Development of a Lung Rescue Team to Improve Care of Subjects With Refractory Acute Respiratory Failure

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BACKGROUND: A lung-protective mechanical ventilation strategy has become the hallmark of ventilation management for patients with acute respiratory failure. However, some patients progress to more severe forms of acute respiratory failure with refractory hypoxemia. In such circumstances, individualized titration of mechanical ventilation according to the patient's specific respiratory and cardiovascular pathophysiology is desirable. A lung rescue team (LRT) was recently established at our institution to improve the medical care of patients with acute respiratory failure when conventional treatment fails. The aim of this report is to describe the consultation processes, the cardiopulmonary assessment, and the procedures of the LRT. METHODS: This was a retrospective review of the LRT management of patients with acute respiratory failure and refractory hypoxemia at Massachusetts General Hospital in Boston, Massachusetts. The LRT is composed of a critical care physician, the ICU respiratory therapist on duty, the ICU nurse on duty, and 2 critical care fellows. In the LRT approach, respiratory mechanics are evaluated through lung recruitment maneuvers and decremental PEEP trials by means of 3 tools: esophageal manometry, echocardiography, and electrical impedance tomography lung imaging. RESULTS: The LRT was consulted 89 times from 2014 to 2019 for evaluation and management of severely critically ill patients with acute respiratory failure and refractory hypoxemia on mechanical ventilation. The LRT was requested a median of 2 (interquartile range 1–6) d after intubation to optimize mechanical ventilation and to titrate PEEP in 77 (86%) subjects, to manage ventilation in 8 (9%) subjects on extracorporeal membrane oxygenation (ECMO), and to manage weaning strategy from mechanical ventilation in 4 (5%) subjects. The LRT found consolidations with atelectasis responsive to recruitment maneuvers in 79% (*n* = 70) of consultations. The LRT findings translated into a change of care in 81% (*n* = 72) of subjects. CONCLUSIONS: The LRT individualized the management of severe acute respiratory failure. The LRT consultations were shown to be effective, safe, and efficient, with an impact on decision-making in the ICU. *Key words: respiratory insufficiency; ARDS; obesity; mechanical ventilation.* [Respir Care 2020;65(4):420–426. © 2020 Daedalus Enterprises]

Introduction

Respiratory management of patients with acute respiratory failure (ARF) is complex because it often requires multiple interventions such as sedation and paralysis, titration of mechanical ventilation, body-positioning, and need of extracorporeal membrane oxygenation (ECMO). A best-practice, protocolized, protective mechanical ventilation strategy (ie, plateau pressure < 28 cm H_2O, driving

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pressure < 15 cm H_2O, tidal volume 4–8 mL/kg, and the application of PEEP) has become the hallmark of ventilatory management during ARF to avoid ventilator-induced lung

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injury.[1] Most patients with ARF quickly improve in the first 24 h of ventilation according to strict compliance with best-practice ventilation protocols.[2] However, some patients progress to more severe forms of ARF with refractory hypoxemia.[3] In such circumstances, advanced monitoring of respiratory mechanics and nonconventional interventions may be required to tailor mechanical ventilation to the patient's specific respiratory and cardiovascular physiology.

Our group has been investigating respiratory mechanics and ventilatory management of patients with obesity and refractory ARF, and our study procedures have often resulted in reversing hypoxemia and improving lung mechanics.[4-6] As a result, several of our ICUs have started requesting a respiratory consult. This process resulted in the development of a consultation team involved in the clinical management of patients with refractory ARF.[7,8] The Massachusetts General Hospital (Boston, Massachusetts) Respiratory Care Service along with the Critical Care staff formally instituted a lung rescue team (LRT) in 2014. The goals of the LRT are the improvement of the standard of care, the promotion of education, and the development of a research program focused on mechanical ventilation. The LRT improves the standard of care via the implementation of best-practice protocols and individualized treatment according to a patient's specific cardiopulmonary physiology when standard best-practice guidelines and protocols fail. The LRT promotes education through periodic discussion and review of complex respiratory cases during ad hoc seminars with the ICU and respiratory care staff, yearly seminars on mechanical ventilation, and writing textbooks on mechanical ventilation and respiratory care. The LRT builds a research enterprise by promoting research studies focusing on mechanical ventilation to continue to improve care of the most critically ill patients. The aim of this manuscript is to describe the consultation processes of the LRT.

QUICK LOOK

Current knowledge

A protocolized protective strategy is the hallmark of ventilatory management during acute respiratory failure. In most cases, patients quickly improve in the first 24 h of ventilation with strict compliance to best-practice ventilation protocols. However, some patients progress to more severe forms of acute respiratory failure with refractory hypoxemia.

