Intensive Care Med (1996) 22: 1414–1417

I. K. Weiss
S. Fink
S. Edmunds
R. Harrison
K. Donnelly

Continuous arterial gas monitoring: initial experience with the Paratrend 7 in children

Received: 19 June 1995
Accepted: 5 August 1996

This study was supported in part by Pfizer/Biomedical Sensors

I.K. Weiss (✉) · S. Edmunds · R. Harrison
K. Donnelly
Division of Pediatric Critical Care Medicine, UCLA Children's Hospital, UCLA School of Medicine, Los Angeles, CA 90095, USA
FAX: +1 (310) 794 6623

S. Fink
Pfizer/Biomedical Sensors, Malvern, PA 19355, USA

Abstract *Objective:* To describe clinical usage of the Paratrend 7 continuous arterial blood gas monitor in children.
Design: Children older than 24 months of age who required significant ventilatory intervention were eligible for sensor placement.
Interventions: The sensor was placed via the arterial catheter to measure pH, PCO_2, PO_2, and temperature. The simultaneous arterial blood gas value was recorded along with the sensor reading.
Results: The sensor functioned for as long as seven days and provided the clinicians with data on the patient's respiratory status. The statistical validity of the device when compared to the arterial blood gas showed that the bias/precision for pH was 0.006/0.024, for PCO_2 – 0.78/4.68 mmHg, and for PO_2 1.9%/17.1% (mmHg).
Conclusions: This report demonstrates actual clinical use of continuous blood gas monitoring in children. The information obtained is a major asset to the management of critically ill children in the intensive care unit.

Key words Intravascular sensors · Blood gas analysis · Acute respiratory distress syndrome · High frequency oscillator ventilation · Critical care · Children

Introduction

The standard for management of respiratory failure in the pediatric intensive care unit is to adjust mechanical ventilation based upon the results of intermittently measured arterial blood gases (ABGs). Usually more than 5 min [1] elapse before these results are available for clinical decision-making. In addition and of major concern to the pediatrician is the amount of blood required for multiple samples every day that the patient is in the intensive care unit [2].

A multiparameter sensor (Paratrend 7, Pfizer/Biomedical Sensors, Malvern, PA) which continuously measures arterial hydrogen ion concentration (pH), carbon dioxide partial pressure (PCO_2), oxygen partial pressure (PO_2) and temperature, and derives the bicarbonate, base excess and oxygen saturation without blood sampling has been developed. We report its accuracy and precision in monitoring five children in respiratory failure who required extensive ventilatory support.

Methods

The Paratrend 7 sensor [3, 4] comprises four separate sensors sheathed within a single sensing element, 0.5 mm or less in diameter. Intensity modulated fiber optic sensors are utilized for the measurement of pH and PCO_2. The measurement of PO_2 is by an electrochemical technique and temperature determination is via a thermocouple. The outer surface of the sensor has a covalently bonded heparin coating [5] to minimize thrombus formation in situ. The sensor is supplied as a single use sterile disposable device, and was inserted through a 20 gauge arterial catheter. At the time of drawing the ABG sample, the display of the Paratrend 7 was recorded. The sample was analyzed in the clinical laboratory using a Corning 178 blood gas analyzer. The results of the ABG and simultaneous sensor reading were stored for later analysis. This paper presents five patients with a mean age of 5.0 ± 3.3 years who underwent monitoring for a mean of 127 ± 60 h (39–168). This study was approved by the Human Subjects Protection Committee of University of California, Los Angeles.

Case reports

Case 1

A 26-month-old Hispanic female developed *Escherichia coli* sepsis following a living related liver transplant. The patient was switched to a high frequency oscillator ventilator (Sensormedics, Yorba Linda, CA) on the 3rd hospital day. The sensor showed that only 3 min were required to obtain a new steady state oxygenation level following conversion to the oscillator. Forty-eight paired blood gas measurements were obtained over 168 h.

Case 2

A six-year-old male with Burkitt's lymphoma developed respiratory distress secondary to *Candida parapsilosis* sepsis and ARDS, shortly after undergoing an allogenic bone marrow transplant. Because of worsening hypoxemia he was placed on a high frequency oscillator ventilator (Sensormedics, Yorba Linda, CA). He continued to have a very unstable course, with the sensor recognizing sudden severe episodes of both respiratory and metabolic acidosis and concomitant response to treatments. Twenty-seven paired measurements were obtained over 121 h.

