Original Article

The Effects of Continuous Blood Gas Monitoring During Cardiopulmonary Bypass: A Prospective, Randomized Study—Part II

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ABSTRACT

The impact of blood gas management during cardiopulmonary bypass (CPB) on patient care has not been examined and remains controversial. The purpose of this study was to determine whether precise blood gas management during CPB influences patient outcome.

Fifty-nine patients were enrolled in an Institutional Review Board-approved, prospective, randomized study. An in-line blood gas monitor (CDI 500) was placed into the arterial and venous lines for all patients. Blood gas monitoring in the control group was managed by intermittent sampling (every 20–30 min), while the treatment group was managed with continuous monitoring. Blood gas control and measured parameters were as follows: pH 7.40 ± 0.05, $PaCO_2$ 40 ± 5 mmHg, PaO_2 200 ± 50 mmHg. The treatment group had the CDI 500 guide clinical decisions.

Compared to the control group, the treatment group consisted of significantly more diabetic (7% vs. 47%, $p \leq 0.001$), renal failure (3% vs. 13%, $p \leq 0.01$), and chronic obstructive pulmonary disease patients (7% vs. 20%, $p \leq 0.01$). Internal thoracic artery utilization was higher in treatment patients than control patients (67% vs. 95%, $p \leq 0.02$). No other differences existed in demographic, pharmacological, surgical, or anesthetic parameters.

In the perioperative period, the control group required antiarrythmic support more frequently than the treatment group (10% vs. 0%, $p \leq 0.05$). Compared to the control group, the treatment group required antiarrythmic (18% vs. 10%, $p \leq 0.05$) and cardiac glycoside therapy (11% vs. 0%, $p \leq 0.05$) less frequently in the postoperative period. Although treatment patients required less intraoperative pacing and cardioversion and spent less time on mechanical ventilation, in the intensive care unit (ICU), and in the hospital than control patients, statistical significance was not achieved.

In conclusion, the use of continuous, in-line blood gas monitoring resulted in improvement in a number of postoperative outcome variables, although ICU and hospital stay was not effected.

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INTRODUCTION

Various hemodynamic parameters are monitored during cardiopulmonary bypass (CPB) procedures, including blood gas status and hydrogen ion, electrolyte, and hemoglobin concentration. During extracorporeal flow, the perfusionist is responsible for monitoring and regulating these variables to assure that homeostasis is maintained. Therefore, the practical application of information contained in blood gas results is a major facet of perfusion, and continuous, accurate information concerning the patient's physiological response to CPB is paramount. Methods for assessing these variables, and thus the adequacy of perfusion, include intermittent blood sampling for laboratory analysis and/or continuous in-line blood parameter monitoring.

Surgical procedures requiring the use of CPB are associated with dramatic shifts in fluids, electrolyte concentration, and artificial cardiopulmonary physiology (1). The patient's electrolyte, acid-base, and oxygenation status are in constant flux, and it is often necessary to obtain repeated blood gas samples to make patient care decisions. When the required information is delayed, these decisions may no longer be appropriate to match the clinical situation (1). We have previously shown that continuous information allows perfusionists to more accurately control blood gas parameters (2).

It is not clear, however, what level of blood gas control is sufficient to avoid adverse outcomes associated with inadequate oxygenation or inappropriate blood gas management. The purpose of part II of this study was to determine whether improved blood gas control during CPB influences patient outcome.

MATERIALS AND METHODS

After Institutional Review Board approval and informed consent were obtained, 59 patients participated in a prospective, randomized comparison of continuous blood gas monitoring versus intermittent blood gas analysis. All patients underwent coronary artery bypass grafting (CABG), valvular surgery, or combined procedures. Patients were randomized into two groups, a control and a treatment group. Patients in the control group had an arterial CDI 500[a] shunt sensor placed in the circuit, but the monitor was blinded and the perfusionist conducted CPB according to institutional guidelines. The same procedure was performed for the treatment group, except the CDI 500 display was used to guide clinical decisions. Maintenance of blood gas variables was set as: pH 7.40 ± 0.05, $PaCO_2$ 40 ± 5 mmHg, PaO_2 200 ± 50 mmHg.

