Use of esophageal balloon manometry in the management of pediatric acute respiratory distress syndrome

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A B S T R A C T

There is paucity of literature regarding the use of esophageal balloon manometry in the management of Pediatric Acute Respiratory Distress Syndrome. We describe our first ever experience of successful usage of esophageal balloon pressure manometry in a child with acute respiratory distress syndrome. This is a six-year-old girl who presented with shortness of breath and fever and was found to be in severe acute respiratory distress syndrome due to septic shock secondary to group A streptococcus. The patient was managed using an esophageal balloon manometry for positive end-expiratory pressure titration. She was liberated from invasive mechanical ventilation on day 7 of hospital course. Esophageal balloon manometry guided positive end-expiratory pressure for 103 out of 155 hours of ventilation with no obvious sequelae. Our case shows the feasibility of transpulmonary pressure measurements in pediatric patients. This practice may be useful to optimize management in pediatric acute respiratory distress syndrome to improve outcomes.

1. Introduction

Previous pediatric research suggests increasing levels of positive end expiratory pressure (PEEP) are required in Pediatric Acute Respiratory Distress Syndrome (PARDS) and insufficient PEEP/FiO$_2$ is associated with higher mortality [1]. Optimal PEEP is required to improve oxygenation and minimize repeated alveolar collapse or over distention. However, there is limited evidence on how to optimize PEEP in a patient-specific way leading to substantial variability in titration among pediatric intensivists [2]. Esophageal balloon manometry measures esophageal pressure, this is a surrogate for pleural pressure and allows for calculation of the transpulmonary pressure needed to distend the lung and the chest wall. A randomized controlled trial by Talmor and colleagues [3] in adults compared mechanical ventilation titrated by the esophageal measurements using balloon manometry vs titration by Acute Respiratory Distress Syndrome Network standard-of-care recommendations (low tidal volume strategy and PEEP/FiO2 charts) and showed that the esophageal pressure guided patients had significantly improved oxygenation with enhanced respiratory-system compliance

resulting in the trend toward improved 28-day survival in the group of very sick patients. Use of an esophageal balloon in PARDS is not well described. We present a case report in which an esophageal balloon was used to optimize mechanical ventilation in a patient with severe PARDS.

2. Case

A six-year-old (22.4kg) otherwise healthy girl was admitted to our pediatric intensive care unit (PICU) for acute hypoxic respiratory failure after nine days of febrile illness and two-day history of shortness of breath. She presented to an outside hospital and was transferred to our PICU with acute hypoxic respiratory failure and septic shock secondary to suspected pneumonia. Initial chest radiograph on admission showed diffuse bilateral interstitial opacities consistent with acute respiratory distress syndrome (Fig. 1). The patient was quickly escalated to non-invasive positive pressure ventilation (NIPPV) and required tracheal intubation approximately 6 h after admission. She was continued on empiric broad spectrum antibiotics and sedation was initiated and titrated for patient comfort.

