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Monitoring of $PETCO_2$ during High Frequency Jet Ventilation for Laryngomicrosurgery

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In general, $PETCO_2$ is well correlated with $PaCO_2$ during spontaneous and conventional mechanical ventilation in normal lungs. However, it is known that during high frequency jet ventilation, $PETCO_2$ may underestimate $PaCO_2$ because of inadequate washout of the anatomical dead space by a small tidal volume and the relatively slow response time of infrared CO_2 analyzers.

The validity of $PETCO_2$ as a reflection of $PaCO_2$ was assessed during HFJV in 40 patients undergoing laryngeal microsurgery. HFJV was applied through an injector inserted into the trachea 6 cm below the vocal cord. $PETCO_2$ was obtained from a sampling line placed 2 cm below the injector. Both $PETCO_2$ and $PaCO_2$ 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. There was a strong correlation ($r = 0.955$, $P < 0.001$) and a good correspondence between the mean $PETCO_2$ and $PaCO_2$ values with an average difference of 1.93 ± 1.21 mmHg and a limit of agreement from -0.49 to 4.35 mmHg. It is suggested that the $PETCO_2$ obtained following a decrease in the jet frequency during HFJV could closely reflect $PaCO_2$.

Key Words: Arterial carbon dioxide tension, capnography, end-tidal carbon dioxide tension, high frequency jet ventilation, laryngomicrosurgery

INTRODUCTION

High Frequency Jet Ventilation (HFJV) has been used for laryngeal microsurgery (LMS) providing an unobstructed surgical view while permitting adequate ventilation. One of the problems of HFJV is the difficult of assessing the adequacy of ventilation due to technical problems associated with measuring the tidal volume. The correlation between end-tidal ($PETCO_2$) and arterial carbon dioxide tension ($PaCO_2$) is a well-recognized phenomenon both in spontaneously and mechanically ventilated patients.[1] However, during HFJV, the $PETCO_2$ does not reflect the $PaCO_2$ accurately because of the slow response times of carbon dioxide analyzers and the small tidal volume delivered. In addition, with some HFJV patterns, there is a considerable dead space ventilation.[2-4] The speculation about rapid equilibration is superfluous: allowing fuller expiration, stopping jet ventilation provides a truer alveolar measurement that is closer to the arterial sample.[4-8] The equilibration of CO_2 is rapidly achieved between pulmonary capillaries and alveoli suggesting that the measurement of $PETCO_2$ during a single deep breath after stopping jet ventilation can reflect $PETCO_2$ as alveolar and arterial CO_2 tension.

The goal of this study was to assess the validity of $PETCO_2$ as a reflection of the $PaCO_2$ during HFJV for LMS by using statistical methods to assess the degree of agreement between the two methods of PCO_2 measurement.

MATERIALS AND METHODS

40 patients (ASA Physical Status 1, mean age 38.8 ± 10.4 yr, weight 59.0 ± 8.0 kg) undergoing laryngeal micro-LASER surgery for benign tumors of the vocal cord were included in this study. Informed consent was obtained from each patient and the Ethics Committee of our institution

