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Archives of Pulmonology and Respiratory Care

CLINICAL GROUP

ISSN: 2581-3684 DOI: https://dx.doi.org/10.17352/aprc

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Received: 04 December, 2017
Accepted: 09 January, 2018
Published: 10 January, 2018

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Keywords: Acute respiratory distress syndrome; Ventilator-induced lung injury; Mechanical ventilation guidelines; Prone positioning

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Review Article

Evaluating mechanical ventilation in patients with Acute Respiratory Distress Syndrome

Abstract

Even though acute respiratory distress syndrome (ARDS) has been intensively and continuously studied in various settings, its mortality remains high. Mechanical ventilation is an essential component of the care of patients with ARDS. Thus, many randomized controlled clinical trials have been conducted, evaluating the efficacy and safety of various methods of mechanical ventilation in order to adapt ventilatory setting to protect patients from ventilator-induced lung injury (VILI) and to treat them effectively.

There is no well-stated practical guideline for mechanically ventilated patients with or without ARDS. However, as general measures low tidal volume, high positive end-expiratory pressure, and conservative fluid therapy seem to improve outcomes.

In conclusion, improving knowledge and evidence regarding the management of mechanically ventilated ARDS patients is critical. Thus, medical personnel managing patients with ARDS should personalize decisions for their patients.

Abbrevations

ARDS: Acute Respiratory Distress Syndrome; VILI: Ventilator-Induced Lung Injury; Ardsnet: Acute Respiratory Distress Syndrome Network; PEEP: Positive End-Expiratory Pressure; Fio2: Fraction Of Inspired Oxygen; PO2: Partial Pressure Of Arterial Oxygen; Pplat: Plateau Pressure; VT: Tidal Volume

Introduction

Acute respiratory distress syndrome (ARDS) has been defined as an acute respiratory failure in terms of acute onset, hypoxia, diffuse infiltrates on chest X-ray, and absence of cardiac failure, or pulmonary edema due to cardiac origin [1,2]. The severity of ARDS is dependent on the oxygenation failure, expressed as PaO_2/FiO_2 ratio of 100, 200, and 300 mmHg as severe, moderate, and mild, respectively. During the last 50 years mortality caused by ARDS decreased but the survival rate is still as low as 70%, while the hospital mortality rate reaches more than 40% amongst patients with moderate or severe ARDS [3].

A recent study showed that ARDS is common in the ICU, occurring in 10% of all patients admitted [4]. Although mechanical ventilation is a cornerstone in the management of patients with ARDS, it can aggravate lung injury, a process referred to as ventilator-induced lung injury (VILI), through several mechanisms including volutrauma, barotrauma and biotrauma [5,6]. Dynamic lung distension and repeated opening and closing of recruitable lung units are considered the two main mechanisms contributing to lung injury. In a large randomised controlled study, the lung protective ventilation strategy using low tidal volume and limiting plateau pressure (Pplat) has been proven to improve survival in patients with ARDS and subsequently it was confirmed in a meta-analysis [7,8]. However, current research still suggests that further reducing VILI is the main avenue to further reduce mortality in this syndrome. Thus, improving knowledge and evidence regarding the management of mechanically ventilated ARDS patients is critical.

Diagnosing ARDS

Diagnosis of ARDS may be challenging as the presenting symptoms are nonspecific. The signs and symptoms of ARDS in the case of patients under mechanical ventilation can vary in intensity, depending on its cause and severity, as well as the presence of underlying heart or lung disease. They include: severe shortness of breath, laboured and unusually rapid breathing, low blood pressure, confusion and extreme tiredness (Table 1). Important changes occur also on the

Citation: Grigorakos L (2018) Evaluating mechanical ventilation in patients with Acute Respiratory Distress Syndrome. Arch Pulmonol Respir Care 4(1): 001-005. DOI: http://dx.doi.org/10.17352/aprc.000031

Table 1: Diagnosing ARDS.