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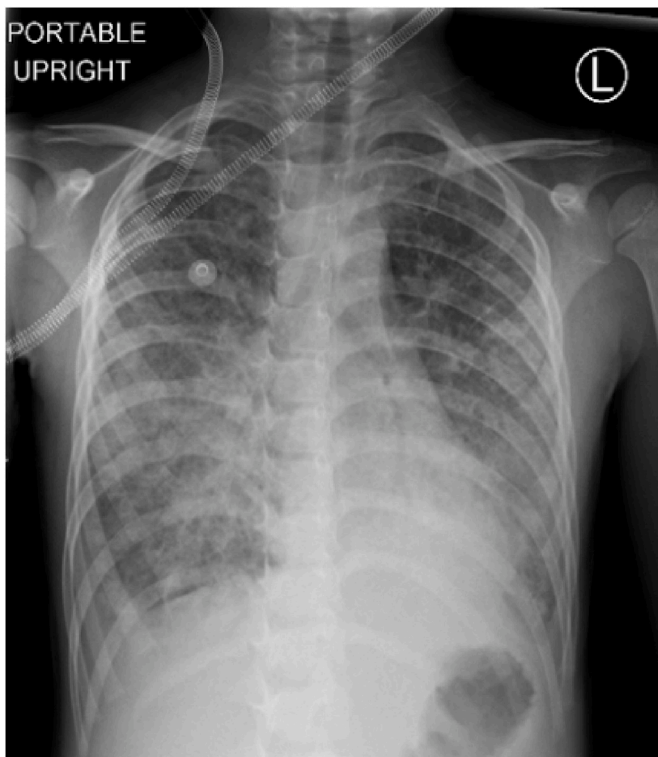 *E-mail address:* insleye@amc.edu (E. Insley).
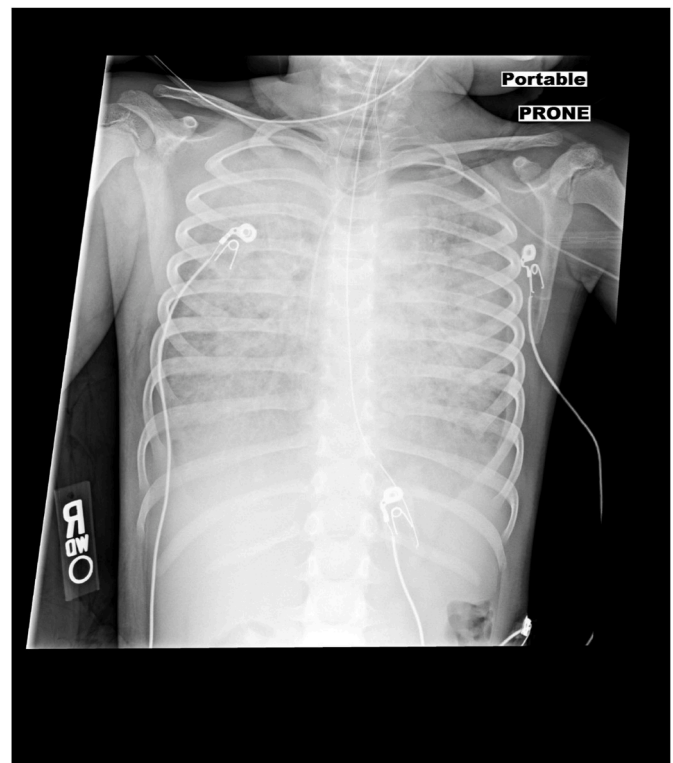
Fig. 1. Chest radiograph on admission.

Fig. 2. Bilateral diffuse opacities with decreased lung volumes.

Initial ventilator support was with Pressure Regulated Volume Control (PRVC) on Servo *i* ventilator (Getinge, Solna, Sweden) with initial settings of tidal volume 200ml (8.9ml/kg), respiratory rate of 30, PEEP of 6 cmH$_2$O, and FiO2 1.0 (mean airway pressure 21 cmH$_2$O, peak inspiratory pressure (PIP) 32 cmH$_2$O). Initial oxygenation index (OI) was 19.3 and PaO2:FiO2 ratio of 102.3 confirming severe PARDS. Arterial blood gas analysis on FiO$_2$ 0.85 showed pH 7.27, PaCO$_2$ 49, PaO$_2$ 87, and base deficit of 4.8. The patient continued to deteriorate despite prone positioning and paralysis with worsening chest x-ray (Fig. 2). A transthoracic echocardiogram revealed normal function (LV shortening fraction 54.9%) with no signs of pulmonary hypertension, which refrained us from the use of inhaled nitric oxide. Decision was made to place an esophageal balloon catheter using a Hamilton G5 ventilator (Hamilton Medical, Reno, NV) to measure transpulmonary pressure and for optimal titration of PEEP.

A 5 French esophageal balloon (Cooper Surgical, Trumbull, CT) was placed. We estimated the length necessary to place the balloon in the lower third esophagus by measuring the distance between the nostril and the xyphoid. After placement, gentle pressure was applied to the abdomen with corresponding pressure increase supporting esophageal placement. The catheter was then slowly withdrawn until cardiac oscillations were detected on esophageal pressure waveform. Position was confirmed by applying pressure to the thoracic ribcage and observing a corresponding pressure increase. Optimal positioning of the esophageal balloon is also shown in Fig. 3.

