Pressure Controlled Versus Volume Controlled Ventilation With Laryngeal Mask Airway

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Study Objective: To quantify the impact on peak airway pressure of pressure-controlled and volume-controlled ventilation during Laryngeal Mask Airway™ (LMA) use.

Design: Prospective, crossover clinical study.

Setting: University-affiliated hospital.

Patients: 32 ASA physical status I and II patients undergoing general anesthesia with the LMA.

Interventions: Patients were ventilated for three minutes both with pressure-controlled and volume-controlled ventilation, provided that tidal volume (VT) and inspiratory time (IT) were constant.

Measurements and Main Results: The monitored parameters were electrocardiography, arterial blood pressure, pulse oximetry, capnography, neuromuscular transmission, airway pressure and flow, and concentration of ventilated vapors and gases. The actually delivered VT was similar with both types of ventilation (volume-controlled = 0.67 ± 0.13 l, pressure-controlled = 0.67 ± 0.14 l; p = 0.688). Peak airway pressure was lower during pressure-controlled ventilation (14.6 ± 3.5 cmH₂O) than during volume-controlled ventilation (16 ± 4 cmH₂O) (p < 0.001). Furthermore, we noted that the higher the airway pressure with volume-controlled ventilation, the greater was the reduction in airway pressure during pressure-controlled ventilation.

Conclusions: Pressure-controlled rather than volume-controlled ventilation can improve the effectiveness of mechanical ventilation in patients with high airway pressure. © 2001 by Elsevier Science Inc.

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Introduction

The Laryngeal Mask Airway™ (LMA) (The Laryngeal Mask Airway Co. Ltd., Nicosia, Cyprus) is widely used for airway management during general anesthesia in fasted patients undergoing elective surgical procedures. During spontaneous breathing in anesthetized patients, the LMA does not present device-related problems, even though minute ventilation (Vₚ) and arterial hemoglobin saturation (SPO₂) are lower and end-tidal carbon dioxide pressure (ETCO₂) is higher than that shown during positive pressure ventilation. During positive-pressure ventilation, air leaks frequently occur when peak airway pressure

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exceeds a threshold value ranging from 20 to 30 cmH2O.2-5 Clinical consequences of air leaks include hypoventilation, gastric insufflation, and operating room pollution.3,4,6,7

As long as tidal volume (VT) and inspiratory time (It) are constant, decelerating inspiratory flow reduces peak airway pressure when compared with constant inspiratory flow.8 Pressure-controlled ventilation generates a decelerating-flow profile, whereas volume-controlled ventilation during general anesthesia is often delivered with a constant inspiratory flow pattern. Therefore, when compared with volume-controlled ventilation, pressure-controlled ventilation with an LMA should decrease peak airway pressure, as well as reducing the incidence of unplanned increases of peak airway pressure and related air leaks, without any reduction in VT and/or expiratory time.

The aim of this study was to quantify the reduction in peak airway pressure during LMA use obtained with pressure-controlled ventilation versus volume-controlled ventilation with constant inspiratory flow.

Materials and Methods

The study was approved by the Catholic Hospital Institutions Ethical Committee and was conducted in accordance with the Helsinki Declaration. Informed written consent to participate in the study was obtained from all patients.

Thirty-two consecutive ASA physical status I and II patients were invited to participate in this prospective crossover study. All patients were scheduled for elective surgery with general anesthesia with the LMA and mechanical ventilation.

General anesthesia was induced intravenously (IV) using propofol 2.5 mg/kg and fentanyl 2-5 µg/kg and was maintained with nitrous oxide and isoflurane or sevoflurane by a low-flow system. All patients were paralyzed with atracurium 0.3 mg/kg. An ADU/AS3 integrated system (Datex-Engstrom Division, Instrumentarium Corp., Helsinki, Finland) was used in all patients to deliver mechanical ventilation and to perform the intraoperative monitoring. Monitoring included electrocardiography (ECG), arterial blood pressure (BP) (monitored either invasively or noninvasively for 3 min), pulse, capnography, neuromuscular transmission (train-of-four), and inspiratory and expiratory concentration of oxygen, carbon dioxide, nitrous oxide, isoflurane, or sevoflurane. Airway pressure and flow were measured at the airway opening. All data were recorded at least every three minutes, saved, and printed out at the end of each surgical procedure.

Immediately after anesthesia induction and before the beginning of the surgical procedure, patients’ tracheas were ventilated both with pressure-controlled ventilation (3 min) and with volume-controlled ventilation (3 min) in random order. During this period, the mechanical ventilator was set to obtain, with both the ventilatory modalities, a VT of 10 mL/kg, a respiratory rate (RR) of 10 breaths/min and an inspiratory/expiratory (I:E) ratio of 1:2. No end-inspiratory pause or positive end-expiratory pressure were used. During pressure-controlled ventilation, a fast increase of the ramp pressure during inspiration was set. At the end of both volume- and pressure-controlled ventilation periods, five different pressure-time curves were recorded and the peak airway pressure was calculated as the mean of five measurements. After the six minutes of the volume- and pressure-controlled ventilation trial, patients continued the anesthesia and the mechanical ventilation according to clinical need.

Statistics. Data are presented as means ± standard deviation. The comparison between data obtained from volume-controlled ventilation and pressure-controlled ventilation was performed by a paired t-test. Hence, the coefficient of correlation of Pearson and the linear regression were calculated between the peak airway pressure during volume-controlled ventilation and the peak airway pressure decrease obtained with pressure-controlled ventilation. Statistical significance was assumed at p < 0.05.