Case 3

A 10-year-old known asthmatic developed severe exacerbation, despite treatment at an outside hospital. She was intubated and mechanically ventilated with an initial blood gas of pH 7.16, PCO_2 56 mmHg and PO_2 170 mmHg noted by the Paratrend 7 and confirmed by ABG. The sensor allowed immediate recognition of her critical pH status on admission, as well as allowing immediate response to her rapidly progressing reactive airway disease. Thirty-four paired observations were obtained over 94 h.

Case 4

A 2-year-old was transferred to our institution with refractory respiratory failure and a history of an unidentified immunodeficiency. The sensor immediately demonstrated a marked response to aggressive therapy. The patient was successfully extubated with the sensor documenting his ability to maintain adequate oxygenation and ventilation. Twenty-nine blood gas samples were obtained over 145 h.

Case 5

A 5-year-old male with complex congenital heart disease had a unifocalization procedure performed. The sensor documented his arterial PO_2 accurately, despite his still marked degree of cyanosis. Twelve paired samples were obtained over 39 h.

Statistical analyses

The bias and precision were used to determine the agreement between the device and the ABG as previously described [6]. Because of the large range of PO_2 values, the percentage difference was used in the analysis of these.

Results

One hundred fifty paired blood samples were obtained and analyzed. The bias for the pH readings was 0.006 and the precision was 0.024, for the PCO_2 values were −0.78 and 4.68 (mmHg) respectively, and for the PO_2 they were 1.9% and 17.1% (mmHg) respectively (Fig. 1). The range of pH values was 7.12–7.58, the PCO_2 value range was 27–105 mmHg, and for PO_2 values this was 39–214 mmHg as measured by the

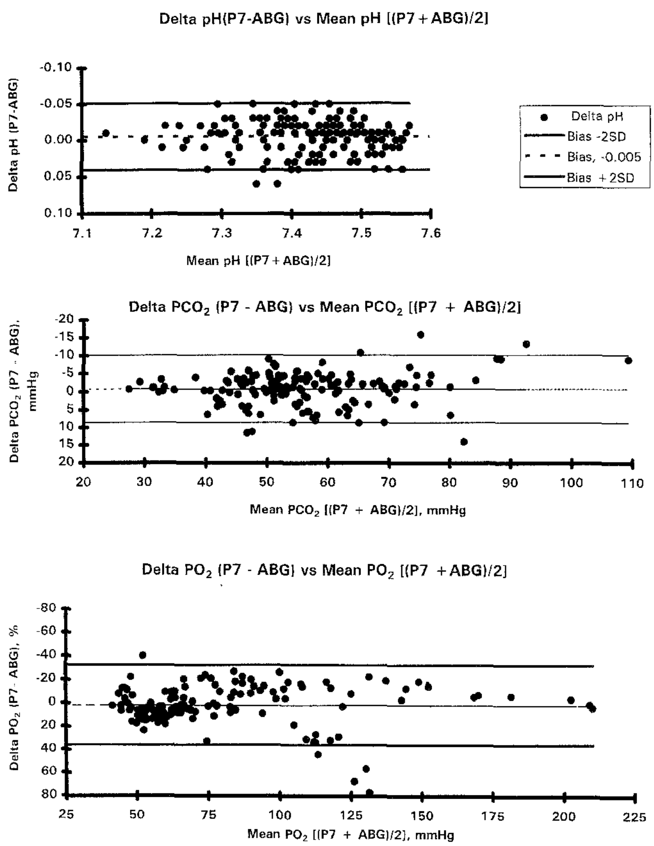

Fig. 1 Bland–Altman plots of the bias and precision for pH. PCO_2 and PO_2 for the five patients discussed in this report