What this paper contributes to our knowledge

A lung rescue team was established to manage patients with acute respiratory failure who do not respond to standard treatment. The lung rescue team individualizes titration of mechanical ventilation according to each patient's specific respiratory and cardiovascular pathophysiology. The consultation process of the lung rescue team was effective, safe, and efficient, and it had an impact on decision-making in the ICU.

Methods

This report is a retrospective review of the impact of the LRT management at Massachusetts General Hospital. The retrospective collection of data was approved by Partners Healthcare Investigational Review Board #2019P001995. Demographic data, diagnosis at ICU admission, cause of ARF, length of mechanical ventilation, and mortality scores are presented in this report. The consultation process is documented in 3 phases: indication for LRT consultation, LRT findings, and interventions performed. The impact of the LRT consultation was evaluated if the intervention was maintained by the ICU clinical team after the LRT consultation. The LRT is a specialized team for the management of refractory respiratory failure, and the team is composed of a critical care physician, the ICU respiratory therapist on duty, the ICU nurse on duty, and 2 critical care fellows.

All mechanically ventilated patients with ARF are ventilated according to the ARDSnet protocol.[1] Respiratory therapists are trained to implement and follow the ARDSnet protocol.[1] An electronic medical chart captures tidal volume, airway pressures, breathing frequency, F_{IO_2}, and S_{pO_2}. Respiratory mechanics and parameters are monitored every 2–4 h by respiratory therapists. The LRT consultation is requested by the ICU physician when treatment of ARF according to the ARDSnet guidelines fails.

The following represent 4 common scenarios in which the LRT has been requested for consultation (Fig. 1):

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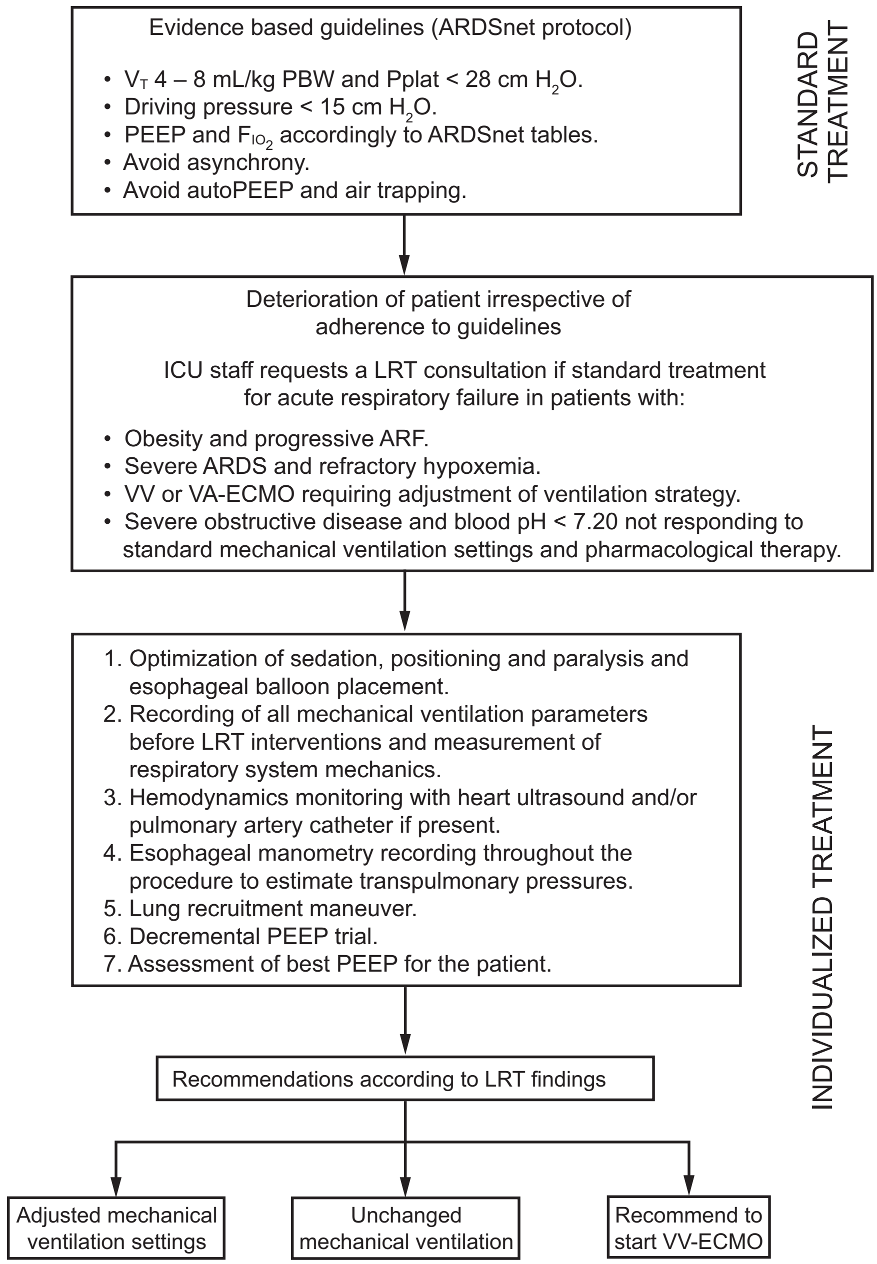

