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Continuous Intra-arterial Blood Gas Monitoring in Patients Undergoing Suprarenal Aortic Surgery

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ABSTRACT

The authors used an on-line, real-time, continuous blood gas monitor in 5 patients undergoing elective suprarenal aortic reconstruction. They retrospectively analyzed data to evaluate its utility in acid-base management and in detection of dynamic changes in oxygenation. Seven sets of data were analyzed since 1 patient underwent two additional periods of aortic crossclamping. A similar group of 7 patients undergoing elective suprarenal aortic surgery without continuous blood gas monitoring was analyzed and served as a control group. There was a highly significant mean decrease in partial pressure of oxygen (PO_2) of 158 mm Hg ($P = 0.0060$) with unclamping. In 1 patient the PO_2 dropped from 218 to 63 mm Hg within sixty seconds of unclamping, and this required immediate reinstitution of two-lung ventilation. Continuous availability of pH permitted accurate therapy with bicarbonate infusion during clamping. As a result there was no significant change in pH between preclamp and immediately after unclamping ($P = 0.97$). In the control group the pH decreased from a mean of 7.38 to a mean of 7.24 ($P = 0.0005$) between preclamp and after unclamping.

In summary, dynamic changes in oxygenation and pH are observed during suprarenal aortic surgery. Continuous blood gas monitoring provided data resulting in improved management of acid-base status and early detection of significant decreases in oxygenation.

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Introduction

Vascular reconstructive procedures that involve the suprarenal aorta pose challenging problems for anesthesiologists and cardiovascular surgeons. Marked hemodynamic and metabolic derangements, such as changes in arterial oxygenation and acid-base status, are frequently noted during the periods of aortic crossclamping and unclamping, especially with the use of one-lung ventilation. The traditional use of intermittent arterial blood gas determinations may be inadequate to detect clinically significant changes in blood gas variables. In addition, pulse oximetry is frequently nonfunctional during these procedures for several reasons, including hypothermia and local vasoconstriction. Failure to identify and correct significant alterations in oxygenation and acid-base balance could potentially produce serious deleterious effects on myocardial function.[1,2] This is particularly important in the patient population developing atherosclerotic aneurysms, in that they frequently have significant comorbid conditions such as previous myocardial infarctions or chronic obstructive pulmonary disease.

We have recently used a commercially available, on-line, real-time continuous blood gas monitor (Puritan Bennett PB 3300) in 5 patients undergoing elective suprarenal aortic surgery to assess its utility in identifying acid-base abnormalities associated with aortic clamping and unclamping. The PB 3300 Intra-arterial Blood Gas Monitoring System directly measures and displays in vivo values for pH, partial pressure of oxygen (PO_2), partial pressure of carbon dioxide (PCO_2), and temperature. The PB 3300 consists of a sensor and monitor. The sterile, disposable sensor is inserted into the artery through a 20-gauge intravascular catheter (In-Syte, Becton-Dickson) and connected to a microprocessor-controlled monitor that displays and continuously updates patient data (every twenty seconds). Fluorescent dyes in the three optical fibers of the blood-compatible sensor tip react to the concentration of pH, PO_2, and PCO_2 in the blood by absorbing high-energy light and then emitting the light at a different wavelength. The intensity and wavelength of the reemitted light is based on the amount of hydrogen, oxygen, and carbon dioxide molecules near the dyes. A thermocouple measures blood temperature, and monitor software is able to compensate for temperature effects on blood and the fluorescent dyes.

This information is measured, converted, and displayed as patient data by the monitor. The presence of the sensor within the arterial catheter does not interfere with the measurement of blood pressure or with the withdrawal of blood samples or introduction of flush solution.

Methods

Data from 5 patients undergoing suprarenal aortic reconstruction in May and June 1993 were retrospectively analyzed. Surgery was performed for repair of thoracic, thoracoabdominal, and suprarenal abdominal aortic aneurysms.