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approved the study. The patients were premedicated with midazolam 1 - 1.5 mg, glycopyrrolate 0.1 mg, and cimetidine 200 mg i.v. 30 minutes before anesthesia. Anesthesia was induced with fentanyl 2 μg/kg and a target controlled infusion (TCI) of propofol (Diprifusor; Fresenius Vial S.A.; Brezins, France) after the administration of 1% lidocaine 3 ml i.v. to reduce the injection pain. Atracurium 0.4 mg/kg or vecuronium 0.08 mg/kg were used a neuromuscular blockade for endotracheal intubation. A 12 French-gauge Teflon catheter, with an attached gas sampling line, was inserted orotracheally below the vocal cord under direct laryngoscopy. The distal tip of the injection catheter was placed 5 - 6 cm below the vocal cords and the distal tip of the gas sampling line was placed 2 cm below the injection catheter. Two catheters were wrapped with aluminum foil to avoid damage from the LASER beam (Fig. 1). The proximal end of the injector was fixed to the skin of the cheek and HFJV (Campos β; Silver Medical; Tokyo, Japan) was started (frequency 100 beats/ min, I : E = 1:3, driving pressure 2.4 - 3 kg/cm^2) through the injector inserted through an oro- pharyngeal artificial airway. A gas sampling line was connected to a gas monitor (Dragerwerk AG; Lubeck, Germany) and continuous monitoring of intratracheal PCO_2 started. The gas sampling rate was fixed at 200 ml/min. The capnogram was calibrated with calibration gas on every morning of the study. Anesthesia was maintained with TCI of propofol. The same laryngologist performed surgery throughout the study. After 10 minutes and 20 minutes of HFJV, the jet frequency was reduced to 15 beats per minute and $PETCO_2$ was monitored over 5 - 6 single breaths. Arterial blood was sampled from the radial artery for simultaneous measurement of the $PaCO_2$. The jet driving pressure was maintained consistently and it was only corrected according to the $PETCO_2$. On completion of the procedure, the residual neuromuscular block was reversed with neostigmine 0.03 mg/kg and atropine 0.01 mg/kg.

A Pearson's product moment correlation was obtained using SW SPSS 9.0 to determine the strength of the correlation between the $PETCO_2$ and the $PaCO_2$ values from two measurements during HFJV. The repeatability of two times measurements and the agreement between the two methods ($PETCO_2$ and $PaCO_2$) were assessed using the method described by Bland and Altman.[9]

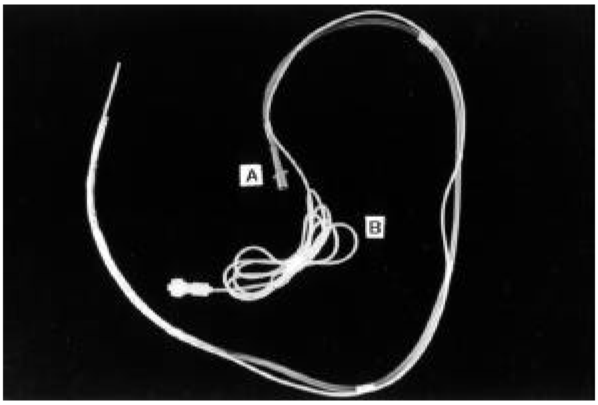

Fig. 1. The two attached catheters used for applying and monitoring the high frequency jet ventilation. Arrow A indicates a polyethylene catheter for jet injection and B indicates a Teflon gas sampling line.

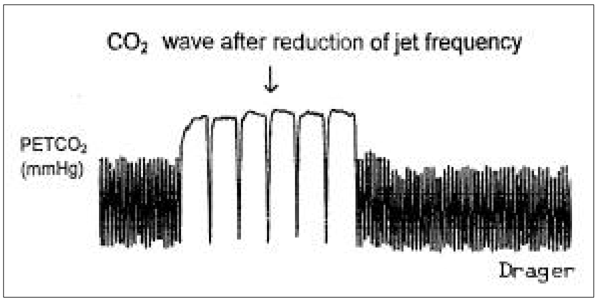

Fig. 2. Capnography during high frequency jet ventilation. Large single waves indicate the carbon dioxide waves after decreasing jet frequency.

RESULTS

Mean duration of the HFJV was 34 ± 8.9 minutes. The capnogram, which was used to characterize every jet impulse, and the $PETCO^2$, after decreasing the jet rates, are shown in Fig. 2. The values for $PETCO_2$, $PaCO_2$ and the difference and mean of $PaCO_2$-$PETCO_2$, and PaO_2 during HFJV are shown in Table 1.

