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ScienceDirect
Journal of the Chinese Medical Association 79 (2016) 17–24
www.jcma-online.com

Original Article

Increased flow resistance and decreased flow rate in patients with acute respiratory distress syndrome: The role of autonomic nervous modulation

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Received July 1, 2015; accepted July 19, 2015

Abstract

Background: The aim of this study was to investigate the flow resistance and flow rate in patients with acute respiratory distress syndrome (ARDS) in the surgical intensive care unit and their relation with autonomic nervous modulation.
Methods: Postoperative patients of lung or esophageal cancer surgery without ARDS were included as the control group ($n = 11$). Patients who developed ARDS after lung or esophageal cancer surgery were included as the ARDS group ($n = 21$). The ARDS patients were further divided into survivor and nonsurvivor subgroups according to their outcomes. All patients required intubation and mechanical ventilation.
Results: The flow rate was significantly decreased, while the flow resistance was significantly increased, in ARDS patients. The flow rate correlated significantly and negatively with positive end-expiratory pressure (PEEP), while the flow resistance correlated significantly and positively with PEEP in ARDS patients. Furthermore, the flow rate correlated significantly and negatively with the tidal volume-corrected normalized high-frequency power but correlated significantly and positively with the tidal volume-corrected low-/high-frequency power ratio. In contrast, the flow resistance correlated significantly and negatively with normalized very low-frequency power and tidal volume-corrected low-/high-frequency power ratio, but correlated significantly and positively with tidal volume-corrected normalized high-frequency power.
Conclusion: The flow rate is decreased and the flow resistance increased in patients with ARDS. PEEP is one of the causes of increased flow resistance and decreased flow rate in patients with ARDS. Another cause of decreased flow rate and increased flow resistance in ARDS patients is the increased vagal activity and decreased sympathetic activity. The monitoring of flow rate and flow resistance during mechanical ventilation might be useful for the proper management of ARDS patients.

Keywords: acute respiratory distress syndrome; autonomic; flow rate; flow resistance; intensive care unit; vagal

1. Introduction

Acute respiratory distress syndrome (ARDS)[1,2] is a life-threatening lung condition that affects patients with and without previous cardiopulmonary disorders. The signs and symptoms of ARDS usually begin within 72 hours of the initial insult or injury to the lung, and may include shortness of breath, fast breathing, and a low arterial oxygen tension. After lung resection or esophagectomy for esophageal cancer, ARDS may occur as a complication in some patients with an incidence of 1–3%.[3–6] ARDS is associated with a high mortality in patients who require mechanical ventilation and intensive care.[6] The overall mortality rate of ARDS is over 40%; it varies widely depending on disease severity and patient age.[5,7,8]

In patients with ARDS, mechanical ventilation with a lower tidal volume (V_T) than is traditionally used may result in

Conflicts of interest: The authors declare that they have no conflicts of interest related to the subject matter or materials discussed in this article.

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http://dx.doi.org/10.1016/j.jcma.2015.10.001

decreased mortality,[9] and decelerating flow pattern associated with pressure modes is thought to provide better gas distribution than volume ventilation does.[10] Although mechanical ventilation provides essential life support, it can worsen lung injury. Mechanisms of ventilator-associated injuries include regional alveolar overdistention, repetitive alveolar collapse with shearing (atelectrauma), and oxygen toxicity.[11] To achieve a better outcome, pressure support or pressure control modes of ventilation is often adopted to minimize the incidence of barotrauma, including alveolar overdistention, pneumothorax, etc. Unfortunately, some important fluid mechanical parameters such as the flow rate and flow resistance of mechanical ventilation are not available in the ventilator settings when pressure control mode is used to ventilate ARDS patients.

Heart rate variability (HRV) analysis is a useful noninvasive method that can be used to evaluate the autonomic nervous modulation of patients with many kinds of illnesses. Several studies have documented the worse prognoses associated with autonomic dysfunction, including acute myocardial infarction,[12] septic shock,[13] and multiple organ failure.[14] Many factors have been found to interfere with the autonomic nervous modulation in critical care patients, such as ischemic heart disease,[15] sedative,[16] and vasoactive[17] drugs. In order to assess the autonomic nervous function of patients, baroreflex (BR) sensitivity may even be used in addition to HRV.