All patients were operated on by one of five surgeons and received identical surgical, anesthetic, and postoperative care. Aside from blinding the CDI monitor in the control group, the perfusion circuit was identical and consisted of a roller pump[b], an oxygenator with an integral heat exchanger[c], an integrated venous/cardiotomy reservoir[d], an arterial line filter[e], and a custom tubing pack[f]. The prime solution consisted of approximately 1400 mL of balanced electrolyte solution to which 100 mL 25% albumin, 100 mL 25% mannitol, and 10000 U of bovine lung heparin were added. During CPB, arterial pressures were maintained between 60–90 mmHg, with flow rates adjusted between 2.0 and 2.4 L min^{-1} m^{-2}. Mild hypothermia (32°C) was used and blood gas management was maintained according to alpha-stat physiology. Both antegrade and retrograde cardioplegia were used, with potassium concentrations adjusted for arrest (24–28 mEq L^{-1}) and maintenance doses (8–10 mEq L^{-1}).

A target activated clotting time (ACT) of 480 sec was sought by heparinizing patients at 300 U kg^{-1} body weight. Additional heparin was administered to maintain the ACT level greater than 480 sec during CPB. At the end of the surgical repair and termination of CPB, heparin was reversed with protamine at a rate of 1 mg protamine for every 100 U of total heparin administered, with the adequacy of heparin reversal assessed via the return of the ACT to baseline, pre-CPB values.

Patient parameters consisted of demographic, preoperative, operative, postoperative, blood gas, and laboratory measures. Patients were monitored continuously throughout the operative period, intensive care unit (ICU) stay, and hospital stay. Transfusion requirements were recorded, and patients were transfused with packed red cells when the hemoglobin level fell below 7 g dL^{-1} in patients less than 70 years of age, and 8 g dL^{-1} in patients over 80 years of age, or if the patient became hemodynamically unstable due to suspected anemia. Patients were transfused with coagulation factors in the form of fresh frozen plasma (FFP), platelets (PLT) and cryoprecipitate (CRYO) only when bleeding was uncontrolled according to the following protocol: FFP when PT was greater than 1.5 times normal, PLT when platelet counts fell below 100,000 μL^{-1}, and CRYO when fibrinogen levels were less than 100 mg dL^{-1}.

OUTCOME ASSESSMENT

In addition to standard laboratory assessment, preoperative and postoperative coagulation determinations of PT, aPTT, and platelet count were drawn in the immediate preoperative period and repeated postoperatively. Preoperative and postoperative laboratory indices of renal function were also drawn, and included creatinine and blood urea nitrogen (BUN).

a Terumo-Sarns, Ann Arbor, MI

b Sorin Biomedica, Stockert, Irvine, CA
c Sorin Biomedica, Monolyth, Irvine, CA
d Sorin Biomedica, Irvine, CA
e COBE Laboratories, Arvada, CO
f COBE Laboratories, Arvada, CO

Patient outcomes were further evaluated using ventilator time, ventilator requirements, ICU stay, postoperative hospital stay, transfusion requirements (RBC, PLT, FFP, CRYO), required pharmacological support, and morbidities (cardiac, cerebral, pulmonary, renal, re-operation, re-hospitalization, mechanical assistance). The guidelines for the Society of Thoracic Surgeons database were used to define preoperative demographic status, morbidities, and complications[g].

Data Comparison

In addition to comparing the treatment group and the control group, the data was analyzed by risk stratification within experimental groups and by relative quality of blood gas control. Stratification of preoperative risk factors was accomplished by using the clinical severity scoring system developed by Higgins and associates (3) (Table 1). The system was modified to exclude emergency cases, which were not included in the study.

The quality of blood gas control during CPB was determined by evaluating the blood gas status of each patient every 7.5 min using the CDI 500 printing function. The number of events that fell outside of range (pH = 7.35–7.45, $PaCO_2$ = 35–45 mmHg, PaO_2 = 150–250 mmHg) were calculated as a percentage of the total recorded events for each patient. The quality of blood gas control was stratified using this data as follows:

A: <Mean % − 1.0 SDEV
B: Mean % − 0.5 SDEV to mean − 1.0 SDEV
C: Mean % ± 0.5 SDEV
D: Mean % + 0.5 SDEV to mean + 1.0 SDEV
E: >Mean % + 1.0 SDEV
*SDEV: Standard deviation from the mean

[g] Society of Thoracic Surgeon, Chicago, IL

Table 1: Cleveland Clinic Clinical Severity Scoring System

Risk factor	Points
Emergency	6
Serum creatinine >1.9 mg dL^{-1}	4
Serum creatinine 1.6–1.8 mg dL^{-1}	1
Severe left ventricular dysfunction	3
Prior cardiac surgery	3
Mitral valve insufficiency	3
Age 75 years or older	2
Age 65 to 74 years	1
Prior vascular surgery	2
Chronic obstructive pulmonary disease	2
Anemia (Hct ≤34%)	2
Aortic stenosis	1
Weight ≤65 kg	1
Diabetes	1
Cerebrovascular disease	1

Statistics

Statistical analysis was performed by loading all data onto a personal computer in spreadsheet format. Parametric data was analyzed using a one-way analysis of variance. Additional multiple comparison tests (Fisher's least significant difference) were performed when significant differences ($p \leq 0.05$) were achieved. Nonparametric data was analyzed using chi-square analysis. Statistical significance was accepted at $p \leq 0.05$.

