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Continuous intra-arterial blood gas monitoring during thoracic surgery

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Abstract

Purpose. This study was undertaken to assess the clinical usefulness of a continuous intra-arterial blood gas (CIABG) monitoring system, Paratrend 7, during thoracic surgery.

Methods. A sensor of the CIABG monitoring system was inserted into the radial artery in 50 patients. During one-lung/differential lung ventilation, arterial blood samples for estimation of blood gases (ABG) were taken every 45–90 min or when clinically needed. The Pco_2, Po_2, and pH values displayed by the CIABG monitor were recorded prior to arterial blood sampling and were compared with the results of ABG analysis. The mean (bias) and the standard deviation (precision) of the differences were calculated from the data for each parameter.

Results. Ninety-four blood samples were obtained. The correlation between CIABG and ABG measurements was strong for each parameter: $r = 0.83$ (Pco_2), 0.89 (Po_2), 0.74 (pH). The bias ± precision between the two methods was 0.4 ± 3.0 mmHg for Pco_2, −6 ± 47 mmHg for Po_2, −1.2 ± 27.4% for Po_2 and −0.01 ± 0.04 for pH. For Po_2 values <150 mmHg, the bias ± precision was 1 ± 28 mmHg.

Conclusion. The agreement between CIABG and ABG measurements was better for Pco_2 and pH than for Po_2. The Po_2 value displayed on the CIABG monitor may not always be reliable during thoracic surgical procedures.

Key words Continuous intra-arterial blood gas monitoring · One-lung ventilation · Thoracostomy · Esophagectomy · Thoracoscopy

Introduction

Paratrend 7 (PT7) (Diametrics Medical, Highwycombe, UK), the only continuous intra-arterial blood gas (CIABG) monitoring system commercially available, is a multiparameter intravascular sensor system for on-line continuous measurement of pH, Pco_2, Po_2, and temperature. The clinical usefulness of the monitor has been reported recently in patients in intensive care units [1] and during cardiac surgery [2].

In a recent study [3], we found that the Po_2 data displayed on the PT7 may not always be reliable during esophagectomy. When arterial blood gas values are rapidly fluctuating, such as during one-lung ventilation (OLV)/differential lung ventilation (DLV), the accuracy of the Po_2 value of the CIABG system may be unacceptable [3] due to the slow response time of the sensor [1].

The objective of the present study was to evaluate the accuracy of the PT7 during OLV/DLV of patients undergoing various kinds of surgical procedures. Because, our information [3] is limited by the small number of patients and the single type of surgery (esophagectomy), in the present study we have included a larger number of patients undergoing esophagectomy, lung surgery, and thoracoscopy who required OLV/DLV.

Materials and methods

Patients scheduled to undergo thoracic surgical procedures ($n = 58$) that required OLV/DLV were eligible for the study. Eight patients were excluded because the sensors were severely damaged ($n = 4$), the sensors could not be inserted into the radial artery due to high resistance ($n = 2$), or the sensors were removed due to severely damped waveforms of the arterial blood pressure that were not usable for blood pressure monitoring ($n = 2$). For analysis of the data not only for overall patients but also for each of the three surgical procedures, the patients were divided according to surgical procedure into the esophagectomy group (E-group, $n =$

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Table 1. Demographic data on the patients (means ± SD)

Characteristic	Esophagectomy group	Lung surgery group	Thoracoscopy group
Age (yr)	59.1 ± 7.0	58.5 ± 9.2	39.9 ± 14.7
Male/female	13/1	12/8	12/4
Height (cm)	164.2 ± 4.9	160.1 ± 9.5	167.0 ± 7.4
Body weight (kg)	62.2 ± 10.6	56.9 ± 10.2	58.0 ± 10.4
ASA I/II/III/IV/V	5/9/0/0/0	7/13/0/0/0	12/3/1/0/0
Dependent lung (left/right)	14/0	11/9	15/1
Anesthesia			
Isoflurane	7	14	6
Fentanyl and propofol	7	6	10
Epidural (yes/no)	13/1	18/2	11/5
Treatment for hypoxemia			
100% oxygen	6	8	2
ND lung CPAP	6	3	0
ND lung ventilation	0	1	1

ND, nondependent; CPAP, continuous positive airway pressure

14), the lung surgery group (L-group, $n = 20$), and the thoracoscopy group (T-group, $n = 16$). Demographic data on the patients are shown in Table 1. The study was approved by the ethical committee of the University, and informed consent was obtained from all patients.