Fig. 1. Lung rescue team (LRT) consultation protocol. V_T = tidal volume; PBW = predicted body weight; Pplat = plateau pressure; ARF = acute respiratory failure; VV/VA-ECMO = venovenous/venoarterial extracorporeal membrane oxygenation.

(1) patients with class III obesity (ie, body mass index > 40 kg/m^2) and progressive ARF, and the ARF does not improve in the first 24 h of ventilation despite strict compliance to best-practice ventilation protocols; (2) patients with severe ARDS and refractory hypoxemia (ie, P_{aO_2} < 60 mm Hg, F_{IO_2} 0.8–1.0, and a PEEP > 10–20 cm H_2O for > 12–24 h[3]; (3) patients on venovenous (VV) or venoarterial (VA) ECMO who require adjustment of the ventilation strategy; and (4) patients with severe asthma and blood pH < 7.2 who are not responding to standard mechanical ventilation settings and pharmacological therapy.

Interventions

The LRT approach utilizes 3 tools in addition to the bedside mechanical ventilator. Esophageal manometry involves positioning a nasogastric tube with an esophageal balloon (AVEA ventilator nasogastric pressure monitoring tube set; CareFusion, San Diego, California) to estimate the intrapleural pressure and to calculate the transpulmonary pressure across the alveoli-capillary membrane. Transthoracic echocardiography is used to assess the effect of high alveolar pressures on hemodynamics; tricuspid annular plane systolic excursion and peak systolic annular velocity (S') are commonly measured before and after the LRT maneuvers to evaluate the impact on right heart function. Electrical impedance tomography (EIT) lung imaging is a noninvasive and radiation-free technology based on the analysis of the variation of impedance during ventilation due to air movement in and out the airways. EIT provides a map of alveolar ventilation with regional distribution of ventilation. The degree of lung collapse and overdistension is determined by comparing each EIT pixel-compliance as previously described.[9]

The LRT approach at the bedside includes 4 steps. First, the LRT optimizes sedation and paralysis, as well as esophageal balloon placement, recording all of the mechanical ventilation parameters, respiratory system compliance, and driving pressure before implementing LRT interventions. Second, the LRT monitors the patient's hemodynamics and records inotropic and vasopressor requirements throughout the procedure. Right heart function evaluated with pulmonary artery pressure measurements and/or ultrasound. Third, the LRT records esophageal manometry throughout the procedure to estimate transpulmonary pressures. Fourth, the LRT performs a lung-recruitment maneuver: pressure controlled mode at 10–15 cm H_2O, inspiratory:expiratory ratio of 1:1, PEEP 15 cm H_2O, F_{IO_2} 1.0, breathing frequency 10–20 breaths/min according to P_{CO_2}. This is followed by a stepwise increase in PEEP in 5-cm H_2O steps (30 s for each step) and a plateau pressure that is not to exceed 40–50 cm H_2O, depending on patient's body mass. Finally, the LRT performs a decremental PEEP trial, which involves volume controlled ventilation at 6 mL/kg of predicted body weight. The LRT starts at 20–30 cm H_2O PEEP and a plateau pressure not to exceed 45 cm H_2O, and PEEP is decreased stepwise by 2 cm H_2O; respiratory system compliance is evaluated after each step (ie, every 30 s). The PEEP value associated with the highest respiratory system compliance and in a range of transpulmonary pressure between -3 and $+3$ cm H_2O represents the best PEEP value for the patient.