A 20-gauge 1¾-inch right radial arterial line was placed and a Puritan Bennett PB 3300 continuous blood gas sensor was calibrated and placed through the arterial line before the induction of anesthesia. Blood gas data were recorded every twenty seconds. Anesthesia was induced and maintained with fentanyl, midazolam, pancuronium, and isoflurane. All patients were ventilated with 100% oxygen. Three patients requiring proximal thoracic aortic crossclamping had a left-sided double-lumen endotracheal tube placed. When required, one-lung ventilation was generally initiated after the pleural space was entered.

Blood gas data were obtained in standard fashion (ie, intermittent sampling) and with the PB 3300 monitor. Data were analyzed just prior to aortic crossclamping, one minute after crossclamping, immediately before unclamping, and one and five minutes after unclamping. A pulse oximeter placed on the right index finger was used in all patients. A continuous bicarbonate drip was given during the crossclamp period, except in the patient in whom a shunt was used, and was titrated according to the continuous pH readout.

The records of 7 randomly selected patients who underwent elective suprarenal aortic surgery without continuous blood gas monitoring within the past year were analyzed and served as a control group. Four of these patients had thoracoabdominal aneurysms, 1 a type B thoracic aortic dissection, 1 had a thoracic aneurysm, and another had a suprarenal aneurysm. One patient underwent left atrial-femoral bypass, and 4 of the 7 patients had one-lung ventilation. Arterial blood gas data were retrieved from anesthesia records prior to aortic clamping and after unclamping. A continuous bicarbonate drip was used in these patients, but the infusion rate was altered only after the results of intermittent blood gas analysis became available. An arterial blood gas sample was routinely sent every ten minutes during the crossclamp period, with an average turnaround time of five minutes.

Results

Seven sets of data were analyzed in the 5 patients who had continuous intra-arterial blood gas monitoring because 1 patient required two additional periods of aortic crossclamping owing to technical difficulties. The location of the aortic crossclamp, the use of one-lung anesthesia, and the use of shunts to provide distal perfusion differed among the 5 patients (Table I). The mean values and ranges for PO_2, PCO_2, and pH recorded at various times during the procedure among all 5 patients are presented in Figures 1–3.

In 4 of the 5 patients, simple aortic crossclamping was used. Bicarbonate infusions were titrated to continuous pH data to maintain a slightly alkalotic pH and normal PCO_2. With these infusions, there was no significant change in mean pH from the precrossclamp to postcrossclamp periods ($P = 0.97$). In the patient in whom left atrial-descending thoracic aortic bypass with the BioMedicus centrifugal pump was used, no change in pH was noted when the crossclamp was removed, even though a bicarbonate infusion was not given. In contrast, a significant change in pH was noted in the 7 control patients in whom intermittent blood gas data were analyzed only before aortic clamping and after unclamping. In these patients a continuous bicarbonate infusion was also given and adjusted based on intermittent arterial blood gas data, in an attempt to attain an alkaline pH and normal PCO_2. The mean pH before crossclamping in these patients was 7.38 and the mean postclamp pH was 7.24 ($P = 0.0005$). The mean pH and ranges for the control group prior to aortic clamping and after unclamping are shown in Figure 4. Three sets of data were analyzed during one-lung anesthesia (patients 2, 3c, and 4).

The changes in PO_2 for each patient with aortic clamping and unclamping are shown in Fig-

Table I

Data in 5 Patients Who Had Continues Intraarterial Blood Gas Monitoring

Patient	Level of Aortic X-clamp	Shunt Used	One Lung Anesthesia
1	Midthoracic	No	No
2	Left subclavian	Yes	Yes
3a*	Midthoracic	No	No
b	Midthoracic	No	No
c	Proximal thoracic	No	Yes
4	Proximal thoracic	No	Yes
5	Suprarenal-infraceliac	No	No

*Patient 3 had two additional periods of crossclamping (b, c).