Results

A total of 59 patients, 29 control and 30 treatment, were included in the analysis. Compared to the control group, the treatment group contained significantly more diabetic (47% vs. 7%, $p < 0.001$), renal failure (13% vs. 3%, $p < 0.01$), and chronic obstructive pulmonary disease (COPD) (20% vs. 7%, $p < 0.01$) patients. No other significant differences in demographic parameters or preoperative medication use were noted (Tables 2 and 3). Both groups received equal operative care, with the exception of internal thoracic artery utilization (95% treatment vs. 67% control, $p \leq 0.02$) (Table 4).

During the perioperative period, patients in the treatment group required antiarrythmic support less frequently than the control group (0% vs. 10%, $p < 0.05$) (Table 2). Patients in the treatment group also required inotropic support, cardioversion, and pacing less frequently than the control group, although statistical significance was not achieved (Table 5). Postoperatively, the treatment group required antiarrythmic (18% vs. 10%, $p \leq 0.05$) and cardiac glycoside (11% vs. 0%, $p \leq 0.05$) therapy less frequently than the control group (Table 3). There

Table 2: Demographic parameters

Parameter	Treatment group	Control group	*p* value
Number	30	29	NS
Age (years)	64.6 ± 12.2	61.1 ± 12.2	NS
Gener (male/female)	22/7	20/10	NS
Weight (kg)	88.1 ± 23.0	85.7 ± 19.6	NS
Height (cm)	169.3 ± 16.5	173.6 ± 11.0	NS
BSA (m^2)	2.01 ± 0.30	2.01 ± 0.25	NS
Re-operation (%)	13%	17%	NS
Diabetic (%)	47%	7%	0.001
Hypertension (%)	60%	48%	NS
Renal failure (%)	13%	3%	0.01
COPD (%)	20%	7%	0.01
MI (%)	27%	17%	NS
CHF (%)	13%	14%	NS
Preop eject fraction (%)	53.2 ± 9.2	48.2 ± 14.3	NS
LM (%)	13%	7%	NS

BSA, body surface area; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; LM, left main disease; MI, myocardial infarction.

Table 3: Preoperative, postoperative, and discharge pharmacological support

Agent	Treatment group	Control group	*p* value
Preoperative			
Aspirin	63%	55%	NS
Nitrates	20%	21%	NS
Ca Channel blockers	23%	21%	NS
Beta blockers	40%	48%	NS
Cardiac glycosides	10%	10%	NS
Antiarrythmics	7%	7%	NS
Diuretics	33%	31%	NS
ACE inhibitors	27%	31%	NS
Steroids	7%	10%	NS
B_2 agonists	3%	3%	NS
Operative			
Inotropes	10%	17%	NS
Antiarrythmics	0%	10%	0.05
Postoperative Day 1			
Aspirin	60%	62%	NS
Nitrates	13%	17%	NS
Ca channel blockers	7%	14%	NS
Beta blockers	50%	52%	NS
Cardiac glycosides	3%	10%	NS
Antiarrythmics	10%	21%	NS
Diuretics	33%	31%	NS
ACE inhibitors	33%	31%	NS
Steroids	7%	14%	NS
B_2 agonists	30%	28%	NS
Postoperative Day 2			
Aspirin	50%	54%	NS
Nitrates	10%	4%	0.05
Ca channel blockers	7%	4%	NS
Beta blockers	50%	68%	0.05
Cardiac glycosides	0%	11%	0.05
Antiarrythmics	10%	18%	NS
Diuretics	40%	43%	NS
ACE inhibitors	37%	46%	NS
Steroids	7%	11%	NS
B_2 agonists	47%	43%	NS
Discharge			
Aspirin	55%	48%	NS
Nitrates	10%	17%	NS
Ca channel blockers	7%	3%	NS
Beta blockers	48%	48%	NS
Cardiac glycosides	0%	7%	NS
Antiarrythmics	7%	14%	NS
Diuretics	14%	34%	NS
ACE inhibitors	28%	34%	NS
Steroids	3%	10%	NS