Parameters for transpulmonary pressure (P$_L$), defined as pressure gradient between plateau pressure and the esophageal pressure at the end of the inspiration, and expiratory transpulmonary pressure(P$_{Lexp}$), defined as the gradient between the PEEP set on the ventilator and esophageal pressure at the end of expiration, were derived based on previous adult research with a goal of P$_L$ ≤ 10 cm H$_2$O and P$_{Lexp}$ of 0 ± 2 [9,10]. Optimization of transpulmonary pressure (P$_L$) and expiratory transpulmonary pressure (P$_{Lexp}$) was accomplished by titration of tidal volume and PEEP respectively. For example. If the P$_{Lexp}$ was negative, PEEP was increased to reach the goal of 0 to +/-2 cmH2O and if P$_{Lexp}$
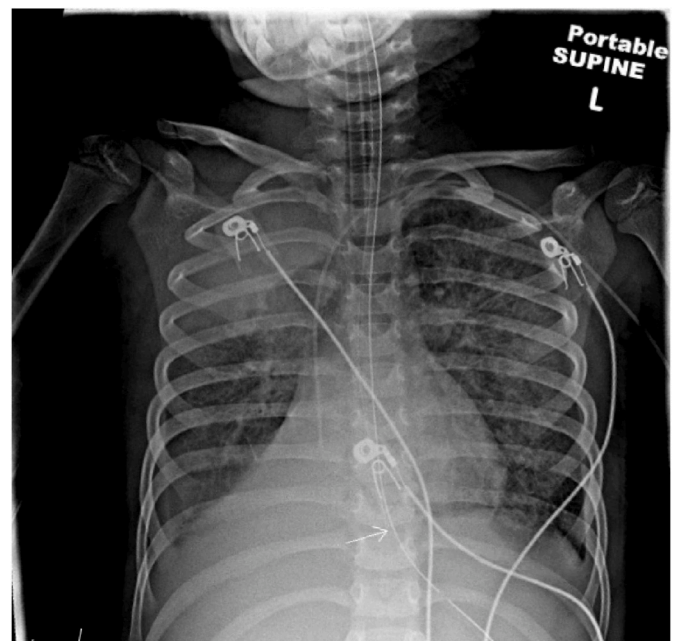

Fig. 3. Distal esophageal balloon large white arrow.

was positive, PEEP was decreased to reach 0 +/-2 cm H20. If P$_L$ was more than 10 cm H$_2$O then the tidal volume is titrated down by 10 ml at a time to achieve the goal of P$_L$ < 10 cm H$_2$O. Fig. 4 Depicts the relationship between the P$_L$ and P$_{Lexp}$ with time and in respect to patient positioning and notably P$_L$ is lower in prone position when compared to supine. Titrating the PEEP and tidal volumes using the P$_L$ and P$_{Lexp}$ assisted in lung recruitment. As shown in Fig. 5, PLexp guided us in achieving the optimal PEEP e.g. Between hours 25–35 as the P$_{Lexp}$ trended more negative (i.e. −6) titrating up the PEEP to achieve the goal
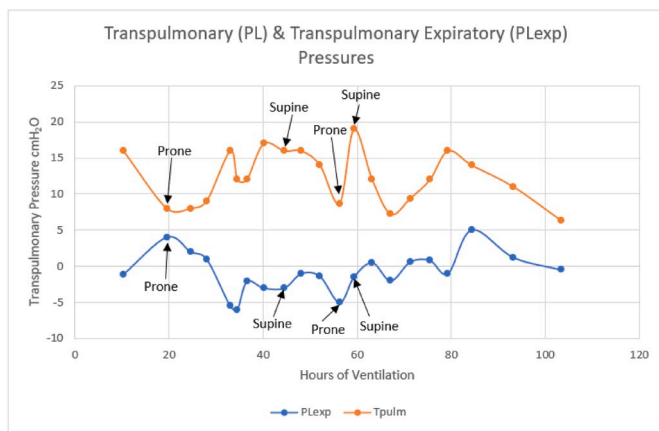
Fig. 4. Trends of PL and PLexp over time in relation to the position of the patient.
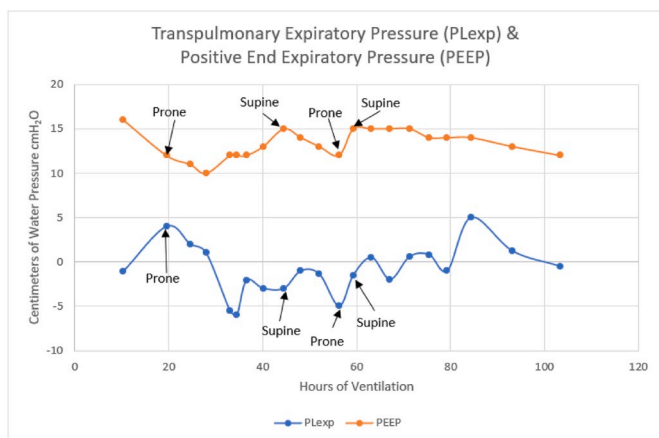

Fig. 5. Trend of PEEP titration in relation to PLexp.