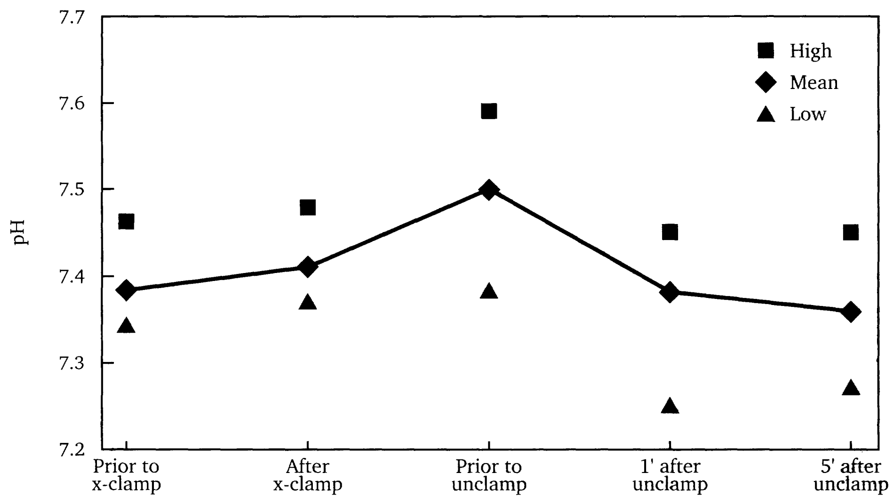

Figure 1. Mean pH during the procedure in 5 patients.

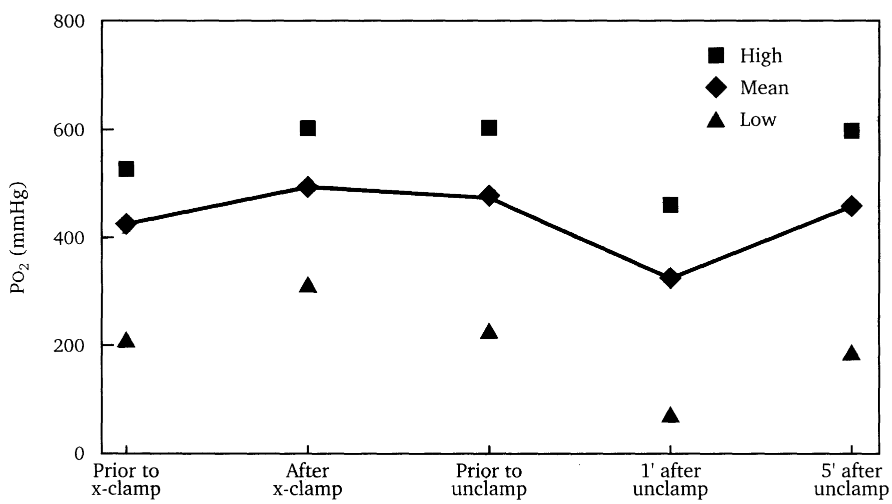

Figure 2. Mean PO_2 during the procedure in 5 patients.

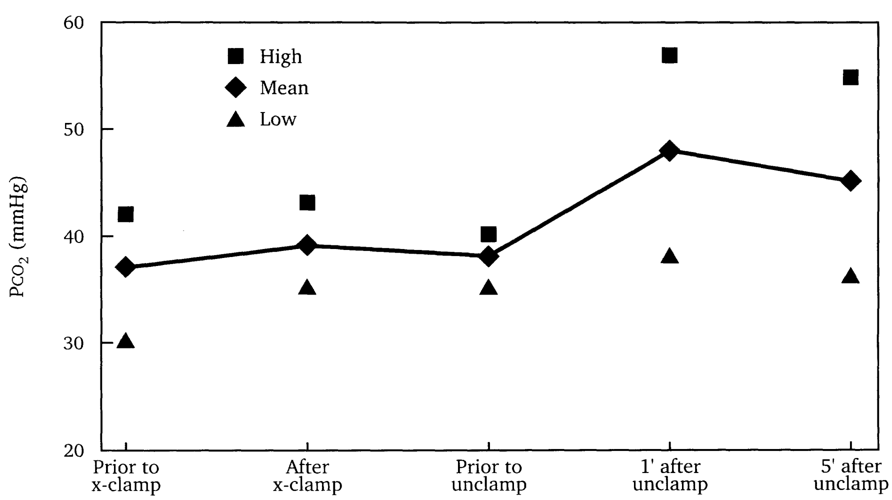

Figure 3. Mean PCO_2 during the procedure in 5 patients.