Symptoms	
Dyspnea	Yes
Hypoxia	Yes
Tachpynea	Yes
Pleuritic chest pain	Yes/No
Sputum production	Yes/No
Signs	
Rales	Yes
Fever	Yes/No
Edema	No
Jugular venous distention	No
Third heart sound	No
Studies	
Hypoxemia	Yes
Bilateral infiltrates	Yes
Pulmonary wedge pressure ≤ 18 mm Hg	Yes
$PaO_2/FiO_2 \leq 200$	Yes
Localized infiltrate	No
Elevated brain natriuretic peptide level	No
Cardiac enlargement	No
Responses	
Antibiotics	No
Diuretics	No
Oxygen	No

FiO2 – fraction of inspired oxygen, PaO2 – partial pressure of arterial oxygen.

monitor parameters: a) increased airway pressure due to increased resistance or reduced Compliance of the system (tube-lung-chest wall), b) changes to PO_2 (a normal change of up to 10% may be observed), c) pressure change (hypertension or hypotension), d) arrhythmias [9,10].

Thus, physicians, in order to narrow the differential diagnosis and determine the optimal course of treatment, must consider patient history (i.e. comorbidities, exposures, medications) in conjunction with a physical examination of other respiratory, cardiac, infectious, and toxic etiologies.

The role of mechanical ventilation in patients with ARDS

The goals of mechanical ventilation in ARDS are to maintain oxygenation, while avoiding oxygen toxicity and the complications of mechanical ventilation.

In an ARDS Network study, patients with ARDS were randomized to mechanical ventilation and it has been demonstrated that subjects in the low-tidal-volume group had a significantly lower mortality rate (31% versus 39.8%) [7]. While previous studies allowed patients to be hypercapnic and acidotic to achieve the protective ventilation goals of low tidal volume and low inspiratory airway pressure, the ARDS Network study allowed increases in respiratory rate and administration of bicarbonate to correct acidosis. More so, patients with severe ARDS receiving mechanical ventilation responded more favourably to early administration of a neuromuscular blocking agent (ie, cisatracurium) than to placebo, showing an improvement in survival and increased time off the ventilator [11]. Evidence suggests that managing medical personnel should not use paralytics in all cases but only in those where length of ventilation is expected to exceed a few hours. Patients should not remain ventilated for longer than it takes for the paralytics to have their effect [11].

Another study examined diaphragmatic weakness during mechanical ventilation along with the relationship between mechanical ventilation duration and diaphragmatic injury or atrophy [12]. It concluded that weakness, injury, and atrophy can occur rapidly in the diaphragms of patients on mechanical ventilation and are significantly correlated with the duration of ventilator support.

General guidelines for ventilator management

During ARDS the lungs are damaged following an insult that may be of pulmonary (i.e. pneumonia, aspiration pneumonitis) or extrapulmonary (i.e. sepsis, trauma, transfusion) origin. Regardless of the source of injury, ARDS is characterized by an acute onset, bilateral airspace infiltrates on chest X-ray, and hypoxemia ($PaO_2/FiO_2 < 300$), assuming no evidence of left atrial hypertension. With damage to the alveolar epithelium, alveolar-capillary membrane and endothelium, lung compliance progressively worsens and hypoxemia becomes refractory. Consequently, mechanical ventilation is necessary.

Unfortunately, while respiratory support is needed in ARDS, mechanical ventilation itself can worsen lung injury. Thus, the goals of mechanical ventilation should include achieving adequate gas exchange while limiting additional injury. This "lung-protective" strategy incorporates low tidal volume (VT) ventilation and low airway plateau pressure (Pplat) with permissive hypercapnia, if needed. Experimental studies demonstrated a 9% absolute mortality reduction in a group of patients randomized to receive 6ml/kg (predicted body weight) VT and Pplat less than 30cmH_2O compared with 12ml/kg VT and Pplat less than 50cmH_2O [13].

