
ORIGINAL ARTICLE

On-Line Arterial PO₂ Measurements During Cardiopulmonary Bypass

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Keywords: Extracorporeal circulation, sensor, monitor

Abstract

A modified intra-arterial PO₂ sensor (O.D. 0.55 mm) and associated automatic temperature correction module (Roche) were evaluated as on-line monitoring devices during extracorporeal circulation (ECC) in six dogs as well as in four patients undergoing open-heart surgery.

Performance of the equipment was assessed by comparing the PO₂ values determined by the sensor with those measured by a blood gas analyzer (AVL). In addition, the reliability of the PO₂ sensor calibration factor and the accuracy of the automatic temperature correction module were determined.

The correlation coefficient between sensor and blood gas analyser was $r = 0.97$ ($n=14$) for laboratory and $r = 0.98$ ($n=14$) for clinical values with blood temperature ranging from 38°C to 22.5°C.

The calibration factor determined in vivo correlated with the value provided by the manufacturer ($r=0.97$, $n=4$).

The correlation factor between calculated and automatic temperature correction was $r=0.97$ ($n=21$). On line PO₂ monitoring is feasible with this equipment and early clinical experience was satisfying.

Introduction

In recent years, continuous intravascular PO₂ monitoring for patients with respiratory failure has become a widely accepted method (1-4). Attempts have been made to extend this technique for use during extracorporeal circulation (ECC).

Problems arose, however, with large and rapid changes in temperature inherent to ECC asking for automatic correction of the temperature induced changes in the PO₂ sensor membrane permeability (1).

The purpose of the present study was to evaluate a modified Roche (a) PO₂ sensor (O.D. 0.55 mm) and associated temperature correction module in the laboratory as well as to test its clinical applicability.

Material and Methods

Monitoring equipment

The PO₂ module 636, the temperature correcting module 242-

100 and the recorder model 3300 are fitted in a common frame (Figure 1) and are interconnected internally.

The PO₂ module incorporates:

- digital display with alarm setting/reset
- manual/automatic temperature selection
- calibration setting and memory switches

The temperature module features:

- digital display with alarm setting/reset
- calibration switch

The two channel pen recorder allows two-color recording of PO₂ and temperature with paper speeds ranging from 0.1 to 10 cm/min. The disposable sensor (Figure 2) uses the Clark principle to measure O₂ tension in blood (1). The new diameter of 0.55 mm allows fast response even under hypothermic conditions (approximately 20 seconds until a change is detected). The sensor is supplied sterile and is precalibrated.

Sensor insertion

- The sensor, the insertion adapter, the stopcock, and a suitable connector with luer port are unpacked under sterile conditions (Figure 3).

- The arterial line is cut between pump outlet and filter.

- The sensor is introduced into the adapter and the lock-nut secured (Figure 4).

- The connector is pushed into the pump-side tubing, the sensor introduced through the luer lock so that the free end will protrude 7-8 cm (Figure 5).

- The sensor is introduced into the filter-side tubing (in direction of flow), the tube connected and secured (Figure 6).

- Figure 7 shows the completed assembly.

- After connecting the sensor with the module, adjusting the calibration factor and fitting the temperature probe to the arterial side of the oxygenator, the system is ready to use.

Equipment evaluation

The equipment was evaluated in our laboratory during six ECC's on dogs by determining the correlation between the arterial PO₂ values measured with the sensor and those measured simultaneously with a blood gas analyser (AVL 940) (b), the accuracy of the calibration factor provided by the

a. Roche Bioelectronic, CH-4000 Basel (At press, this product was supplied by Roche. Today, it is distributed by Kontron.)

b. AVL Medizintechnik, CH-8200, Schaffhausen

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Figure 1

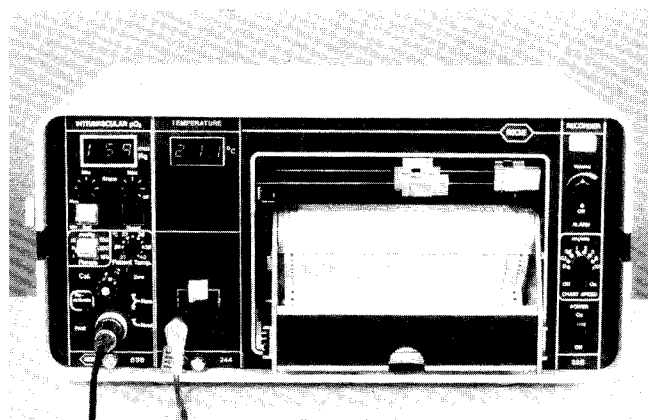


Figure 1: Monitor used for the study.