Hydroxyzine 25–50 mg and atropine 0.25–0.5 mg were given intramuscularly 30 min before the induction of anesthesia. Before the induction of general anesthesia, an epidural catheter was inserted in 42 patients between the fourth and the eighth thoracic interspaces, depending on the site of surgery. General anesthesia was induced with 2 mg·kg^{-1} of intravenous propofol, and endotracheal intubation was facilitated with 0.2 mg/kg^{-1} of intravenous vecuronium. A left-sided double-lumen endotracheal tube (Bronchocath, Mallinckrodt, Argyle, NY, USA) was used for OLV/DLV, and the correct position was confirmed by auscultation and by a fiberoptic bronchoscope. Anesthesia was maintained with 0.5%–1.5% isoflurane ($n = 27$) or intravenous propofol (4–10 mg·kg^{-1}·h^{-1}) combined with small doses (3–8 μg·kg^{-1}) of fentanyl ($n = 23$). Patients were ventilated mechanically at a constant tidal volume (V_T = 10 ml·kg^{-1}), and the respiratory rate was adjusted to keep the end-tidal carbon dioxide pressure (P_{ETCO_2}) at approximately 35 mmHg. The inspired fraction of oxygen (Fio_2) was set at 0.8. The rectal temperature was monitored and kept constant by a warm-water blanket. A bolus dose of 8–12 ml of 1% mepivacaine was injected epidurally, followed by continuous administration of 4–8 ml·h^{-1}.

A 20-gauge intravascular catheter was inserted into the radial artery. The multiparameter intravascular sensor, which had been calibrated with precision gases bubbled in sequence through the tonometer under microprocessor control, was advanced through the arterial catheter into the radial artery to a length of 15 cm. The arterial catheter was maintained with a continuous heparinized saline flush at a concentration of 0.4 units·ml^{-1} through the side port. This side port allows simultaneous blood pressure monitoring and provides access for blood sampling. After positioning of the patient according to the surgical requirements, the position of the double-lumen tube was reconfirmed. Before the surgical procedure was started, the monitoring system was calibrated to the conventional blood gas analysis according to the manufacturer's recommendation. The data collected by the monitoring system were corrected to the corresponding values at 37°C.

Just before the pleura was opened, OLV was commenced. The dependent lung was ventilated with a tidal volume of 8 ml·kg^{-1} and an Fio_2 of 0.8. The respiratory rate was increased to keep the arterial carbon dioxide tension ($Paco_2$) at approximately 40 mmHg. If the pulse oximetry (Spo_2) reading decreased below 95% and could not be maintained at 96% during OLV, major causes of hypoxemia (e.g., double-lumen tube malposition, poor hemodynamic status, or leaks or disconnection of the ventilating system) were ruled out, and if required, Fio_2 was increased to 1.0 and nondependent lung continuous positive airway pressure (CPAP), intermittent nondependent lung ventilation [4], or both were performed.

Arterial blood for conventional blood gas analyses (ABG) was sampled every 45–90 min or when clinically required during OLV/DLV. Just prior to arterial blood sampling, the values of Pco_2, Po_2, and pH displayed by the CIABG system [Pco_2 (PT7), Po_2 (PT7), and pH (PT7), respectively] were recorded. All arterial blood samples were analyzed without delay with a laboratory blood gas analyzer (STAT Profile 5 gas analyzer, NOVA Biomedical, Waltham, MA, USA). With the laboratory blood gas analyzer, both one- and two-point calibration

were performed using the standard gas mixtures (gas A: 20.0% O_2, 5.0% CO_2, and balance N_2; gas B: 10.0% CO_2, and balance N_2). A two-point calibration using both gas A and B was initiated automatically at intervals of several hours. A one-point calibration was performed using gas A at approximately 45-min intervals.

The data from the CIABG system were compared with the data from ABG [Pco_2 (ABG), Po_2 (ABG), and pH (ABG)]. A correlation analysis of the CIABG and ABG data was performed, and the correlation was described by Pearson's *r* value. The method of Bland and Altman [5] was used for the comparison. The "bias" of the PT7 sensor was calculated as the mean of the difference between the sensor and the radial arterial blood gas values, and the "precision" was calculated as the standard deviation of the differences. The means and the standard deviations of the fractional or percentage errors ("% bias" and "% precision," respectively) were calculated for the Po_2 data. In addition, the accuracy for the clinically important range of Po_2, i.e., less than 150 mmHg, was separately analyzed.

Results

Both anesthesia and surgery proceeded without any serious complications in all patients. Esophagectomy with right thoracotomy was performed in all the patients in the E-group. The patients in the L-group underwent lobectomy for lung cancer ($n = 16$) or pulmonary aspergillosis ($n = 1$) or partial resection for biopsy ($n = 2$) or open drainage for empyema ($n = 1$). The patients in the T-group underwent thoracic sympathectomy ($n = 5$), bullectomy ($n = 5$), esophagectomy under thoracoscopy ($n = 3$), lung tumorectomy ($n = 2$), or mediastinal tumorectomy ($n = 1$).