By applying Pearson's product moment correlation, we found a significant correlation between the means of $PETCO_2$ and $PaCO_2$, based on the measurements taken ($r = 0.955$, $p < 0.001$), and a

Table 1. Values of $PETCO_2$, $PaCO_2$, Mean and the Difference, and PaO_2 during High Frequency Jet Ventilation

	N = 40				
	$PETCO_2$	$PaCO_2$	Mean of $PETCO_2$ - $PaCO_2$	Difference	PaO_2 (FiO_2 0.24 - 0.3)
10 minutes	33.90 ± 4.35	35.18 ± 4.47	34.11 ± 4.02	1.27 ± 0.82 (95% CI 1.00, 1.53)	130.21 ± 16.58
20 minutes	32.89 ± 3.57	35.86 ± 4.54	34.27 ± 3.83	2.95 ± 1.16 (95% CI 2.58, 3.32)	129.68 ± 14.18
Mean	33.36 ± 3.89	35.30 ± 4.30	34.54 ± 4.89		
Difference	0.96 ± 1.47	0.68 ± 1.15	1.93 ± 1.21 (95% CI 1.54, 2.32)		

Unit: mmHg.

correlation between $PETCO_2$ and $PaCO_2$ from the first (r = 0.983, $p < 0.001$) and the second set of measurements (r = 0.962, $p < 0.001$). The mean difference of the mean scatter diagram in the mean values of $PETCO_2$ and $PaCO_2$ from the first measurement showed 1.27 ± 0.82 mmHg (95% CI 1.00, 1.53) with a limit of agreement between (0.37 and 2.91 mmHg. In second set of measurements, the mean difference was 2.95 ± 1.16 mmHg (95% CI 2.58, 3.32) with a limit of agreement from 0.63 to 4.11 mmHg. The repeatability coefficient of $PETCO_2$ and $PaCO_2$ in two measurements was 2.94 mmHg and 2.30 mmHg. The mean difference against the mean scatter diagram of the mean values of $PETCO_2$ and $PaCO_2$ for the two sets of measurements was 1.93 ± 1.21 mmHg (95% CI 1.54, 2.32) with a limit of agreement from -0.49 to 4.35 mmHg (Fig. 3).

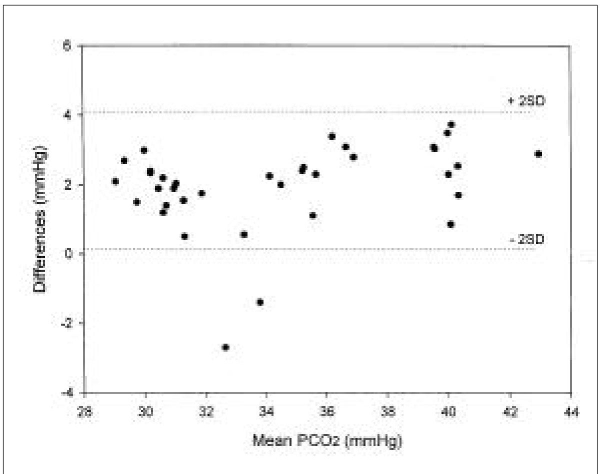

Fig. 3. Differences between the mean PCO_2 of $PETCO_2$ and $PaCO_2$ from the two measurements.

DISCUSSION

$PETCO_2$ is well correlated with $PaCO_2$ during spontaneous and conventional mechanical ventilation in the normal lungs. In a healthy, alert, and spontaneously breathing patient, the $PETCO_2$ is only 1 to 4 mmHg less than $PaCO_2$.[10] This difference is influenced by several patient-related factors, which include tidal volume.[11-15] During HFJV, injected and expired gases are mixed in the anatomical dead space and this contributes to the underestimation of the $PaCO_2$ by tracheal PCO_2 measurement because expired CO_2 is diluted by inspired gas.[11,16-19] In addition, the short expiratory time and the low tidal volume make it difficult to determine whether the CO_2 waveform actually showed exhaled alveolar gas or merely response limited by the characteristics of the infrared CO_2 analyzer. Therefore, to overcome the problem related to the low tidal volume, the measurement of $PETCO_2$ must be taken after stopping HFJV and following intermittent deep breaths or sighs produced by a conventional ventilator or alternatively, by decreasing the jet frequency.[8,20,21]