Figure 2

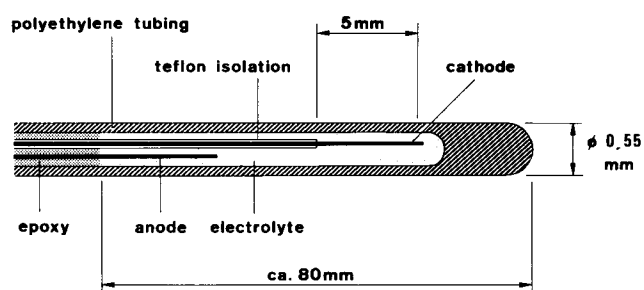


Figure 2 is the scheme of the sensor. (Adapted from Eberhard, P. et al. 1979 (1))

Figure 3

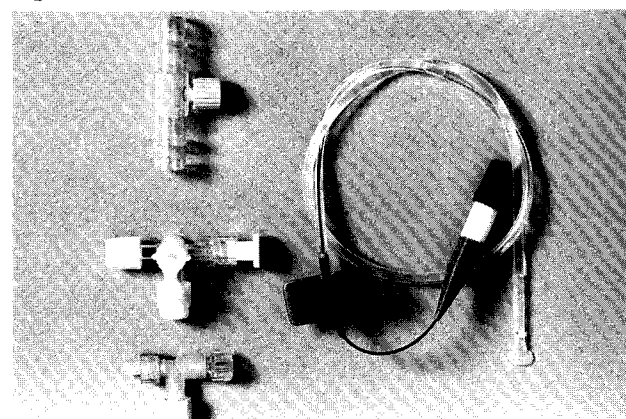


Figure 3 - Parts needed for pO₂ monitoring.

Figure 4

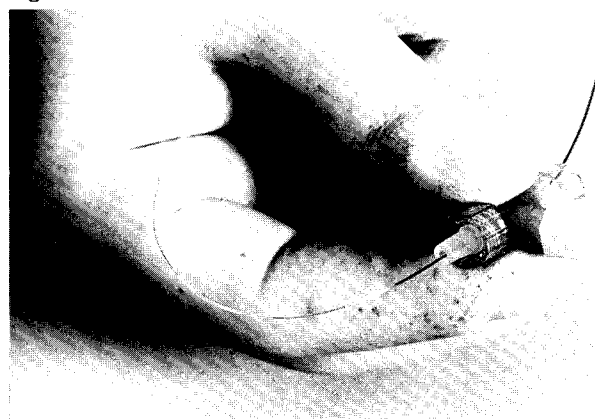


Figure 4: The sensor is introduced through the insertion adapter and secured with the lock-nut.

Figure 5

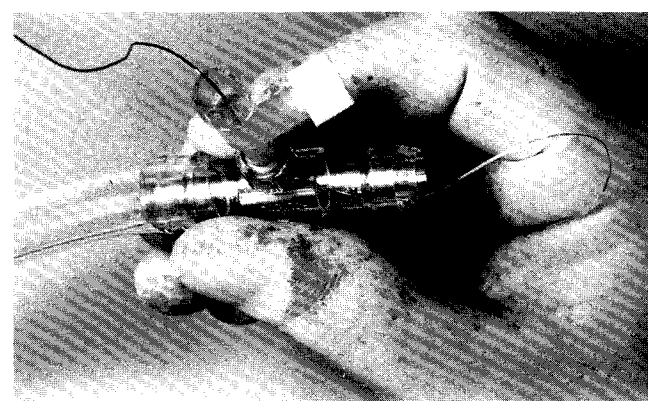


Figure 5: The sensor is introduced in the connector and the pump-side tubing is connected.

Figure 6

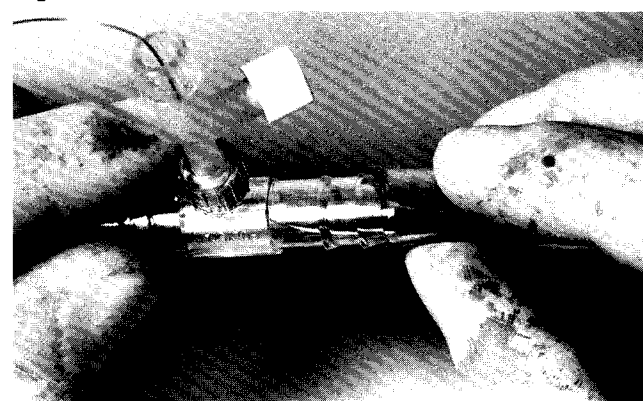


Figure 6: The sensor is pushed for at least 7-8 cm. into the filter side tubing and connection is made.