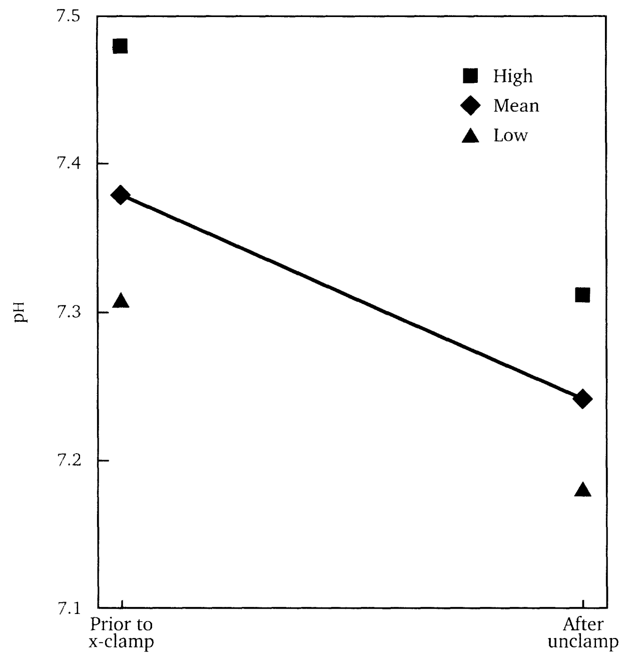

Figure 4.
Mean pH and ranges for control group before clamping and after unclamping.

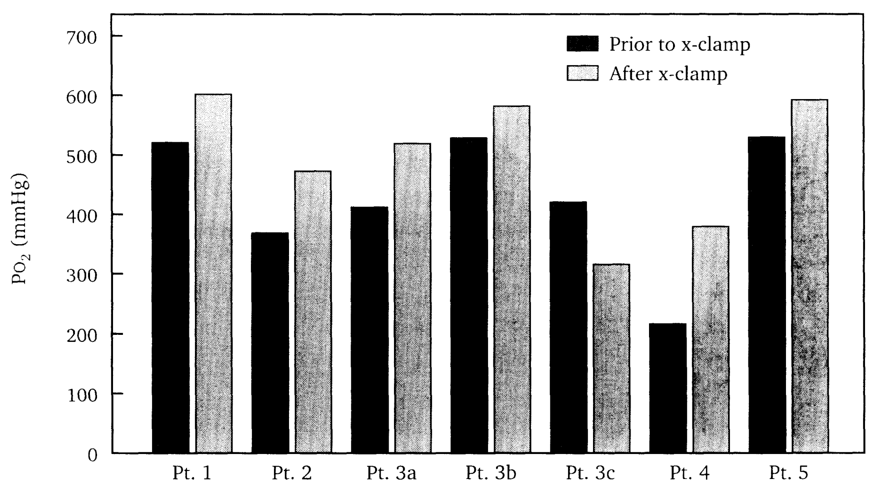

Figure 5.
Changes in PO_2 for each patient with aortic clamping.