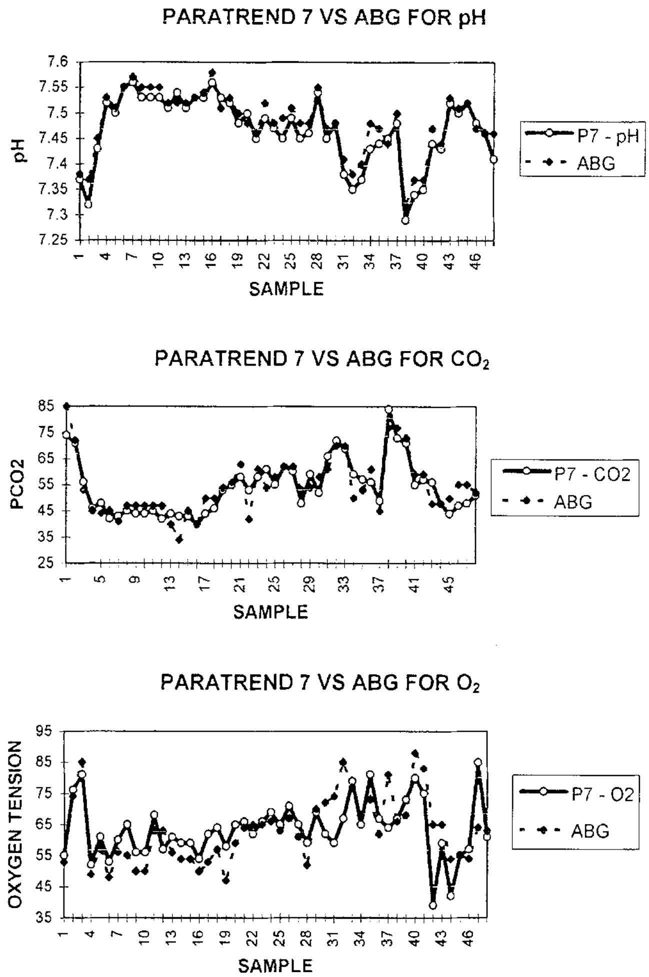

Fig. 2 Graphs of the values recorded from the Paratrend 7 plotted against the simultaneous arterial blood gas results returned from the clinical laboratory for pH, PCO_2, and PO_2 for Case 1. Note the very close agreement for almost all of the 48 specimens over the 7 days the device was in use

Paratrend 7. Figure 2 shows the use of the device for the entire 168 h monitoring period of Case 1. The results of all ventilatory changes made were detected immediately by the sensor, well before the availability of the ABG measurements from the laboratory.

Discussion

Continuous ABG monitoring is a new technology that has only recently become available to the intensivist. Although there are several studies which show very good bias and precision data of the particular device used in this study, as well as several other similar devices [3, 4, 7–11], none of these included pediatric patients. The results described here compare very favorably with the published adult and animal data for the Paratrend 7 (Table). The animal data provides the best agreement with blood gas analysis. This is probably the result of the tightly controlled nature of an animal study as compared to actual clinical practice. The most variability from the ABG in all of the human studies, including this one, is noted for the PO_2 values. The oxygen sensor is required to function over a large range of values, between 30 and 500 mmHg. For cyanotic patients accuracy at lower PO_2 values is vital, as small changes can have great significance. Yet, in this series, patient 5, who had severe cyanosis, demonstrated an acceptable bias/precision of only 5%. Trend analysis at higher PO_2 levels is usually more significant than the exact measurement. The Paratrend 7 can still document declining PO_2 measurements at high oxygen tensions which would be undetectable by other methods, such as pulse oximetry, until critically low values were reached. An explanation for the relative inaccuracy of the oxygen electrode is uncertain; more data is needed to determine if the bias/precision for the oxygen sensor increases over time, or other factors play a role. Nevertheless, in critical situations the oxygen electrode provided timely information, despite a relatively poor precision.

The immediate and continuous availability of all the blood gas values (as multiple interventions, such as high frequency ventilation were performed on these patients) was perhaps the major benefit of continuous blood gas monitoring. The sensors provided vital information well in advance of the results of specimens sent to the laboratory. For example, endotracheal suctioning of patients on the oscillator was shown to be associated with a marked drop in pH and rise in PCO_2

Table 1 Comparison of several published studies of the Paratrend 7

Ref.	Subject	Age	Number of data subjects	points	Time (t)	Site (artery)	pH		PCO_2 (mmHg)		PO_2 (%)	
							Bias	Prec.	Bias	Prec.	Bias	Prec.
3	Pig		8	292	8	Carotid	– 0.030	0.040	0.65	3.10	– 3.80	5.80
4	Human	64.8	13	158	43	Radial	0.010	0.060	1.65	5.00	4.70	27.30
10	Human	Adult	19	341	70	Radial	0.006	0.026	1.28	2.48	– 1.20	12.50
11	Human	57	10	71	10	Femoral	0.006	0.070	1.65	12.38	5.10	14.30
*	Human	5	5	145	128	Femoral	– 0.005	0.023	– 0.78	4.68	1.93	17.05

which persisted for several minutes. Because of this finding, the suctioning protocol for such patients was modified to decrease its frequency and duration.

