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Blood gas optodes are accurate but fragile

Yoshiko Kasuya[1], Tsuyoshi Nakahashi[1], Motoyasu Takenaka[1], Takeshi Sakamoto[1], Toshimasa Kato[1], and Kunio Suwa[2]

[1] Department of Anesthesia, Prefectural Gifu Hospital, 6-1 Noisshiki 4-chome, Gifu-shi, Gifu, 500 Japan
[2] Department of Anesthesia, Faculty of Medicine, University of Tokyo, 3-1 Hongo 7-chome, Bunkyo-ku, Tokyo, 113 Japan

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Arterial blood gas analysis is essential for patients receiving anesthesia or intensive care. The usual method of sampling the arterial blood by a syringe and then analyzing it offline has been well established for the last 30 years. In vivo blood gas measurements, or measuring the blood gases from the blood still flowing in the body, have been attempted using a variety of methods. A recently developed optoelectrical measuring system may be suitable for in vivo measurements, because it may be made thin enough to be inserted into a vessel, yet it can be used to measure more than one parameter. We recently had an opportunity to test this system under clinical conditions. We herein discuss the results of this test.

The electrodes (PB-FoxS sensor kit: disposable unit, Kansas City, Kansas USA), and measuring and calibrating system (PB3300, Puritan-Bennett, Overland Park City, Kansas USA) were used. The electrodes were calibrated using the attached calibrating system immediately before every clinical use.

Before surgery, the patients gave informed consent to participate in data collection protocols. Seven patients were chosen from the daily anesthesia schedule, all requiring placement of an arterial catheter. Out of these seven, four underwent cardiac surgery using cardiopulmonary bypass, two had subtotal gastrectomy, and one had radical cystectomy. The arterial catheters were inserted while the patients were awake in the four patients undergoing cardiac surgery, while they were placed after induction of anesthesia in the remaining three patients. After ensuring correct placement of the catheter, the electrode was inserted into the catheter. Then the in vivo measurements were started. From the same catheter, the arterial blood was sampled in a usual manner and was measured offline using a standard blood gas analyzer (Corning 280 system Corning Tokyo, Japan).

At least eight samples were obtained from the individual patients, spaced approximately equally over the surgery. The total number of blood samples for these patients was 41.

The linear regression equations and correlation coefficients were calculated for each variable.

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pH: $Y = 1.023X - 0.127$ ($r = 0.959$)
Pa_{CO_2}: $Y = 0.806X + 7.236$ ($r = 0.850$)
Pa_{O_2} $Y = 1.016X - 8.649$ ($r = 0.997$)

where X are those measurements by optodes and Y are those by offline analysis. They were all highly significant at 0.1% levels.

In two of seven cases, the measurements were extended over 72 h. The system ceased to function at 30 h in one case, and at 19 h in another. The electrode was removed at 5 h in one patient because he no longer required monitoring. In one case, the system ceased to function soon after the electrode was inserted, while in another the electrode began to malfunction even before it was placed into the artery.

In one case, blood sampling became difficult during the time course and we were forced to insert another arterial catheter. Including this case, the arterial pressure waves obtained were all apparently normal. There were no complications observed in this series.

With various technological advance, including the use of computers, greater emphasis is being placed on moni-

Address correspondence to: Y. Kasuya
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toring systems which are noninvasive, continuous and/or permit real-time measurement [1].

In the field of blood gas monitoring, several types of intravascular platinum electrodes and their measuring systems were developed, some of which were eventually tested clinically and distributed commercially. The stability and the credibility of the system were less than satisfactory, however, and they never gained wide application.

In 1987, Barker et al. [2] reported their results of using an "optode", which measures fluorescence quenching by various substances, including oxygen, thereby measuring its amount. They measured Pao_2 in four dogs, and compared them with 290 determinations of Pao_2 measured offline in a standard blood gas analyzer. They reported an correlation coefficients of 0.96 and concluded that this system is an excellent monitoring method. In 1989, Shapiro et al. [3] reported correlation coefficients of 0.97 for pH, 0.96 for $Paco_2$, and 0.99 for Pao_2.

While precise comparison is not possible, it is our impression that the Pao_2 values measured with the current system are considerably better than those with the previous platinum electrode systems. The current system is also superior because it measures not only Pao_2, but pH and $Paco_2$ as well. It also incorporates a system to check the temperature accurately. With these values combined and with the aid of a computer system, this system provides not only the raw value, but also other derived parameters such as So_2, HCO_3^-, base excess, and total CO_2. It does not measure the hemoglobin level, however. Entry of the hemoglobin value obtained separately is required for accurate calculation of these derived variables.

The system claims the endurance of 72 h for its electrode. Yet, we failed to obtain any value in two out of seven cases. The electrode is of miniature structure and must be handled with the utmost care. In one case, in which the system ceased to function as soon as the electrode was inserted, the operator met a slight resistance while inserting the electrode, even though the backflow of the arterial blood was excellent. In retrospect, we speculate that the space between the tip of the catheter and the vascular wall may not have been wide enough to allow the electrode to pass easily, and the subtle friction of the electrode tip against the wall might have damaged the electrode. Smith et al. [4] reported a similar experience of electrode failure even before beginning any measurement. Its pH measuring principle is slightly different from those for other parameters. The fluorescent dye is covered by semipermeable membrane, which allows the hydrogen ions to move. The function of the electrode is easily altered by drying this membrane and cannot be recovered by wetting in water. The instruction manual of the instrument states that the electrode should not be left in the air for more than 2 min. This goal is more difficult to achieve in practice.

The electrodes are disposable and cost as much as ¥90,000 (US$ 850). While we all hope that this device becomes more rugged and less expensive by mass production, although such a reduction in price is highly unlikely because of the technical difficulty involved.

Blood gas monitoring can be and is actually being achieved with the use of the standard blood gas analyzer, though, admittedly, they are not online and they are not real-time. Furthermore, the pulse oximetry and capnography yield similar information far more efficiently and inexpensively, complementing the blood gas analysis. The use of the current system, therefore, may be limited to a relatively small group of patients, presumably those on cardiopulmonary bypass; those with severe burns over a wide surface causing rapid, fulminating metabolic changes; those undergoing extensive surgical procedures involving the loss and of a large amount of blood and transfusions; and those in severe respiratory failure. Some investigators report its use for one-lung ventilation [5], while others report its usefulness in cases with large pulmonary shunt in whom a Swan-Ganz catheter was considered too much [6]. Its use has also been reported for monitoring when air embolism was anticipated [7].

We confess that we were attracted by the beauty of obtaining parameters continuously and that we were impressed with the technical advances behind such an innovative device.

A Swan-Ganz catheter cost as much as ¥50,000 when it was first introduced in Japan. Considering the cost of living and the average income at that period, it might have been closer to ¥200,000 at current levels. Yet, it prevailed and achieved wide application. There were good reasons for this. The information recovered through this catheter was all new and could not be obtained by other methods in the operating room or at bedside: the pulmonary arterial pressure, wedge pressure, the mixed venous blood gases, and the cardiac output. For the online blood gas optode, the situation is entirely different. As stated earlier, we could obtain similar information simply by sampling blood and using an offline instrument, combined with pulse oximetry and capnography.

We conclude, therefore, that this device should be used only to limited cases which truly require such monitoring. Its physical fragility and enormous expense must be greatly improved before it is widely applied.

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