

## Monitoring of CO<sub>2</sub> Tension during High Frequency Jet Ventilation\*

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**Abstract:** In general, end-tidal CO<sub>2</sub> tension (PetCO<sub>2</sub>) is well correlated with arterial CO<sub>2</sub> tension (PaCO<sub>2</sub>) during spontaneous and conventional mechanical ventilation in normal lungs. However, it is known that during high frequency jet ventilation (HFJV), PetCO<sub>2</sub> may underestimate PaCO<sub>2</sub> because of inadequate washout of the anatomical dead space by a small tidal volume and the relatively slow response time of infrared CO<sub>2</sub> analyzers. The purpose of the present study was to investigate the validity of PetCO<sub>2</sub> as a reflection of PaCO<sub>2</sub> during HFJV in anesthetized dogs with and without histamine-induced lung injury. Twelve mongrel dogs of either sex were randomly divided into two groups: six control dogs and six histamine-induced lung injury dogs. The dogs were anesthetized and then ventilated on HFJV with frequency of 60, 100 or 200 breaths/min at random. After 20 min of each change in ventilator setting, both PetCO<sub>2</sub> and PaCO<sub>2</sub> were measured simultaneously after decreasing the frequency from 60, 100 or 200 breaths/min to 20 breaths/min for 6~8 breaths. The results showed that with frequency of 60, 100 and 200 breaths/min, there were no significant differences between PaCO<sub>2</sub> and PetCO<sub>2</sub> in anesthetized dogs. There was a significant correlation ( $r=0.83$ ,  $p<0.01$ ) between PaCO<sub>2</sub> and PetCO<sub>2</sub>. With frequency of 60 and 100 breaths/min, PaCO<sub>2</sub> ( $5.21 \pm 0.86$  and  $5.78 \pm 0.82$ ) was significant higher than PetCO<sub>2</sub> ( $3.58 \pm 0.54$  and  $4.36 \pm 0.52$ ) in dogs with histamine-induced lung injury ( $p<0.01$ ). There was a significant correlation ( $r=0.80$ ,  $p<0.01$ ) between PaCO<sub>2</sub> and PetCO<sub>2</sub>. It is suggested that the PetCO<sub>2</sub> following a decrease in the jet frequency during HFJV could provide an accurate prediction of PaCO<sub>2</sub> in anesthetized dogs with and without histamine-induced lung injury.

**Key words:** high frequency jet ventilation; end-tidal CO<sub>2</sub> tension; histamine; dogs

As a new type of mechanical ventilation, high frequency jet ventilation (HFJV) has been widely used in anesthesia, resuscitation, intensive care and respiratory treatment [1-3]. When patients are anesthetized and ventilated with normal tidal volumes at low frequencies, the arterial CO<sub>2</sub> tension (PaCO<sub>2</sub>) may be estimated from the end-tidal CO<sub>2</sub> tension (PetCO<sub>2</sub>). However, during HFJV, due to the high frequency and low tidal volume, and the presence of mixed inspired and expired gases in the trachea, P(a-et)CO<sub>2</sub> appears to increase, so that the estimation of PaCO<sub>2</sub> becomes inaccurate [4, 5].

Measurement of PetCO<sub>2</sub> following one or three large breaths has been demonstrated to reflect accurately PaCO<sub>2</sub> during HFJV [6-8]. But it necessitates a special insufflations system and a cuffed tracheal tube, which is not convenient. It has been shown that PaCO<sub>2</sub> can be predicted by capnography when the frequency was temporarily reduced to obtain a steady PetCO<sub>2</sub> during HFJV in patients with normal lung [9, 10]. We have developed a method that PaCO<sub>2</sub> may be estimated from measurement of PetCO<sub>2</sub> after decreasing the frequency to 20 breaths/min for

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6~8 breaths during HFJV. The purpose of the present study was to investigate the validity of PetCO<sub>2</sub> following a decrease in the jet frequency as a reflection of PaCO<sub>2</sub> during HFJV in anesthetized dogs with and without histamine-induced lung injury.

