS). Most of these patients ended up requiring mechanical ventilation (MV).[2]

Barotrauma is defined as tissue injury that occurs as a consequence of the pressure difference between a poorly-ventilated body cavity and the surrounding air, fluid interface or across a tissue plane. Pulmonary barotrauma can manifest in a variety of ways, including spontaneous pneumothorax (PTX), subcutaneous emphysema (SE), pneumopericardium and pneumomediastinum.[3]

Pulmonary barotrauma is a known complication of MV with ARDS, and COVID-19 was an independent risk factor for increasing the possibility of developing this complication.[4,5] However, exact incidence of pulmonary barotrauma injury secondary to MV for the management of CARDS is not well documented.

The current study was planned to fill the gap by documenting the incidence of various manifestations of pulmonary barotrauma secondary to MV for CARDS management, and to compare it with the incidence of pulmonary barotrauma secondary to MV related to any other cause.

Materials and Methods

The retrospective case-control study was conducted at the Aga Khan University Hospital (AKUH), Karachi, and comprised patient data from October 1, 2020, to March 31, 2021.

After obtaining exemption from the institutional ethics review committee, the sample was raised using convenience sampling method. Data was extracted from the hospital information and management system (HIMS),

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using key word 'mechanical ventilation' and also the International Classification of Diseases-10 (ICD-10) coding system.[6] Data included was related to patients of either gender, aged 18 and above, who underwent MV for any reason. Data was excluded in cases where there was evidence of pulmonary barotrauma on first radiological image, as the identification of MV as being the cause of pulmonary barotrauma could not be ascertained. The final cohort comprised patients who underwent MV in acute care unit (ACU), surgical intensive care unit (SICU), medical ICU (MICU), COVID-19 ICU, coronary critical care unit (CCCU), coronary ICU (CICU), with chest radiograph before MV initiation and post-initiation.

Data of CARDS patient formed group 1, and that of ARDS with any other formed control group 2.

Demographic data and reason for MV were recorded for all patients, while clinical data, including the highest serum ferritin levels, highest C-reactive protein (CRP) levels, outcomes, such as mortality or discharged in stable condition, were recorded on a predesigned proforma for group 1 patients.

Pulmonary barotrauma secondary to MV in both groups was defined as development of pneumothorax, pneumo-mediastinum, subcutaneous chest wall emphysema or pneumopericardium after MV initiation (Figure-1). Presence of pulmonary barotrauma associated with other procedures, such as insertion of central venous lines and chest tubes, was ignored. Radiographic evidence of MV initiation was determined by visualisation of a BiPAP mask shadow which was reconfirmed through clinical indication and radiological identification of endotracheal or tracheostomy tube (Figure-2). This was subsequently reconfirmed through retrospective review of patient records.

Digital Imaging and Communications in Medicine (DICOM) images[7] of chest radiographs performed on both groups of patients were reviewed by a pulmonary barotrauma review panel consisting of two national board certified diagnostic radiologists, each having >7 years of clinical experience. The images were reviewed on the departmental Picture Archiving and Communication