A total of 94 blood samples were obtained. The ranges of the measured variables were 28.7–60.2 mmHg for Pco_2, 60–445 mmHg for Po_2, and 7.28–7.50 for pH. The statistical comparison between the CIABG and ABG data is shown in Tables 2 and 3. The correlation between CIABG and ABG measurements was strong for each parameter, not only for overall patients (Table 2) but also in each group (Table 3). The bias and

Table 2. Statistical comparison of the continuous intra-arterial blood gas monitoring values with simultaneous arterial blood gas analysis in all patients

Value	Pco_2 (mmHg)	Po_2 (mmHg)	pH (pH unit)	% Po_2 (%)	$Po_2 < 150$ mmHg (mmHg)
Linear regression					
Slope	0.88	0.94	0.99		
Intercept	5.33	5.20	0.10		
Pearson's *r* value	0.83	0.89	0.74		
Bias	0.4	−6	−0.01	−1.2	1
Precision	3.0	47	0.04	27.4	28

Table 3. Statistical comparison of the continuous intra-arterial blood gas monitoring values with simultaneous arterial blood gas analysis in each group

Group/value	Pco_2 (mmHg)	Po_2 (mmHg)	pH (pH unit)	% Po_2 (%)	$Po_2 < 150$ mmHg (mmHg)
Esophagectomy group					
Slope	0.90	0.86	1.23		
Intercept	3.59	22.06	−1.69		
Pearson's *r* value	0.81	0.89	0.91		
Bias	−0.5	−1	−0.01	3.3	2
Precision	3.6	43	0.03	33.6	29
Lung surgery group					
Slope	0.91	0.99	0.86		
Intercept	5.00	7.02	1.05		
Pearson's *r* value	0.85	0.90	0.56		
Bias	1.2	−9	−0.01	−3.7	−3
Precision	2.9	53	0.05	24.7	28
Thoracoscopy group					
Slope	0.69	0.91	0.83		
Intercept	12.45	10.01	1.30		
Pearson's *r* value	0.89	0.89	0.82		
Bias	−0.1	−7	0.00	−2.0	7
Precision	2.0	42	0.02	24.7	27

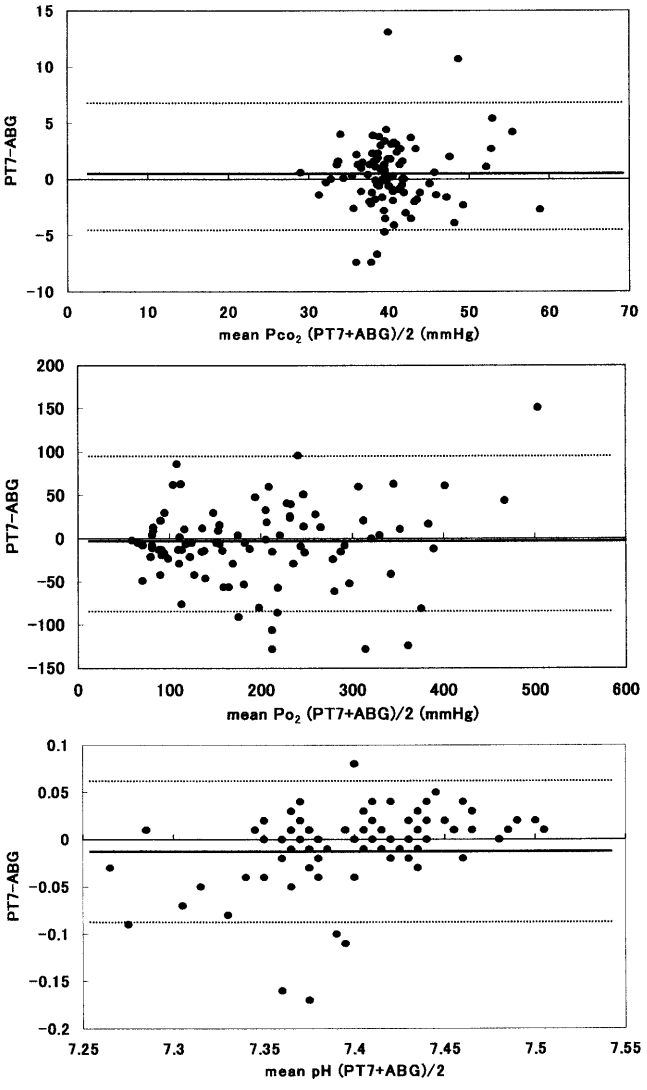

Fig. 1. Bland and Altman diagrams of Pco_2 (**upper**), Po_2 (**middle**), and pH (**lower**) for overall patients. The mean of PT7 and ABG is plotted on the X axis and the difference between the two methods on the Y axis. *Solid lines* represent bias and *thin dashed lines* represent bias ± 2 SD

precision between CIABG and ABG data for each parameter were similar among the three groups.