## MATERIALS AND METHODS

### 1. Materials

Twelve mongrel dogs of either sex were randomly divided into two groups: six control dogs weighing  $14.9 \pm 2.06$  kg; six histamine-induced lung injury dogs weighing  $13.6 \pm 1.61$  kg. Anesthesia was induced with pentobarbitone 30 mg/kg i.v., and then maintained with a continuous infusion of pentobarbitone  $4\sim 6$  mg·kg<sup>-1</sup>·h<sup>-1</sup>. The dogs were placed in a supine position on a well-fitted animal board made of plastics. The trachea was incubated with a tracheal tube (9 mm i.d.) with its tip 3~4 cm below glottis. Then the animals were ventilated with HFJV by a program controlled two-way jet ventilator (Airplane Manufacture Company of Nanchang, China), which was driven by 21% oxygen supplied. The ventilation frequency was 100 BPM and the inspiratory/expiratory ratio is 1: 2. The animals were paralyzed with succinylcholine 1 mg/kg i.v., and maintained with an infusion of succinylcholine every 15~20 min. Driving pressure was adjusted to maintain PaCO<sub>2</sub> ranging between 4.00 and 5.33 kPa. An arterial catheter was inserted through the right femoral artery to measure arterial blood pressure and to collect arterial blood sample. A venous catheter was inserted through the right femoral vein and subsequently used for injections of drugs and infusion of saline ( $10\sim 15$  ml·kg<sup>-1</sup>·h<sup>-1</sup>).

### 2. Methods

Arterial blood-gas analyses were performed with an automated blood-gas analyzer (Radiometer ABL3, Denmark). PetCO<sub>2</sub> was measured with a 1H21A expired gas monitor (Sanrei, Japan). The gas collecting tube was positioned outside the tracheal tube, and its tips located at about 6 cm before the tips of tracheal tube. After conditions had stabilized for 20 min, a control arterial blood sample was obtained and PetCO<sub>2</sub> recorded. The control group dogs were ventilated on HFJV with frequency of 60, 100 or 200 breaths/min at random after 30 min. The lung injury group dogs were intravenously infused with histamine at  $5\mu\text{g}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ . After 30 min the animals were ventilated on HFJV with frequency of 60 and 100 breaths/min at random. Subsequent measurements were made 20 min after each change in ventilator setting. Both PetCO<sub>2</sub> and PaCO<sub>2</sub> were measured simultaneously after decreasing the frequency from 60, 100 or 200 breaths/min to 20 breaths/min for 6~8 breaths.

All data were compared by analysis of variance and Student's t-test test. The relationship between PetCO<sub>2</sub> and PaCO<sub>2</sub> was analyzed by linear regression analysis. Statistical significance was set at  $p < 0.05$ .

## RESULTS

### 1. Changes of PaCO<sub>2</sub> and PetCO<sub>2</sub> in anesthetized dogs with normal lung

PaCO<sub>2</sub> and PetCO<sub>2</sub> increased progressively with frequency from 60 up to 200 breath/min while P(a-et)CO<sub>2</sub> remained unchanged. There were no significant differences between PaCO<sub>2</sub> and PetCO<sub>2</sub> at each of the frequencies of ventilation (Table 1). There was a significant correlation between PaCO<sub>2</sub> and PetCO<sub>2</sub>,  $\text{PaCO}_2 = 0.73 \text{ PetCO}_2 + 1.35$ ,  $r = 0.83$  ( $p < 0.001$ , Figure 1)

### 2. Changes of PaCO<sub>2</sub> and PetCO<sub>2</sub> in anesthetized dogs with lung injury

PetCO<sub>2</sub> increased progressively with frequency from 60 up to 100 BPM. PaCO<sub>2</sub> showed a tendency to increase. P(a-et)CO<sub>2</sub> remained unchanged. PaCO<sub>2</sub> was significant higher than PetCO<sub>2</sub> at each of the frequencies of

ventilation (Table 2). There was a significant correlation between PaCO<sub>2</sub> and PetCO<sub>2</sub>,  $\text{PaCO}_2 = 1.05 \text{ PetCO}_2 + 1.32$ ,  $r = 0.80$  ( $p < 0.001$ , Figure 2)