Safety Precautions

LRT interventions are immediately interrupted and previous mechanical ventilation settings are resumed if any one of the following occurs: heart rate > 130 or < 60 beats/min; persistent systemic blood pressure < 90 mm Hg or > 180 mm Hg despite the use of vasopressor or vasodilators; incremental increases in vasopressors administration (> 15 µg/min for norepinephrine and dopamine, > 10 µg/min for epinephrine, or > 50 µg/min for phenylephrine); acute hypoxemia ($P_{aO_2} < 60$ mm Hg) and desaturation ($S_{pO_2} < 90\%$); signs of lung overdistention (ie, determined as a relative increase in driving pressure when compared to the driving pressure measured before LRT interventions); or signs of cardiac impairment (ie, ultrasound tricuspid annular plane systolic excursion and S' decrease $> 20\%$, systolic pulmonary arterial pressure increases > 15 mm Hg, and cardiac index decreases $> 20\%$).

Results

Subjects ($n = 89$) who received consultation from the LRT were admitted to surgical (60%, $n = 53$) or medical (40%, $n = 36$) ICUs (Table 1). Initially, the activity of the LRT was focused on ARF management of patients with obesity, and about 56% ($n = 50$) of the subjects had class III obesity. ARF was the primary cause of ICU admission, followed by postsurgical complications and septic shock. The first 3 causes of respiratory failure reflect the primary 3 diagnoses at ICU admission: pneumonia, postoperative pulmonary complication, and ARDS associated with septic shock. Subjects who received consultation from the LRT were critically ill as evidenced by high severity scores (ie, APACHE II 51.5 ± 20.6, SAPS II 51.5 ± 20.6, and SOFA 11.1 ± 4.1) and by a 33% mortality rate during ICU admission.

LRT consultation was requested within 48 h of initiation of mechanical ventilation in $> 50\%$ of subjects. The most common reason for requesting LRT consultation was to optimize mechanical ventilation settings and to titrate PEEP, followed by management of ventilation in subjects on ECMO and management of weaning strategy from mechanical ventilation. In the majority of cases (78.6%), the LRT found consolidation with atelectasis responsive to recruitment maneuvers followed by evidence of pulmonary edema and nonrecruitable consolidation. The LRT findings translated into a change of medical care in the days following consultation in 81% of subjects. Following LRT procedures, no pneumothoraces or other adverse events were recorded, although there was a temporary increase of vasoactive drugs in 15% of subjects. The LRT was consulted to evaluate 15 subjects before starting VV-ECMO; after the consult, VV-ECMO was started in just 2 subjects. Similarly, tracheostomy was avoided in 3 subjects previously considered for tracheostomy.

Discussion

In this report we have documented the activity of a LRT that specializes in ARF management when conventional treatment fails. The LRT consultation process occurred within 48 h of the start of mechanical ventilation in $> 50\%$ of consultations. The LRT adjusted mechanical ventilation settings in $> 75\%$ of consulted cases according to the

Table 1. Subject Demographics and Lung Rescue Team Consultation Process

Variable	Data
Age, y	58 (41–66)
Female	38 (43)
Body mass index, kg/m^2	41.3 (34.3–52.2)
Diagnosis at ICU admission	
Acute respiratory failure	35 (39.3)
Post-surgery admission	21 (23.6)
Septic shock	15 (16.9)
Cardiogenic shock	9 (10.1)
Trauma	7 (7.9)
Pulmonary embolism	2 (2.2)
Primary cause of respiratory failure	
Pneumonia	33 (37.9)
Postoperative pulmonary complication	22 (25.3)
ARDS in septic shock	16 (18.4)
Pulmonary edema	7 (8.0)
Pulmonary embolism	4 (4.6)
COPD/asthma exacerbation	3 (3.5)
Chest trauma	2 (2.3)
Length of ICU stay, d	14.5 (7–25)
Indication for LRT consultation	
Optimizing ventilation and PEEP titration	77 (86.5)
Ventilation management in patients with extracorporeal life support	8 (9.0)
Weaning from mechanical ventilation	4 (4.5)
LRT findings	
Recruitable consolidations with atelectasis	70 (78.6)
Pulmonary edema	11 (12.3)
Nonrecruitable consolidations	6 (6.7)
Flow limitation	1 (1.1)
Pulmonary embolism	1 (1.1)
Change in medical care	72 (81.0)
Mechanical ventilation duration before LRT consultation, d	2 (1–6)
Complications due to lung rescue team procedures	
Pneumothorax	0 (0)
Increase in vasoactive drugs requirement	13 (14.6)
Consultation in subjects with VA-ECMO	9 (10.1)
Consultation to start VV-ECMO	15 (16.9)
Actual VV-ECMO start after consultation	2 (13.3)
Tracheostomy planned	34 (38.2)
Actual tracheostomy placement	31 (91.2)

N = 89 subjects. Data are presented as *n* (%) or median (IQR).
IQR = interquartile range
VV-ECMO = venovenous extracorporeal membrane oxygenation
VA-ECMO = venoarterial ECMO

subject's individual pathophysiology. The majority of LRT findings translated into changes of care in the days following the consultations. The procedures performed during the LRT consultations were safe, in that < 15% of subjects required a temporary increase of vasoactive drugs and no pneumothorax was recorded.