Table 4: Operative parameters

Parameter	Treatment group	Control group	*p* value
CABG	63%	69%	NS
Grafts	3.5 ± 1.2	3.5 ± 1.1	NS
ITA Use	95%	67%	0.02
Valve	24%	24%	NS
Combo	13%	7%	NS
CPB time (min)	98.4 ± 30.0	96.0 ± 35.7	NS
Cross clamp time (min)	69.4 ± 27.3	66.0 ± 27.2	NS
UO-CPB	387 ± 251	356 ± 204	NS
UO-total	683 ± 381	649 ± 293	NS
Ultrafiltrator use	20%	10%	NS

CABG, coronary artery bypass grafting; CPB, cardiopulmonary bypass; UO, urine output.

Table 5: Outcome parameters

Parameter	Treatment group	Control group	*p* value
Hospital stay (days)	5.8 ± 1.9	6.5 ± 2.6	NS
ICU stay (days)	1.3 ± 0.5	1.8 ± 1.4	NS
Ventilator time (h)	8.6 ± 4.8	9.5 ± 5.8	NS
Mortality	3%	0%	NS
Morbidity			
Cerebral	0%	0%	NS
Pulmonary	0%	3%	NS
Renal	0%	3%	NS
Cardiac	0%	0%	NS
Intraoperative complications			
Cardioversion	3%	14%	NS
Pacing	10%	17%	NS
IABP	0%	0%	NS
VAD	0%	0%	NS
Postoperative complications			
Reoperation	7%	0%	NS
Arrythmia	7%	13%	NS

IABP, intraaortic balloon pump; ICU, intensive care unit; VAD, ventricular assist device.

were no significant differences in transfusion requirements between groups in either the perioperative period or the postoperative period (Table 5).

No differences in morbidities or mortality between the experimental groups were noted (Table 5). Compared to the control group, patients in the treatment group tended to spend less time on mechanical ventilation, in the ICU, and in the hospital, although statistical significance was not achieved (Table 5).

Outcomes by Risk Stratification

The patients were stratified according to preoperative risk

Table 6: Transfusion requirements

Parameter	Treatment group	Control group	*p* value
Intraoperative			
Packed red blood cells	0.4 ± 0.9	0.5 ± 1.0	NS
Fresh frozen plasma	0.1 ± 0.4	0.1 ± 0.4	NS
Platelets	0.3 ± 1.9	0.3 ± 1.9	NS
Postoperative Day 1			
Packed red blood cells	0.5 ± 1.3	0.3 ± 0.8	NS
Fresh frozen plasma	0.3 ± 0.9	0.3 ± 1.2	NS
Platelets	0.6 ± 2.2	0.4 ± 1.9	NS
Postoperative Day 2			
Packed red blood cells	0.3 ± 0.7	0.1 ± 0.4	NS
Fresh frozen plasma	0.0 ± 0.0	0.0 ± 0.0	NS
Platelets	0.0 ± 0.0	0.0 ± 0.0	NS
Postoperative Day 3			
Packed red blood cells	0.0 ± 0.0	0.1 ± 0.4	NS
Fresh frozen plasma	0.1 ± 0.4	0.0 ± 0.0	NS
Platelets	0.0 ± 0.0	0.0 ± 0.0	NS

scores. The median risk score was 3, with the low risk groups defined by a score of 0–3, and the high risk groups were defined by a score of >3. The control group consisted of 12 high-risk and 17 low-risk patients, and the treatment group consisted of 12 high-risk and 18 low-risk patients. No significant differences occurred between experimental groups or risk categories, although high-risk patients tended to spend more time on mechanical ventilation, in the ICU, in the hospital, and had higher rates of complications (Figure 1). In addition, high-risk and low-risk treatment patients spent less time in the ICU and hospital than the corresponding control patients, but statistical significance was not achieved (Figure 1). Likewise, high-risk treatment patients spent less time on mechanical ventilation and had fewer complications than high-risk control patients, but statistical significance was not achieved (Figure 1).