## DISCUSSION

Being characterized by high ventilation frequency, low tidal volume, low airway pressure and little effects on cardiovascular function, HFJV has been widely used in anesthesia and respiratory treatment. Several studies have evaluated the accuracy of PetCO<sub>2</sub> measurement as a reflection of PaCO<sub>2</sub> during conventional mechanical ventilation. But during HFJV the measurement of PetCO<sub>2</sub> does not reflect PaCO<sub>2</sub>. Several factors may contribute to this: decreased CO<sub>2</sub> elimination due to the higher ventilation frequency and lower tidal volume, the presence of mixed inspired and expired gases in the trachea<sup>[4]</sup>, and the inadequate capnograph response time<sup>[5]</sup>. So it is difficult to assess the adequacy of CO<sub>2</sub> elimination clinically during HFJV. Regular monitoring of blood gas tensions is usually considered essential during HFJV. A rapid non invasive test that can be performed frequently would be a useful aid to the monitoring of HFJV in an intensive care unit and in the respiratory treatment as an alternative to frequent arterial blood sample<sup>[11]</sup>. Measurement of PetCO<sub>2</sub> following a single large breath has been demonstrated to reflect accurately PaCO<sub>2</sub> during HFJV. The correlation coefficient reached 0.98 in the study of Mihm and colleagues<sup>[6]</sup>, 0.99 in the study of Mason<sup>[7]</sup>. However, it necessitates a special insufflations system and a cuffed tracheal tube, which is not always convenient.

Our results indicate that, during HFJV, the PaCO<sub>2</sub> may be estimated from measurement of the PetCO<sub>2</sub> following a decrease in the jet frequency in dogs with normal lungs. It is possible that the increase in tidal volume and improvement in gas mixing that occurs when ventilation frequency being changed to conventional frequency during HFJV may account for the accurate reflection of PaCO<sub>2</sub> by PetCO<sub>2</sub>. When ventilation frequency was changed to 20 breaths/min from 60, 100 and 200 breaths/min, we found that, the PetCO<sub>2</sub> tended to stabilize following 6~8 breaths that would reflect accurately PaCO<sub>2</sub>. This technique of measuring PetCO<sub>2</sub> following a decrease in the jet frequency that does not need changing ventilator appears more accurate and convenient. This conclusion agrees with the data of previous studies<sup>[9, 10]</sup>. Simon et al<sup>[10]</sup> investigated the validity of PetCO<sub>2</sub> as a reflection of PaCO<sub>2</sub> during HFJV in 40 patients undergoing laryngeal microsurgery. PetCO<sub>2</sub> and PaCO<sub>2</sub> were measured simultaneously after decreasing the frequency from 100 beats per minute to 15 beats per minute 10 and 20 minutes after the commencement of HFJV. They found that there was a strong correlation ( $r = 0.955$ ,  $p < 0.001$ ) and a good correspondence between the mean PetCO<sub>2</sub> and PaCO<sub>2</sub>. Simon's study demonstrated the PetCO<sub>2</sub> obtained following a decrease in the jet frequency during HFJV could closely reflect PaCO<sub>2</sub>.

Changes in the mechanical properties of the bronchopulmonary system and mismatching of ventilation and perfusion may be induced by the infusion of an active substance like histamine<sup>[12, 13]</sup>. Our early studies have shown that histamine infusion can result in disorders of respiratory and cardiovascular functions with a decrease in PaO<sub>2</sub>, arterial blood pressure, pulmonary and respiratory system compliances, and an increase in PaCO<sub>2</sub>, Qs/Qt, peak inspiratory pressure, pulmonary and respiratory system resistances<sup>[13]</sup>. The results of this study show that there was a significant correlation between PaCO<sub>2</sub> and PetCO<sub>2</sub> in dogs with histamine-induced lung injury during HFJV. It suggests that better prediction of PaCO<sub>2</sub> can be done by PetCO<sub>2</sub> following a decrease in the jet frequency in dogs with histamine-induced lung injury during HFJV. So PetCO<sub>2</sub> following a decrease in the jet frequency could be used as regular monitoring of blood gas CO<sub>2</sub> tension in critical care patients with lung injury. The P(a-et)CO<sub>2</sub> difference was higher in dogs with histamine-induced lung injury during HFJV. It is possibly because

of the mismatching of ventilation and perfusion and changed lung mechanics.

In summary, the PetCO<sub>2</sub> following a decrease in the jet frequency during HFJV could provide an accurate prediction of PaCO<sub>2</sub> in anesthetized dogs with and without histamine-induced lung injury.