Since the ARDSnet protocol was published,[1] the ARDSnet lung-protective strategy has significantly improved survival of patients with severe ARDS.[2] Research has been focused over the years on multiple mechanisms and therapies that aim to improve ventilatory management in this setting. Among the different variables that define lung-protective ventilation, Amato and colleagues[10] found that the driving pressure (ie, the difference between plateau pressure and PEEP) was the strongest independent variable correlated to survival of subjects with ARDS. Thus, only changes in tidal volume or in PEEP that lead to a decreased value of driving pressure can be considered protective for patients with ARF and ARDS. The role of driving pressure has been recently explored in spontaneously breathing subjects with ARDS.[11] The results support the feasibility of measuring the driving pressure during assisted mechanical ventilation, and the authors noted improved survival in subjects with lower driving pressure and higher respiratory system compliance.[11]

An optimal patient-ventilator interaction is important to avoid unnecessary high intrapulmonary pressures and high tidal volume, and ultimately to reduce the risk of ventilator-induced lung injury. Patient-ventilator asynchronies have been found to be more common than expected, occurring during all modes of mechanical ventilation, and they are correlated with worse prognosis.[12,13] Although multiple studies have investigated the impact of patient-ventilator interaction on clinical outcomes, a clear causal effect on mortality has yet to be demonstrated. In that sense, the use of neuromuscular blocking agents (NMBAs) in patients with ARDS has been extensively debated, with a cornerstone study was published in 2010.[14] In that randomized controlled trial, the early use of NMBAs in subjects with severe ARDS was associated with lower mortality at 90 d and a higher number of ventilator-free days.[14] A second randomized controlled trial was published 9 years later to test the benefits of early administration of NMBAs in a larger population of subjects with moderate and severe ARDS.[15] The study did not find any significant difference in 90-d mortality between the intervention and control groups. In the last decade, the ventilatory management of ARDS has advanced remarkably (eg, higher PEEP values, lung recruitment maneuvers, pronation, and ECMO). These changes may explain the different results of the aforementioned trials conducted 10 years apart. However, although the understanding and the management of ARF has significantly improved, when the ARDSnet protocol fails, there are no further ventilatory strategies available other than rescue therapies such as paralysis, pronation, and VV-ECMO as recommended by the most recent guidelines.[16] In some specific populations, an individualized titration of mechanical ventilation has produced positive physiological benefits.[4,6]

The presence of the LRT addresses the need for an individualized strategy to manage mechanical ventilation in severely critically ill patients who do not respond to conventional treatment. We acknowledge that the data from this report are limited. However, avoiding more invasive procedures, such as tracheostomy and ECMO, is among the potential benefits of having the LRT. When following standard local guidelines is not sufficient, the LRT staff is able to tailor mechanical ventilation management by integrating clinical findings and advanced respiratory mechanics parameters obtained with equipment that typically is not used in standard practice. The research and educational activities of the LRT have led to the improvement of local guidelines, better management of patients with refractory ARF, and ultimately improvement of medical care when no other options are feasible.

This study has some limitations. The use of EIT deserves special consideration because this technology has been approved by the Food and Drug Administration only recently. The use of EIT is supported by strong scientific rationale,[17-21] and our group has been using it in recent years, either as part of research studies[6,22] or as part of the LRT quality-improvement project. The introduction of the EIT technology has progressively helped the LRT better understand the impact of respiratory maneuvers on pulmonary physiology. Further, the number of lung-recruitment maneuvers interrupted for hypotension or hypoxia was not recorded. However, none of our subjects experienced pneumothorax or marked acute respiratory or hemodynamic changes, and only 15% of subjects required a transient increase of vasoactive drugs.

Conclusions

The management of mechanical ventilation in patients with ARF and refractory hypoxemia can be challenging when conventional treatment fails. When there are no further options, an individualized titration of mechanical ventilation according to the patient's specific pathophysiology is desirable. The development of the LRT has allowed the individualized management of severe ARF. The LRT was effective, safe, and efficient, and had an impact on decision-making in the ICU.

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