The sensor did not interfere in any way with the ability of the catheter to monitor blood pressure. The data presented in the Table demonstrates that femoral placement of the device in children can safely provide extended periods of monitoring. The femoral artery of a 4-year-old is nominally 7.0 mm in diameter, while an adult radial artery is nominally 2.25 mm in diameter [12, 13]. Thus the sensor (<0.5 mm in diameter) occupies a relatively small percentage of the cross-section of even a child's femoral artery. The design of this study did not affect the number of blood gases required for clinical care. However, once the clinical information from this device is clinically accepted, without the need for validation via blood specimen, its use will lead to a significant lessening of the requirement of blood sampling and may cause a decreased need for blood transfusions in small critically ill patients.

The cost of the disposable sensor is currently $275, and the current price of the monitor is $20,000. Despite the cost of the monitor, we suggest that this device can lead to cost savings because of its ability to demonstrate changes in the patient's condition more rapidly, thus potentially allowing patients to be weaned more rapidly from the ventilator, resulting in shorter intensive care unit stays.

In conclusion, this report demonstrates the potential for a new technology that allows continuous monitoring of the ABGs. Information is provided to the clinician that is not obtainable using currently available monitors. The use of the device in these patients was safe and markedly aided their care. We anticipate that the widespread use of this technology on small pediatric patients who require intensive ventilatory support will be beneficial and cost-effective.

Acknowledgements The assistance of all the nurses taking care of these patients, who recorded the data, is greatly appreciated.

References

1. Fleisher M, Schwartz MK (1990) Strategies of organization and service for the critical care laboratory. Clin Chem 36: 1557–1561
2. Silver MJ, Li Y, Gragg LA, Jubran F, Stoller JK (1993) Reduction of blood loss from diagnostic sampling in critically ill patients using a blood-conserving arterial line system. Chest 104: 1711–1715
3. Clutton-Brock TH, Fink S, Markle D, Luthra AJ, Hendry SP (1994) The evaluation of a new intravascular blood gas monitoring system in the pig. J Clin Monit 10: 387–391
4. Venkatesh B, Clutton-Brock TH, Hendry SP (1994) Continuous measurement of blood gases using a combined electrochemical and spectrophotometric sensor. J Med Tech 18: 165–168
5. Larm O, Larrsson R, Olson P (1983) A new non-thrombogenic surface prepared by selective covalent binding of heparin via a modified reducing terminal residue. Biomater Med Dev Artif 11: 161–173
6. Bland JM, Altman DG (1986) Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1: 307–310
7. Haller M, Kilger E, Briegel J, Forst H, Peter K (1994) Continuous intra-arterial blood gas and pH monitoring in critically ill patients with severe respiratory failure: a prospective, criterion standard study. Crit Care Med 22: 580–587
8. Zimmerman JL, Dellinger RP (1993) Initial evaluation of a new intra-arterial blood gas system in humans. Crit Care Med 21: 495–500
9. Shapiro BA, Mahutte CK, Cane RD, Gilmour IJ (1993) Clinical performance of a blood gas monitor: a prospective, multicenter trial. Crit Care Med 21: 487–494.
10. Venkatesh B, Clutton-Brock TH, Hendry SP (1994) A multiparameter sensor for the continuous intraarterial blood gas monitoring: a prospective evaluation. Crit Care Med 22: 588–594
11. Abraham E, Gallagher TJ, Fink S 1996 Clinical evaluation of a multiparameter blood gas sensor. Intensive Care Med 22: 507–513
12. Steinberg C, Weinstock DJ, Gold JP, Notterman DA (1992) Measurements of central blood vessels in infants and children: normal values. Cathet Cardiovasc Diagn 27: 197–201
13. Siche JP, De Gandermaris K, Riacchi M, Maalon JM (1992) Relationship between low-frequency oscillations of blood pressure and changes in arterial diameter. J Hyperten 10 (Suppl 6): S45–S48