Figure 7

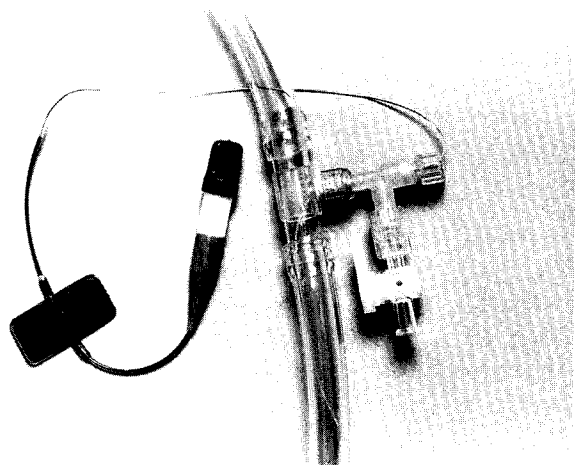


Figure 7: Assembly completed. The stop-cock is used for blood gas sampling.

Figure 9

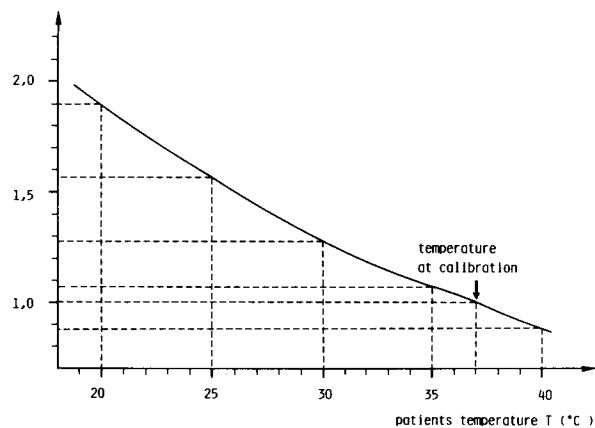


Figure 9: Temperature correction curve for manual (37°C) pO₂ correction. The value on display is multiplied with the corresponding factor. (e.g. readings taken at 20°C are multiplied by 1.9) Adapted from Eberhard, P. et al. 1979 (1)).

Figure 8

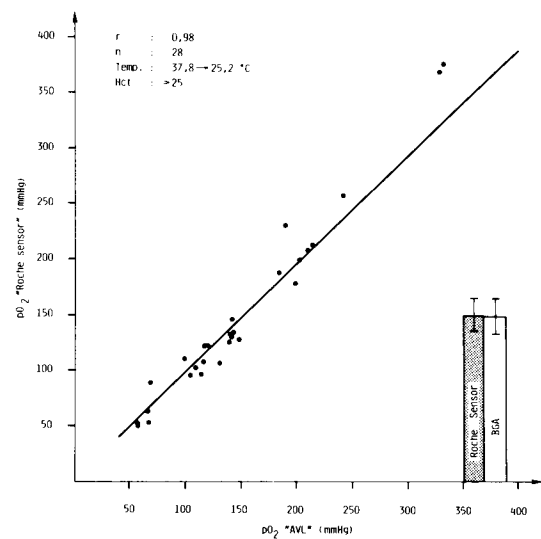


Figure 8: Correlation between sensor and blood gas analyser.

Figure 10

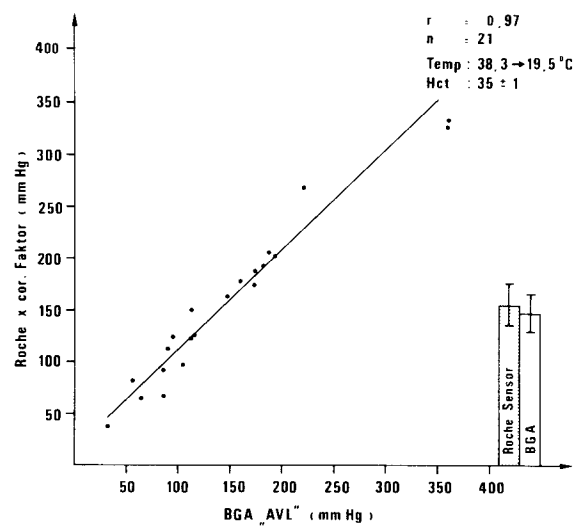


Figure 10: Correlation between calculated and automatic pO₂ readings.