It is already known that respiratory activity and breathing pattern can affect the cardiac autonomic nervous modulation of a patient.[18] Thus, spectral analysis of heart rate, respiration, and blood pressure signals is a noninvasive approach that is widely used to investigate cardiovascular and cardiorespiratory control mechanisms.[19]

The first aim of this study was to obtain the flow rate and flow resistance of mechanically ventilated ARDS patients under pressure control mode, and to investigate the determinants of flow resistance and flow rate in patients with ARDS who required mechanical ventilation and critical care in the surgical intensive care unit (SICU) at a tertiary-care center. The second aim of this study was to investigate whether autonomic nervous modulation of mechanically ventilated ARDS patients played a role in the regulation of the flow rate and flow resistance.

2. Methods

2.1. Study design

This was a prospective cohort study with retrospective data analysis. The study protocol was approved by the Institute Review Board of the hospital, and written informed consent was obtained from the next-of-kin of the patients before their enrollment in the study.

2.2. Study setting and population

This study was conducted in the SICU of a tertiary medical center. All patients were older than 18 years and had received thoracic surgery due to lung or esophageal cancer. The patients were transferred to the SICU for postoperative care. Patients without postoperative complication of ARDS were enrolled as the control group. Patients complicated by ARDS were enrolled as the ARDS group. ARDS was diagnosed according to the Berlin Definition.[2] Three mutually exclusive categories of ARDS based on the degree of hypoxemia were proposed as the draft definition: mild [200 mmHg < PaO_2/fraction of inspired oxygen (FIO_2) ≤ 300 mmHg], moderate (100 mmHg < PaO_2/FIO_2 ≤ 200 mmHg), and severe (PaO_2/FIO_2 ≤ 100 mmHg) hypoxemia with four ancillary variables for severe ARDS: radiographic severity, respiratory system compliance (≤ 40 mL/cmH_2O), positive end-expiratory pressure (≥ 10 cmH_2O), and corrected expired volume per minute (≥ 10 L/min). Patients who had severe coronary artery disease, persistent arrhythmia, cardiac pacing, diabetes mellitus, cerebral vascular accident, or major diseases of kidney or autoimmune system were excluded from the study.

2.3. Study protocol and data collection

All patients needed intubation and mechanical ventilation. Fentanyl was administered to all patients as an analgesic. The alveolar–arterial oxygen difference and Acute Physiology and Chronic Health Evaluation II score were determined for all ARDS patients when they were admitted to the SICU. The demographic data, vital signs, medications, ventilator readings, and relevant clinical data were recorded within 4 hours of admission to the SICU. Blood pressures were collected through the arterial line placed in the radial arteries of the patients and the bedside monitor of the SICU. Twelve minute electrocardiographic (ECG) signals were recorded in the supine position using the MP35 ECG device (BIOPAC Systems, Inc., Goleta, CA, USA). The output ECG signals were digitized by an A/D converter (BIOPAC Systems, Inc.), and stored in a notebook computer for later HRV analysis. During ECG recording, bedside care such as suction and invasive procedures that could interfere with HRV was avoided.

2.4. Flow rate and flow resistance

Flow rate is the amount of fluid flowing in a given length of time. It can be expressed as the volume of fluid stored during a given period of time. In fluid mechanics, the flow rate equals the volume of fluid divided by the time used to deliver the volume. Thus, the flow rate in mechanical ventilation is given by

$$F = \frac{V_T}{T_{insp}},$$

where F is the flow rate, V_T is the tidal volume, and T_{insp} is the inspiration time. The flow resistance is determined by the pressure applied onto the volume of fluid and the flow rate according to the well-known relationship among flow, pressure and resistance: $Q = \Delta P/R$. Thus, the flow resistance of air