P_{Lexp} of 0 ± 2 helped maintain the lung volumes.

On hospital day 3 neuromuscular blockade was discontinued and we began slowly weaning PEEP while continuing to monitor P_L and P_{Lexp}. The esophageal balloon was removed on hospital day 5 (total 103 hours of monitoring) once she was steadily tolerating weans with stable P_{Lexp}. The patient was extubated successfully on hospital day 7 after 155 hours of invasive mechanical ventilation and ultimately weaned off respiratory support.

3. Discussion

Transpulmonary pressure measurement via esophageal balloon is not well described in the pediatric literature. Gleich et al. [4] mentioned in their study that overall, very few pediatric patients are managed with esophageal pressure measurements and so the benefit of transpulmonary pressure monitoring in children with pediatric respiratory distress syndrome is less clear leading to insufficient evidence to recommend or against routine esophageal pressure monitoring. The 2015 PARDS consensus recommendations from the Pediatric Acute Lung Injury Consensus Conference notes that inspiratory plateau pressure (P_{plat}) limits for protective lung ventilation are flawed as they do not account for patient specific variation in chest wall elastance based on patient habitus and changes as the disease itself evolves [5]. PARDS particularly poses significant challenges in management due to decreased lung compliance and immature lungs, which are particularly prone to injury [6]. The recommended P_{plat} limitations may result in overly low transpulmonary pressures and insufficient inflation of the lungs [5]. Given

these issues, real time measurement of transpulmonary pressure is important to guide management of PARDS by ensuring optimal inflation and thus optimizing oxygenation.

Transpulmonary pressure is the true distending pressure of the lungs defined as the difference in pressure between the alveoli and the pleural space [7]. It can be used to titrate settings in a patient specific way to optimize oxygenation and ventilation while minimizing volutrauma, atelectotrauma, and oxygen toxicity. Esophageal manometry measures esophageal pressure, which is used as a surrogate for pleural pressure [8]. Parameters for P_L and P_{Lexp} were derived based on previous adult research with a goal of $P_L \le 10$ cmH$_2$O being lung protective and avoidance of levels >15 cmH$_2$O to prevent over distention. P_{Lexp} goals of 0 to +/-2 cmH$_2$O correlate to optimal PEEP with more negative values a risk for alveolar collapse and more positive values a risk for over distention [3,9,10].

Our patient's hospital course reflects a challenge in optimizing ventilator settings based on traditional parameters, particularly PEEP, early in the disease process. Following esophageal balloon placement, the patient's clinical course was less variable. With the guidance of transpulmonary pressure measurements we were able to more accurately account for the degree of lung disease and variation in chest wall and lung compliance. Without this data, there may have been less aggressive and less successful optimization of PEEP leading to a more protracted and complicated disease course. The transpulmonary pressure measurement helped us optimize the PEEP in our patient above the comfort of our conventional limits while improving the patient's oxygenation.

This case adds to the growing body of literature describing the efficacy and feasibility of transpulmonary pressure monitoring for the titration of ventilator settings in PARDS [4,11]. There are inherent limitations in our case, given that it is a single patient case report and the challenges with the use of the esophageal balloon for example, maintaining the optimal balloon volume and placement, particularly with position changes, affected accuracy and reliability of measurements as discussed by Hotz [12,13]. In our case, chest X-ray was a useful adjunct when there was uncertainty about placement of the balloon by pressures alone. Nonetheless, with continued experience, careful monitoring and documentation of esophageal balloon positioning, and reliable transpulmonary pressure trends, esophageal manometry can allow for individualization and optimization of ventilator settings in PARDS. Development of guidelines and research on the use of transpulmonary pressure in PARDS is needed to assess for potential complications and evaluate the impact of this practice on patient outcomes.

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