Figure 11

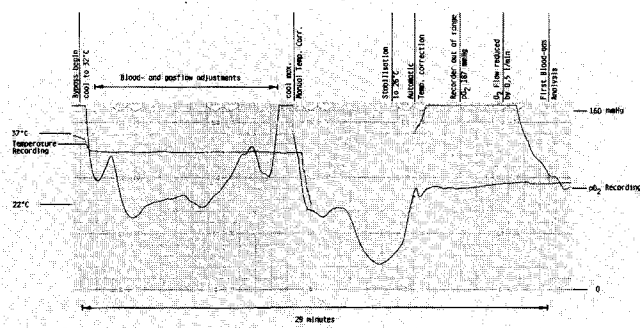


Figure 11: The first 31 minutes of bypass (see text).

Figure 12

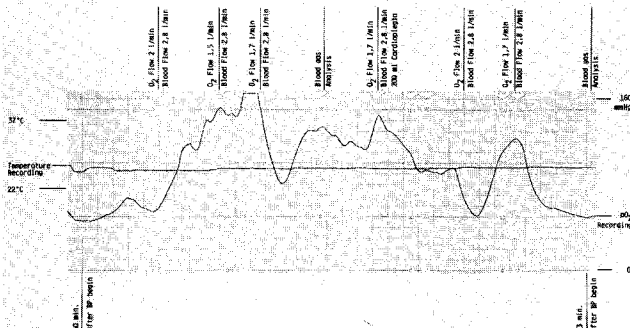


Figure 12: Stable bypass conditions (see text).

Figure 13

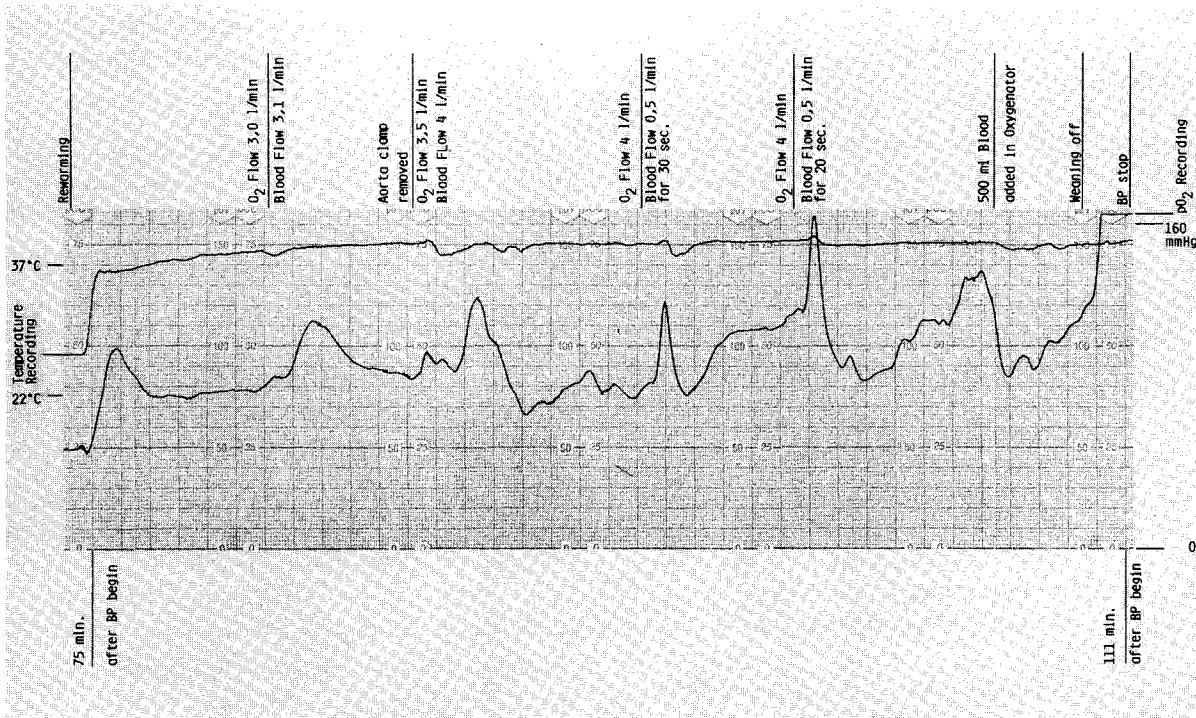


Figure 13: Rewarming phase and end of bypass (see text).

manufacturer, and the accuracy of the temperature correction module.