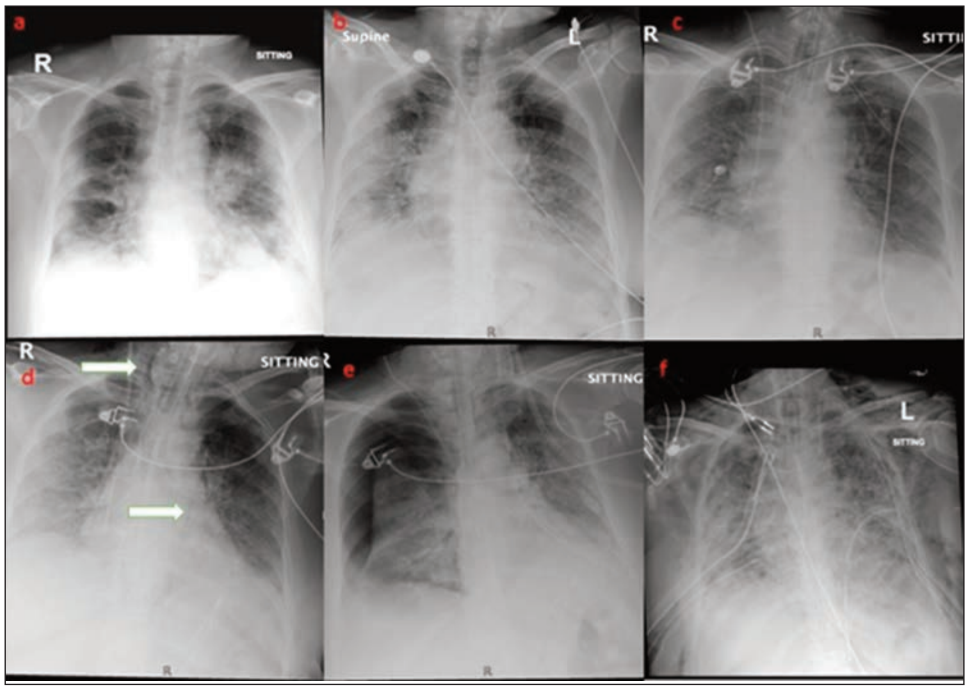

Figure-1: A 60 year old female presented to emergency room (ER) with a 7-day history of fever and worsening shortness of breath. On investigation, she was found to be positive for coronavirus disease-2019 (COVID-19) on polymerase chain reaction (PCR) assay. Chest radiograph obtained at presentation (a) revealed patchy consolidations in bilateral mid and lower lung fields typical of viral pneumonia secondary to COVID-19 infection. Her radiographs obtained on day 10 of admission (b) showed worsening of inhomogeneous shadowing along with increased oxygen dependence clinically. Therefore, she was intubated and positive-pressure mechanical ventilation (MV) started (c). On the 4th MV day(d), the patient developed suspicion of lucency within the mediastinal soft tissue planes, extending along the descending thoracic aortic interface and into the neck soft tissues (white arrows), indicating pneumomediastinum. On the 7th MV day (e), a large lucency devoid of vascular markings was noted along the right lateral hemithorax with underlying lung collapse, indicating pneumothorax. The patient was subsequently managed with multiple chest tubes for barotrauma, but due to worsening airspace disease (f), the patient eventually expired on the 19th day of admission.

Figure-2: Multiple patients with radiographic findings consistent with coronavirus disease-2019 (COVID-19) pneumonia. (a) A shadow of the external respirator device is seen (white arrow), which was reconfirmed to be a bilevel positive airway pressure (BiPAP) device. Such patients were managed with (b) invasive positive-pressure ventilation through endotracheal tube, and (c) tracheostomy.

System (PACS). Both radiologists were blinded to the clinical indication for MV at the time of image interpretation. The panel documented its findings on a predesigned chart, including type of MV, presence of pulmonary barotrauma on radiographs acquired post-initiation of MV till radiological evidence of discontinuation of MV, and the day of pulmonary barotrauma occurrence post-initiation of MV.

Data was analysed using SPSS 24. Qualitative variables were expressed as frequencies and percentages, while quantitative parameters were expressed as mean±standard deviation (SD). Two tailed Fisher's exact test was used to compare the associations. P<0.05 was considered statistically significant.

Results

Of the 261 cases, 115(44%) were in group 1; 87(75.6%) males and 28(24.3%) females. There were 146(56%) controls in group 2; 96(65.7%) males and 50(34.2%) females. There were 142(54.4%) subjects aged >60 years; 61(43%) in group 1 and 81(57%) in group 2 (Table 1).

In group 2, indications for MV included post-surgical anaesthesia recovery 55(37.67%), road traffic accidents 34(23.28%), stroke 28(19.17%), others 29(19.86%).

A total of 3,859 chest radiographs were reviewed for both groups. A mean of 19±13 standard deviation radiographs were reviewed for each patient in group 1, while a mean of 11±9 standard deviation radiographs were reviewed for each patient in group 2.

The incidence of pulmonary barotrauma in group 1 was 39(34%) and 8(5.5%) in group 2 ($p<0.0001$).

Table-1: Demographic data.

	CARDS	Controls
Gender		
Male	87(75.7)	96(65.8)
Female	28(24.3)	50(34.2)
Total	115	146
Age (years)		
18 – 39	8(6.9)	9(6.16)
40 - 60	46(40.0)	56(38.4)
> 60	61(53.0)	81(55.47)
Total	115	146

CARDS: Coronavirus-disease-2019 (COVID-19)-associated acute respiratory distress syndrome.

Table-2: Association of MV and pulmonary barotrauma for management of CARDS.

Indication for MV	Pulmonary barotrauma		
	Yes	No	*p*-value
CARDS	39 (33.9%)	76 (66.1%)	0.0001
Controls	8 (5.5%)	138 (94.5%)	
Total	47 (18%)	214 (82%)	261

MV: Mechanical ventilation, CARDS: Coronavirus-disease-2019 (COVID-19)-associated acute respiratory distress syndrome.

Table-3: Inflammatory markers and length of hospital stay in CARDS group.

	Serum Ferritin levels	CRP levels	Length of hospital stay
All patients in CARDS group.	2254.10±7092.10	169.64±729.52	10.21±7.43
Subset of patients who suffered pulmonary barotrauma	3243.40±11510.50	105.53±64.84	12.22±8.20

CARDS: Coronavirus-disease-2019 (COVID-19)-associated acute respiratory distress syndrome, CRP: C-reactive protein.

The frequency of pulmonary barotrauma increased with prolonged duration of MV. The highest fraction of patients in group 1 developed barotrauma on or after the 6th MV day 16(41%), followed by day 2-5 13(33.3%) and day 1 10(25.6%).