Results

Patients were 38.5 ± 17.6 years old, their weight was 66.3 ± 19.8 kg; 20 patients were classified as ASA physical status I and 12 as ASA physical status II. A size 4 LMA was used in 18 patients and a size 5 LMA in the other 14 patients.

The actual delivered VT was similar with both types of ventilation (volume-controlled ventilation = 0.67 ± 0.13 l/t, pressure-controlled ventilation = 0.67 ± 0.14 l/t, p = 0.688). Peak airway pressure was lower during pressure-controlled ventilation (14.6 ± 3.5 cmH2O) than during volume-controlled ventilation (16 ± 4 cmH2O) (p < 0.001). Furthermore, there was a linear relationship between the level of peak airway pressure during volume-controlled ventilation and the decrease of peak airway pressure obtained with pressure-controlled ventilation (Figure 1).

Discussion

This study demonstrates that the use of pressure-controlled ventilation during general anesthesia with the LMA reduces peak airway pressure compared with volume-controlled ventilation at the same VT and It. This study also shows that the higher the peak airway pressure value during volume-controlled ventilation, the greater its decrease with pressure-controlled ventilation.

The clinical utility of peak airway pressure limitation during mechanical ventilation is usually questionable: the plateau pressure, which is measured during the end-inspiratory pause, is considered the more reliable pressure limit because it avoids the main complications caused by positive-pressure ventilation (i.e., pulmonary overinflation and barotrauma).9

However, with the increasing popularity of minimally invasive devices for airway management during positive-pressure ventilation (e.g., the LMA and the cuffed oropharyngeal airway [COPA]) the peak airway pressure value is gaining a clinical relevance, as is the importance of an appropriate mechanical ventilation setting, even during elective surgery. The impact of peak airway pressure greater than 20 to 30 cmH2O on the air leaks from the...
LMA is well recognized: clinical consequences may include hypoventilation, gastric insufflation and operating room pollution. A recent study demonstrated that air leaks occur with the COPA at a lower peak airway pressure value than with the LMA. Consequently, pressure-controlled ventilation should be useful with the COPA even more so than with the LMA.

The mean value of peak airway pressure during volume-controlled ventilation with LMA usually ranges between 15 and 22 cmH₂O, as shown in our study and in the literature. Consequently the peak airway pressure value is frequently near that of the air leak’s pressure threshold, underlining the importance in daily practice of a careful mechanical ventilation setting so as to lower peak airway pressure.

The data of the present protocol were obtained without any end-inspiratory pause. This option allowed the reduction of the inspiratory flow and consequently, peak airway pressure during volume-controlled ventilation, rendering this type of ventilation preferable to the pressure-controlled form. However, this could reduce mean airway pressure and oxygenation with respect to pressure-controlled ventilation. Furthermore, in our protocol, peak airway pressure was measured at the airway opening: values recorded at the ventilator would be higher (and the peak airway pressure difference between pressure-controlled ventilation and volume-controlled ventilation would therefore be greater) due to the resistive load of the inspiratory line.

Pressure-controlled ventilation probably reduces the peak airway pressure due to the resistive load. The simplified equation of motion of the respiratory system is \( P_{\text{appl}} = P_{\text{el}} + P_{\text{res}} = V_T/C + R V' \), where \( P_{\text{appl}} \) is the pressure applied to the respiratory system, \( P_{\text{el}} = \) elastic, \( P_{\text{res}} = \) resistive components, \( C = \) the compliance, and \( R = \) the resistance of the respiratory system, whereas \( V' = \) the inspiratory flow rate. In all ventilatory modalities, the highest \( P_{\text{el}} \) occurs at the end of inspiration and \( C \) and \( V_T \) are the only determinants. The \( V' \) and \( P_{\text{res}} \) at the end of the inspiration are higher during the square wave (volume-controlled ventilation) than during the decreasing (pressure-controlled ventilation) inspiratory flow pattern. Consequently, the difference in peak airway pressure between volume-controlled ventilation and pressure-controlled ventilation is due only to the \( R V' \) product: the higher the resistance the greater the decrease in \( P_{\text{appl}} \) due to the reduction of the end-inspiratory flow. Our data cannot experimentally support this interpretation because we did not perform the end-inspiratory pause. As a result, we cannot calculate \( P_{\text{el}} \) and \( P_{\text{res}} \) in the study population.

The increase of the resistance of the respiratory system can be related to patient characteristics, i.e., chronic obstructive lung disease or obesity, to the surgical procedure itself, i.e., laparoscopy, or to patient positioning during the surgery: Trendelenburg or prone position. These frequent conditions are probably the main indication for the use of pressure-controlled ventilation during mechanical ventilation with the LMA.

Probably many patients can be ventilated safely with volume-controlled ventilation or pressure-controlled ventilation. Patients with high airway pressure (e.g., in obesity, those with chronic obstructive pulmonary disease, patients undergoing upper abdominal surgery, laparoscopy, patients placed in the Trendelenburg position) mainly benefit by the pressure-controlled ventilation with LMA: air leaks are pressure-related and the higher the peak airway pressure during volume-controlled ventilation, the greater the peak airway pressure decreases with pressure-controlled ventilation. The use of pressure-controlled ventilation should be the first step in the clinical management of the pressure-related air leaks from the LMA.

![Figure 1. Relationship and linear regression of peak airway pressure (Ppk) during volume-controlled ventilation (VCV) and the decrease in peak airway pressure with pressure-controlled ventilation (PCV) (with tidal volume and inspiratory time remaining constant).](image-url)
if necessary, other changes in the ventilation setting can be added to this simple and effective measure.

In conclusion, this study demonstrates that pressure-compared to volume-controlled ventilation can improve the effectiveness of mechanical ventilation through the LMA for those patients with high peak airway pressure.

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