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**Table 1 PaCO<sub>2</sub> and PetCO<sub>2</sub> following a decrease in the jet frequency in anesthetized dogs during high frequency jet ventilation**

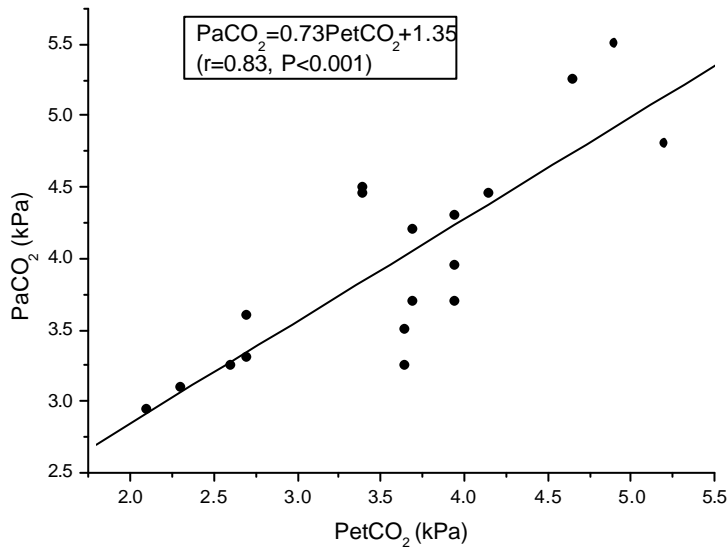
Parameter	Frequency (breaths/min)		
	60	100	200
PetCO <sub>2</sub> (kPa)	3.20 ± 0.78	3.58 ± 0.62	4.11 ± 0.96**#
PaCO <sub>2</sub> (kPa)	3.46 ± 0.48	4.00 ± 0.52*	4.54 ± 0.82**#
P(a-et)CO <sub>2</sub> (kPa)	0.26 ± 0.50	0.43 ± 0.45	0.43 ± 0.54

Mean ± SD (n=6). \* *p*<0.05, \*\* *p*<0.01 vs 60 breaths/min; # *p*<0.05 vs 100 breaths/min

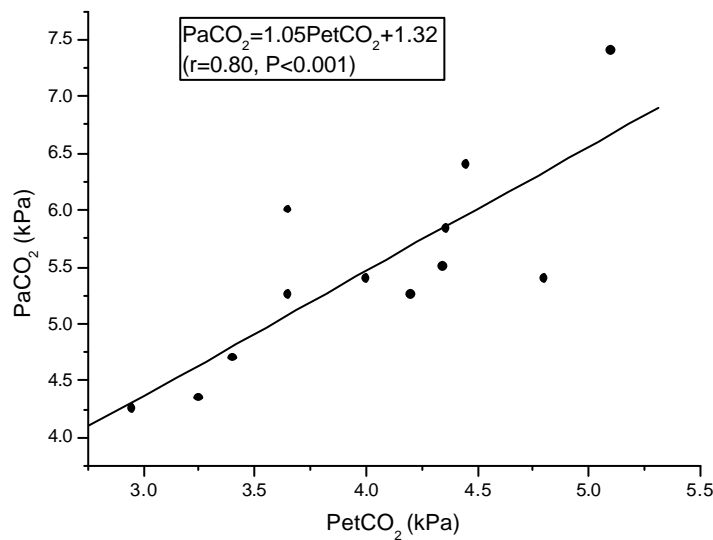
**Table 2 PaCO<sub>2</sub> and PetCO<sub>2</sub> following a decrease in the jet frequency in dogs with histamine-induced lung injury during high frequency jet ventilation**

Parameter	Frequency (breaths/min)	
	60	100
PetCO <sub>2</sub> (kPa)	3.58 ± 0.54	4.36 ± 0.52##
PaCO <sub>2</sub> (kPa)	5.21 ± 0.86**	5.78 ± 0.82**
P(a-et)CO <sub>2</sub> (kPa)	1.64 ± 0.45	1.43 ± 0.59

Mean ± SD (n=6). \*\* *p*<0.01 vs PetCO<sub>2</sub>; ## *p*< 0.01 vs 60 breaths/min



**Fig. 1 Relationship between PaCO<sub>2</sub> and PetCO<sub>2</sub> following a decrease in the jet frequency in anesthetized dogs during high frequency jet ventilation**



**Fig. 2 Relationship between PaCO<sub>2</sub> and PetCO<sub>2</sub> following a decrease in the jet frequency in dogs with histamine-induced lung injury during high frequency jet ventilation**