Presence of air at multiple extra-alveolar locations, including pleural cavity, chest wall, mediastinum and pericardium, was observed more frequently in patients in group 1 18(46.15%) compared to 1(12.5%) in group 2 ($p<0.13$).

The most frequent type of pulmonary barotrauma in both groups was pneumomediastinum; 29(74.4%) in group 1 compared to 3(37.5%) in group 2 ($p<0.0001$). The incidence of pneumopericardium was 18(46.15%), subcutaneous emphysema 17(43.58%), and pneumothorax 15(38.46%) in group 1.

Overall, invasive MV was used in 248(95%), including access through endotracheal tube 235(94.7%) and tracheostomy tube 13(5.2%). The remaining 13(5%) cases were mechanically ventilated using a BiPAP device.

Within group 1, the difference between patients who developed pulmonary barotrauma after non-invasive MV and those who developed it after invasive MV was significant ($p<0.01$).

The mean serum ferritin values and length of hospital stay was higher while serum CRP level was lower in group A patients with pulmonary barotrauma compared to overall group 1 values (Table 3)

In group 1, overall mortality was 65(56.5%); 27(69%) in the pulmonary barotrauma subset compared to 38(50%) of those who did not have pulmonary barotrauma.

Discussion

The study reported pulmonary barotrauma in 39/115 (34%) hospitalised adult patients who underwent MV for CARDS compared to only 8/146 (5.5%) such events in cases of pulmonary barotrauma secondary to MV for all other causes. The incidence was higher compared to 13.6%, 15% and 9% reported globally.[8-10] The incidence of pulmonary barotrauma among patients undergoing MV for causes others CARDS has been reported to be about 6.5%.[11] The 34% frequency of pulmonary barotrauma in CARDS reported in the study was much higher than the reported frequency of pulmonary barotrauma in ARDS cases.[12,13] In the current study, pneumomediastinum was the most common type of pulmonary barotrauma in CARDS (74%) while its occurrence 37.5% in the control group. This pattern is similar to earlier reports; 13.6% versus 1.9%.[8] The increased incidence of pulmonary barotrauma secondary to MV in CARDS patients can be multifactorial. One possible explanation is fragility of the lung parenchyma as a consequence of the infection resulting in increased susceptibility to rupture secondary to positive-pressure ventilation.[14] In the current cohort, the subset of CARDS patients who received non-invasive positive-pressure ventilation (NIPPV) demonstrated higher incidence of pulmonary barotrauma (77%) versus the incidence in IPPV cases (30%). Jones et al. and Hamouri et al. have also reported similar findings.[15,16] The increased incidence of pulmonary barotrauma secondary to NIPPV is multifactorial. One possible explanation is that the tidal volumes and transpulmonary pressure in NIPPV are dependent on patient's spontaneous respiratory effort, control of which can help in reducing the risk of pulmonary barotrauma.[17] The spontaneous effort results in fluctuant pressure gradients, thereby increasing the incidence of pulmonary barotrauma with NIPPV.[18,19] The higher incidence of pulmonary barotrauma in NIPPV might be also attributed to the limited use of sedation and muscle relaxant compared to IPPV which impacts patient-ventilator dys-synchrony, and subsequently higher risk of developing pulmonary barotrauma.[20,21] Many clinical and laboratory variables were investigated in the current cohort, looking for predictors associated with a higher risk of developing pulmonary barotrauma in patients receiving MV. Some studies have speculated the role of inflammatory markers as possible predictors of poor outcomes. Hamouri et al.[16] found that the pulmonary barotrauma group had higher levels of ferritin (p=0.07) and no significant difference in CRP levels, which is concordant with the current results. Inflammatory markers may help identify patients at the highest risk of developing ARDS, assess response to therapy and the risk of pulmonary barotrauma. Subsequently, they may also be useful in improving risk stratification.[22,23] However, a larger sample size will be needed to study general trends and the likelihood of complications.

The current study has limitations because of single-centre data which limits generalisability of the findings. An assessment of patients' comorbid and extensive laboratory investigations may help in better understanding the causative factors that lead to pulmonary barotrauma. The current study was based on a reductionist perspective to correlate the two factors. A better understanding can be developed if the other factors, like comorbidities, could be made more consistent to minimise the impact of potential confounding factors.

Conclusion

The management of CARDS using MV was found to be associated with increased incidence of pulmonary barotrauma. Physician must be aware of this critical complication that will allow prevention, early detection and management of the condition and help reduce associated mortality.

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Author Contribution:

SK: Concept of idea, data collection, data analysis, manuscript writing and review.
KH: Data collection, analysis, review
AA: Concept of idea, data collection, review.
AN: Data collection.
SZZR: Writing the text.
TH: Concept of idea, review of final article