This device was also used during four open heart operations in patients undergoing multiple coronary artery bypass grafting. Mean bypass time was 92 ± 12 minutes.

In all cases, the sensor was introduced into the bypass system using the method described above. Calibration was carried out to manufacturer's specifications. During the clinical application, the perfusionist was asked to run the bypass as usual and not to try to adjust gas flow according to PO_2 readings. This was done for two reasons:

1. As a safety measure until confidence in the equipment could be gained in the clinical set-up.
2. To document the routine performance of extracorporeal bypass technique in our surgical department.

During the fast cooling phase, the PO_2 monitor had to be set on manual mode as the temperature module will presently work between 39°C and 22°C only.

Results

Sensor accuracy

The correlation coefficients between the PO_2 values measured by the sensor and those determined with the AVL blood gas analyzer were $r = 0.97$ ($n=14$) in the laboratory and $r = 0.98$ ($n=14$) during clinical application. Blood temperature ranged from 38°C to 22.5°C (Figure 8). Blood samples were taken at the insertion site of the sensor.

Calibration factor

The calibration factor determined in vitro correlated well with the calibration factor provided with the sensor by the manufacturer ($r=0.97$, $n=4$).

Temperature correlation module

The PO_2 values displayed in manual mode were corrected for temperature-induced changes in the permeability of the sensor membrane potential using the curve shown in Figure 9 and plotted against the readings taken in automatic mode. The correlation coefficient was $r = 0.97$ ($n=21$), with temperature ranging from 38.3 to 22.5°C (Figure 10).

Comments

The Roche PO_2 sensor previously used (5) to try to monitor PO_2 for heart-lung bypass did not reach clinical acceptance. The main problem then was the lack of automatic temperature compensation.

Subsequently, the equipment has been improved in such a way that ECC application seems possible; one limitation being that the temperature module works to date only within the range of 39°C to 22°C . This problem was overcome by switching the correction mode to manual (37°C) during the fast cooling phase and correcting the readings using the curve in Figure 9.

One might question the need to monitor PO_2 on line during ECC.

The original continuous PO_2 and temperature recordings during extracorporeal bypass for coronary surgery in a 66-year-

old male patient as shown in Figures 11-13 point at the usefulness of on line PO_2 monitoring during ECC as compared to punctual arterial PO_2 determinations. The perfusionist had no view of the PO_2 monitor.

Figure 11 shows the first 31 minutes of bypass.

During the fast cooling phase (temperature correction in manual mode), a rapid and large decrease of PO_2 is observed. The curve has to be corrected at this point and the lowest actual PO_2 was 43 mmHg. This PO_2 decrease during rapid cooling was observed in all clinical cases and may at least or in part be caused by the temperature-induced shift to the left of the hemoglobin dissociation curve.

Due to the lack of stable conditions during this period, punctual blood gas determinations are of limited value. Therefore, considerable time elapsed until the first blood gas analysis was taken (mean 23 minutes). The curve shown in Figure 12 is drawn during the stable phase of bypass. Sampling for blood gas analysis taken 56 minutes after bypass began read 135 mmHg. The sampling time was purely accidental and the PO_2 value confirmed correct bypass conditions. The large fluctuations in PO_2 during this period are difficult to explain. One reason could be fluctuations in venous saturation caused by manipulation of the heart (single cannula in RA).

The last period of bypass from rewarming until the end of bypass is shown in Figure 13. Changes in PO_2 between the 75th and 90th minutes are caused by blood and gas flow adjustments during rewarming. Reduction of ECC blood flow to fill the heart (0.5 l/min. during 30 and 20 sec. respectively) results in a sharp rise in PO_2 as soon as normal ECC flow is restored.

It can be concluded, based on these observations, that on line PO_2 monitoring during ECC may be helpful for the perfusionist to maintain PO_2 values within physiological ranges, thus optimizing quality of ECC. Further investigations are needed, however, to assess the cost-benefit relationship of the device. Blood gas analysis is still required to measure all the other parameters of importance.

References

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This paper was peer reviewed (in original form) for publication in the Journal of Extra-Corporeal Technology.