Additionally, CT imaging of patients with ARDS has shown that the lung consolidation is heterogeneous. As such, the preserved, highly compliant, lung may be more prone to be exposed to higher tidal volumes and inflation pressures. It has been suggested to use positive end-expiratory pressure (PEEP) and possibly recruitment manoeuvres to expand collapsed alveoli, which may also help to redistribute lung water while reducing injury related to the repeated expansion and collapse of alveoli. Trials suggest greater ventilator-free days and possibly a mortality benefit with high PEEP.

The current protocols do not specify any particular ventilator mode. However, general guidelines have been elaborated in order to cope with ARDS patients under mechanical ventilation [14, 15] (Table 2).

Technical guidelines for the management of patients with ARDS under mechanical ventilation

An important parameter in the management of patients

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with ARDS under mechanical ventilation is the good knowledge and effective handling of the ventilator itself. Thus, in the case of ARDS manifestation, evidence shows that some initial actions should be followed by the medical personnel [16] (Table 3). If respiratory distress stops with Ambu, this means that the ventilator does not work well or that the parameters were not correct for the patient or that the blockage was removed through suction.

More so, specific problems related to the function of ventilator may also encounter. These are related either to technical airways or with ventilator malfunction.

Problems related to technical airways

1. Incorporation of the tube into a main bronchus can cause atelectasis of the opposite lung. It is characterized by a reduction in respiratory sounds in the left hemithorax compared to the right one. Pulling the tube 2-3 cm solves the problem.

Table 2: General guidelines for ARDS management.

General measures	Ventilator settings	Monitoring parameters	Adjunctive measures
Nutritional support	Choose any mode, such as volume assist	Arterial pH of 7.30 to 7.45	Conservative fluid therapy
Prophylaxis (Stress Ulcer, Venous thromboembolism)	Inspiratory to expiratory ration of 1:1 to 1:3	Oxygen saturation of 88 to 95 percent	Possible corticosteroids
	PEEP and FiO_2 set in accordance with ARDSNet protocol*	PaO_2 of 55 to 80 mm Hg	Prone positioning
	Respiratory rate ≤ 35 breaths per minute	Plateau pressure ≤ 30 cm H_2O	Extracorporeal membrane oxygenation only after applying lung-protective strategies such as PEEP
	Tidal volume of 6 mL/kg and up to 8 mL/kg (when double triggering or inspiratory airway pressure falling below PEEP)		

ARDSNet – Acute Respiratory Distress Syndrome Network; FiO2 – fraction of inspired oxygen; PaO2 – partial pressure of arterial oxygen; PEEP – positive end-expiratory pressure.

• Sample ARDSNet protocol for FiO2 and PEEP.

FiO_2	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.5	0.5	0.5-0.8	0.8	0.9	1.0	1.0
PEEP	5	8	10	12	14	14	16	16	18	20	22	22	22	24

Table 3: Initial actions that should be followed.

1. Disconnecting the patient from the ventilator
2. Administration of 100% O2 through an Ambu system
3. Lungs and Heart auscultation
4. Checking vital signs
5. Checking the ventilator parameters
6. Aspiration
7. Suspicions of airway obstruction or pneumothorax - Thoracic radiography is required

2. Cuff Problems:

a. Obstruction caused by excessive air introduction to the cuff or by cuff's herniation at the end of the tube. Here we see increased pressure in the airways, difficulty passing the suction catheter, musical sounds during inhalation. If we deflate the cuff we can estimate the situation.

b. Failure to seal the airways because we have an air leak from the cuff or have insufficiently inflated it. This can be appreciated when we deflate the cuff. Failure to suck the same volume of air we used to inflate the cuff confirms a loss of air or rupture of the cuff. This may be solved by replacing the tube with a new one.

3. Anonymous artery rupture: This is recognized by the blood stream from the tube and is more common in tracheostomy tubes. If this is the case, we need to swirl the cuff as a means of stamping the vase. In this case, a thoracic surgeon intervention is needed.