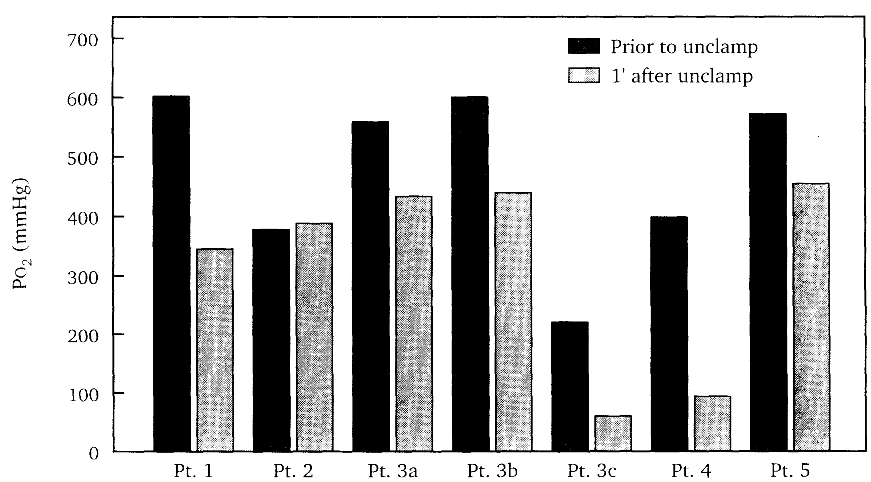

Figure 6.
Changes in PO_2 for each patient with aortic unclamping.

ures 5 and 6, respectively. An increase in mean partial pressure of arterial oxygen (PaO_2) (67 torr, $P = 0.077$) was seen after clamping of the aorta but did not attain statistical significance (Figure 5). (The decrease in PO_2 noted in patient #3 occurred during a third period of crossclamping and was the result of instituting one-lung ventilation just before reclamping of the aorta.) In contrast, with aortic unclamping, there was a highly significant decrease in mean PO_2 from 473 to 315 torr ($P = 0.0060$) (Figure 6). Patient #3c experienced a dramatic decrease in PO_2 from 218 to 63 torr during one-lung ventilation in the first minute after removal of the aortic crossclamp. He required the immediate reinstitution of two-lung ventilation to ensure adequate arterial oxygenation. In this patient, the pulse oximeter was not functional immediately after unclamping. Several minutes later, when the PO_2 was 400 torr, it displayed an accurate heart rate but only an 85% oxygen saturation. The PO_2 of patient #4 fell from 395 to 94 mm torr but rose to 172 torr within 5 minutes although one-lung ventilation was maintained. The PO_2 rose in only 1 patient (case #2), in whom the BioMedicus shunt was used.

No data were available immediately after aortic crossclamping in the control group since the first routine sample is usually not obtained until hemodynamic stability is achieved after aortic crossclamping (a process usually requiring several minutes). The first arterial blood gas sample after unclamping was obtained after hemodynamic stability was achieved, an average of ten minutes after unclamping. The mean PCO_2 was 49 and the mean PO_2 was 246 at this time. No complications secondary to radial artery cannulation or the PB 3300 sensor were noted.

Discussion

Suprarenal aortic crossclamping and subsequent unclamping during extensive vascular reconstructive surgery have been associated with significant hemodynamic and metabolic alterations. During the crossclamp period, proximal hypertension is accompanied by distal hypotension and potential hypoperfusion of the kidneys, spinal cord, and lower extremities. This produces a marked metabolic acidosis that may be exacerbated after unclamping. With the use of transesophageal echocardiography, we have documented significant alterations in myocardial function and pulmonary artery (PA) hemodynamics that, without adequate monitoring, could lead to inappropriate and potentially dangerous interventions.[3] For example, significant elevations in PA pressures after unclamping suggest that the left ventricle is failing and fluid overloaded; however, echocardiography has demonstrated that the heart is hypovolemic and requires volume. Although the cause of significant pulmonary hypertension is unclear and may be caused by the release of mediators or oxygen free radicals, it is possible that unrecognized hypoxia or acidosis could exacerbate these abnormalities.