In two studies by Bourgain and collegues[7] and Novak-Jankovic and collegues,[22] gas samples for $PETCO_2$ were obtained after stopping HFJV from a sample line inserted into the trachea through the cricothyroid membrane and tracheotomy site. In their results, differences between $PaCO_2$ - $PETCO_2$ were not small enough (6.3 ± 5.4 mmHg in the study by Bourgain and colleagues and 11.55 - 12.6 mmHg in the study by Novak-Jankovic and colleagues). Moreover, ventilation might be insufficient to obtain gas samples during the cessation of HFJV. The important variables in the clinical practice of HFJV are the driving pressure, the injection frequency, and the I:E ratio. As the minute volume delivered depends only on the driving pressure and the I:E ratio, large tidal volume can be obtained decreasing jet rates at constant driving pressure and I:E ratio.[23] In a study by Klein and colleagues, small differences (3.3 - 4.4 mmHg) of $PaCO_2$ - $PETCO_2$ resulted from the distally-located sampling port of a rigid bronchoscope by intermittently reducing the jet rates to 10 - 12 beats per minute.[8] We increased tidal volume by temporarily decreasing the jet rates to 15 beats per minute, thus allowing adequate air sampling for $PETCO_2$. Our results, show $PaCO_2$-$PETCO_2$ difference of 1.27 - 2.95 mmHg, which is smaller by other studies.

Theoretically, sampling gas for $PETCO_2$ measurement should take place as close to the alveoli as possible to reduce mixing at the interface between the dead space and the alveolar gas in order to more accurately reflect $PaCO_2$.[24] The position of the jet injector has been varied by researchers and practitioners. The common site of the injector is at the proximal end of the endotracheal tube or the side port of the suspension laryngoscope. The efficiency of the jet injector depends upon the driving pressure used, the jet cannula to tracheal radius ratio, and the geometry of the injector.[25] A lower injector position would enable smaller tidal volumes to be used, by bypassing the part of the anatomical dead space. In addition, a gas sampling line placed as close as possible to the carina can, also, be used to obtain $PETCO_2$, diluting expired gases with anatomical dead space gases. Therefore, during HFJV, $PETCO_2$ measurement should be performed as close to the alveoli as possible, and during a large tidal volume, to reflect $PaCO_2$ as closely as possible. However, if the position of the jet injector is too close to the carina, injected gas may irritate the carina and cause trauma to the airway epithelium.[23] We placed the gas sampling line for $PETCO_2$ 2 cm below the distal part of the injector.. A large tidal volume was obtained by reducing the jet frequency intermittently to 15 beats per minute and by maintaining a consistent driving pressure, an enough sampling gas can be delivered to the monitor.

In terms of the monitoring of $PETCO_2$ during HFJV, although many studies has shown a high correlation coefficient between $PETCO_2$ and $PaCO_2$ values in terms of the product moment correlation, only some of these studies have shown good agreement between the two methods.[5,7,8,22] In the present study, we found a level of agreement that is sufficiently small to allow $PETCO_2$ to replace $PaCO_2$ during HFJV for LMS. In addition, relatively good measurement repeatabilities were obtained for $PETCO_2$ and $PaCO_2$ during 10 and 20 minutes of HFJV, respectively. Repeatability is relevant to the study of the comparative method because the repeatability of the two methods determines limit the agreement possible.[9]

In conclusion, these results suggest that the $PETCO_2$ obtained through a sampling line placed distally following decrease in jet rates during HFJV closely reflects $PaCO_2$. This simple, non-invasive, and cost-effective method may be applied safely to monitor $PETCO_2$ during HFJV.

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