Ventilator malfunction

1. The most common problem with ventilators is the air leakage from the system, the wrong pipe connection and insufficient FiO_2.

a. Leakage of the system is indicated by low pressure leading to alarms' start. We can also see the leakage by comparing the set tidal volume with patient' s delivered and expired tidal volume.

b. The new types of ventilators have a special instrument for FiO2 display and therefore, any deviation from the desired FiO_2 is immediately visible.

c. Incorrect sensitivity of the ventilator results in asynchrony between the patient and the ventilator.

2. Wrong Alarm. The most common cause of the wrong alarm is the inability to achieve a minimum pressure, which would prevent alarm's activation. This is very common in patients with normal compliance or in patients with increased compliance due to emphysema. This can be corrected by increasing the respiratory rate resulting in an increase of the peek pressure. A very small breathing frequency can also cause a false alarm because it does not meet the minimum time requirements necessary to sensitize the alarm.

If the manifestations of respiratory distress continue while the patient is connected to Ambu-Bag and 100% O_2, the most likely cause of distress is a respiratory complication under tension. In this case, a systematic assessment of the patient should be attempted in order to investigate the cause of distress (Table 4).

Discussion

Diagnosing ARDS requires confirming the presence of bilateral pulmonary infiltrates, using radiographs, and the absence of left atrial hypertension, using pulmonary

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Table 4: How to investigate causes of distress.

Patient overview. Measurement of its vital signs-thoracic and auscultation for localized reduction of respiratory sounds.
Control of heart rate and pulse width.
Control of airway pressures.
Endotracheal aspiration for secretions or sputum plugs.

artery occlusion pressure. However, evidence shows that both measures may be unreliable [17,18]. More so, various pathophysiologies are represented in ARDS (i.e. diverse groups of patients are grouped into a single syndrome diagnosis). Additional sources of heterogeneity in the literature include diverse leading causes, variation with respect to the phases of ARDS in which specific treatments were given, and variability in the mechanisms of lung injury [19,20]. As a recent systematic review indicated [21], therapy that benefits one sub-group of patients with ARDS may not benefit another sub-group. Recently it has been proposed that a more precise and research-focused approach of ARDS is needed to help better understand these conditions and conduct research focused on this topic [22].

Hypoxemia is one of the main clinical concerns in ARDS but the leading cause of mortality is multi-organ failure [23,24]. The mechanisms leading to multi-organ failure are as diverse as the leading cause and subsequent pathophysiologies. One such mechanism is further lung injury caused by vigorous mechanical ventilation to manage hypoxemia, which can induce the production of pro-inflammatory cytokines, endotoxins, or bacteria, resulting in multi-organ failure [25]. Thus, effective management of ventilators are of high importance for a positive outcome.

More so, prone positioning may improve oxygenation. Yet, it may not contribute significantly to decreasing mortality in ARDS patients [26]. Kinetic therapy or lateral positioning with head of bed >30° and sitting with head of the bed >30° may be used for routine positioning of patients with ventilated ARDS [27].

Step-wise early mobilization of ICU patients is safe and is associated with positive outcomes in terms of both hospital length of stay and functional ability of the patient [28,29]. Early intervention of sufficient frequency and duration and over an adequate period are the key to success for many physiotherapy interventions for ventilated ARDS patients.

Conclusions

Although general guidelines and recommendations may help medical personnel in managing the treatment of ARDS patients, they should not be considered mandatory and can never consider all the features of the individual patient. Therefore, clinicians should always personalize their decisions for each patient by assessing the risks and benefits of an intervention for the specific patient, and the potential for combining it with another treatment for greater effect.

New types of ventilators offer a range of tools and features that not only enable clinicians to apply the interventions recommended in the general guidelines, but to customize ventilation therapy to each individual patient. Thus, good knowledge and effective handling of ventilators is extremely important for ventilated ARDS patients' outcome.

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