It has traditionally been difficult to obtain arterial blood gas data quickly enough to track the dynamic metabolic changes that occur during extensive aortic surgery. Using the principles of optical fluorescence, we now have a simple and easy-to-use monitor that provides essentially continuous, on-line measurement of blood gas variables through a standard 20-gauge arterial line. Excellent correlation has previously been documented between in vitro blood gas measurement and the PB 3300 continuous blood gas monitor.[4-7] In this study, we retrospectively analyzed data from 5 patients to evaluate the utility of this device in detecting changes that occur during suprarenal aortic surgery and its role in guiding management of acid-base status and oxygenation.

Although recommended doses for bicarbonate infusions have been published most anesthesiologists titrate the rate of infusion to blood gas data obtained intermittently during the crossclamp period.[8] We have found it difficult to obtain the results of blood gas data quickly enough to change infusion rates and assess the adequacy of our interventions. With the use of a titratable bicarbonate infusion and continuous blood gas monitoring, we were able to maintain a stable, mildly alkalotic pH and normal PCO_2 in all patients during simple aortic crossclamping with either one- or two-lung anesthesia. This allows for optimal buffering capacity before removal of the crossclamp. This strategy appears to be effective in that we found no significant change in pH between the preclamp and postclamp periods. As expected, metabolic acidosis did not develop when a shunt was used to provide distal perfusion, thus obviating the need for a bicarbonate infusion.[9]

Changes in arterial PO_2 were seen both with aortic clamping and unclamping. The PO_2 rose in all but 1 patient after clamping, although the increases did not attain statistical significance. This may be related to a change in pulmonary blood flow induced by clamping or possibly by the increased oxygen content of mixed venous blood. We did not measure mixed venous blood gases after clamping; use of an oximetric pulmonary artery catheter capable of measuring mixed venous oxygen saturations continuously might have been helpful in analyzing these data.

The arterial PO_2 decreased significantly after unclamping in all patients undergoing simple aortic crossclamping without a shunt. Two patients had a decrease in PO_2 to clinically significant levels. No intervention was used in patient #4, in whom the PO_2 decreased from 395 to 94 torr but increased to 172 torr within five minutes. However, reinstitution of two-lung ventilation was required in patient #3c when the PO_2 fell from 218 to 63 torr immediately after unclamping. In both of these patients, the pulse oximeter was not functioning, and these marked changes in oxygenation would likely have gone undetected since a blood gas sample is usually not obtained until five to ten minutes after unclamping.

In patient #3c, even when the pulse oximeter resumed functioning, there was a significant discrepancy between the measured PO_2 (415 torr) and the oximetric readout of 85% oxygen saturation. This discrepancy between pulse oximetry and true oxygen saturation during acute changes in arterial oxygenation has been reported previously.[10]

The mechanism for the acute decrease in arterial PO_2 with unclamping is not clear but might also be responsible for the acute pulmonary hypertension that we have previously observed. Humoral mediators, such as bradykinin and oxygen free radicals released from ischemic and reperfused tissues after unclamping, and possibly increased oxygen consumption in previously ischemic tissues may be contributory.[11] Casthely and associates reported that the administration of superoxide dismutase, an oxygen free radical scavenger, before aortic crossclamping in dogs prevented the decrease in PO_2 noted after unclamping.[12] Similarly, experimental studies have shown a decrease in spinal cord injury during thoracic aortic surgery with use of oxygen free radical scavengers.[13] These results suggest that hypoxemia accompanying reperfusion injury may be a contributory factor to spinal cord ischemia and renal insufficiency and that maintaining satisfactory arterial PO_2 during reperfusion would be desirable.

Conclusions

The use of continuous intra-arterial blood gas monitoring is safe and accurate in patients undergoing suprarenal aortic surgery. Arterial pH and PCO_2 during aortic crossclamping and unclamping are managed more precisely and in a more timely manner than when standard intermittent arterial blood gas data are relied upon. A clinically significant decrease in PO_2 after unclamping that may warrant intervention was noted. This rapid decrease in oxygenation was undetected by standard monitors. Because of the potential benefits of early intervention in optimizing acid-base status, such as optimizing myocardial function and possibly minimizing reperfusion injury, we recommend its routine use in patients undergoing suprarenal aortic reconstruction.

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