Bland-Altman diagrams [5] of the data for each parameter collected during OLV/DLV for overall patients are shown in Fig. 1.

Discussion

We have assessed the accuracy and the reliability of the CIABG monitor during OLV/DLV by evaluating the agreement of the data between CIABG and ABG. The CIABG data for each parameter were linearly correlated with the ABG data, not only for overall patients but also in each subgroup. The bias and the precision for each parameter were similar in each subgroup.

The overall bias and precision for Pco_2 and pH during OLV/DLV in the present study were similar to those in our previous study [3] as well as those reported in other situations, such as intensive care [1] and open heart surgery [2]. The biases of Pco_2 and pH in the present study were within acceptable limits [6]. As discussed in our previous study [3], adjusting the respiratory rate to keep the $Paco_2$ constant may have resulted in acceptable accuracy in the $Paco_2$ and pH measurements.

The precision (% precision) of Po_2 in the present study was larger than those in published reports [1,2]. Even in the clinically important range of Po_2 (<150 mmHg), the error will be theoretically <56 mmHg with 95% reliability, suggesting that the true Pao_2 may be between 24 and 136 mmHg when Po_2 (PT7) is 80 mmHg. Although the strong correlation between CIABG and ABG for each parameter indicates that the CIABG system is clinically useful for monitoring trends in blood gas changes, the present study demonstrates that the accuracy of the Po_2 (PT7) value may not always be reliable during OLV/DLV. The large precision observed in our study may be explained, in part, by the slow response time of the sensor [1] and the characteristics of OLV/DLV where arterial blood gas values rapidly fluctuate [3]. The present study may reconfirm our previous report [3] and suggest that Po_2 (PT7) measurements may be unacceptable during various kinds of surgical procedures that require OLV/DLV.

To the best of our knowledge, there has been only one other institution that has investigated the accuracy and clinical performance of PT7 during OLV [7,8]. Zollinger et al. evaluated the accuracy of the CIABG monitor during thoracoscopic surgery in patients undergoing OLV and reported the bias and the precision (1.96 SD) for Po_2 in their study to be 0.38 ± 9.52 torr [7]. The precision for Po_2 in their study was smaller than that for the thoracoscopy group in the present study, and the discrepancy may be attributed, in part, to the timing of the data collection: Zollinger et al. included data that were collected when OLV was not performed. The recent study by Zaugg et al. collected data during the whole period of OLV and reevaluated the accuracy of the PT7 during thoracoscopic surgery [8]. The precision for Po_2 (1.96 SD) in their study was 81.05 mmHg, similar to the value for the thoracoscopy group (1.96 SD = 82.3 mmHg) in the present study. The authors mentioned that the Po_2 sensors of the PT7 were accurate during OLV on the basis of strong linear correlation and Bland-Altman plots [5]. However, it is unclear what degree of precision for Po_2 was considered clinically acceptable in their study. In our clinical experience, we assumed that the error for Po_2 should be less than 10–

20 mmHg in the clinically important range of Po_2 (<150 mmHg) to detect and treat hypoxemia without delay.

It seems rational to conclude that the large precision of Po_2 is explained by the slow response time and the characteristics of OLV/DLV, but there are many other possible explanations (e.g., incorrect handling of the blood sample, the accuracy and variability of the laboratory blood gas analyzer [9], and the "wall effect" [10] of the sensor of the CIABG system). It may be very difficult to evaluate those effects on the difference between Po_2 (PT7) and Po_2 (ABG) in our clinical setting. The "wall effect" was not observed during the study period, but it is impossible to exclude transient and/or mild contact of the sensor tip with the vessel wall during monitoring. All these problems are encountered when we compare CIABG and ABG data. To demonstrate that these factors are not the predominant reasons for the large precision of Po_2, it may be necessary to compare the accuracy of the CIABG sensor between the OLV/DLV situation and two-lung ventilation, as we have done in the previous study [3].

In conclusion, the agreement of data between CIABG and ABG was acceptable for Pco_2 and pH during OLV/DLV in thoracic surgery. Although there is a strong relationship between the Pao_2 values measured during CIABG and ABG, the Po_2 value displayed on the CIABG monitor may not always be reliable during thoracic surgical procedures.

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