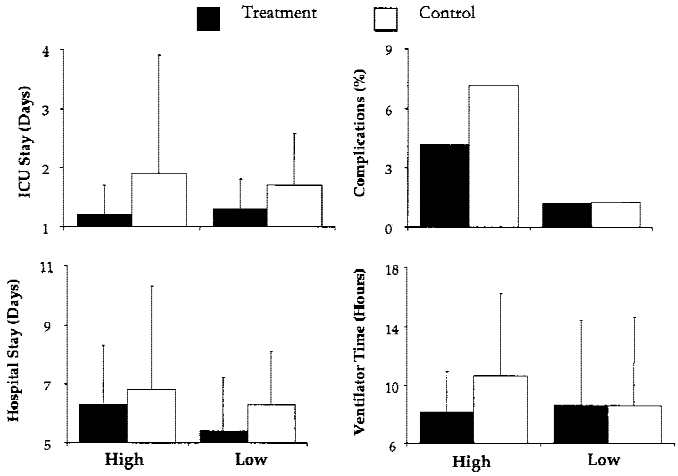

Figure 1: Outcome data by experimental group and preoperative risk status. (A) hospital stay; (B) ICU stay; (C) ventilator time; (D) complication rates. High risk: patients with a preoperative risk score >3, and low risk: ≤3 according to the Cleveland Clinic Clinical Severity Scoring System. Complication rate includes the occurrance of all perioperative and postoperative complications, morbidities, and mortalities.

Outcomes by Blood Gas Management Quality

The patients were also stratified according to the overall quality of CPB blood gas management. The patients blood gas parameters fell outside of range 10.8 ± 8.7% of the time. Eight patients qualified for the A category (<2% out of range), including seven treatment patients and one control patient. Fourteen patients qualified for the B category (2.1–6.3% out of range), including 13 treatment patients and 1 control patient. The largest category was the C group (6.4–15.2% out of range), which was composed of 8 treatment and 12 control patients. The D category (15.3–19.7% out of range) consisted of two treatment and seven control patients, and the E category (>19.8% out of range) included seven control patients and one treatment patient (Figure 2B).

There were no differences in preoperative risk between blood gas management groups (Figure 2C). Patients in the A and B categories spent significantly less time on mechanical ventilation (6.1 ± 2.8 and 7.1 ± 4.6 vs. 11.7 ± 6.1, respectively,

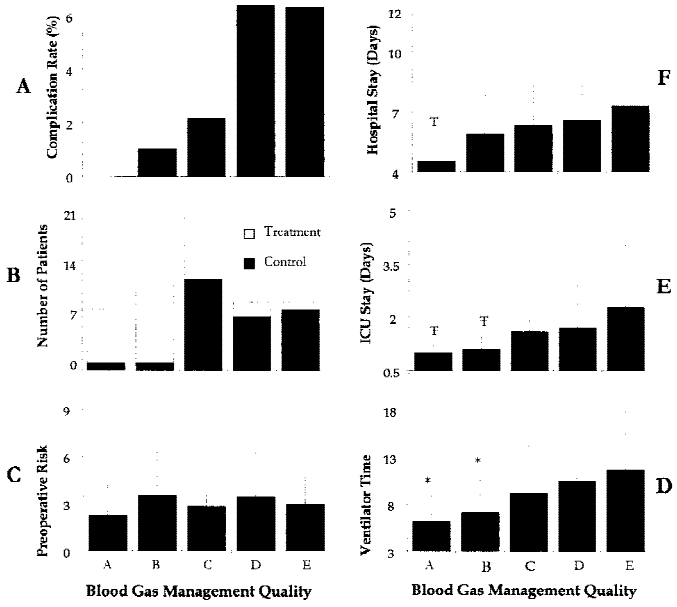

Figure 2: Demographic and outcome data by blood gas management quality group. (A) complication rates; (B) distribution of patients; (C) preoperative risk scores; (D) ventilator times; (E) ICU stay; (F) hospital stay. Ave., Average; ICU, Intensive care unit. Complication rate includes the occurrance of all perioperative and postoperative complications, morbidities, and mortalities. $p < 0.01$ vs. E group; *$p < 0.05$ vs. E group. Difference in complication rate between all groups, except between the D vs. E category, $p < 0.01$.

$p \leq 0.05$) and in the ICU (1.0 ± 0.4 and 1.1 ± 0.4 vs. 2.4 ± 2.2, respectively, $p \leq 0.01$) when compared to the E category (Figure 2E and 2F). The A category also spent significantly less time in the hospital compared to the E category (4.5 ± 0.9 vs. 7.3 ± 3.8, respectively, $p \leq 0.01$) (Figure 2D). The differences in complication rates were significant between all groups with the exception of the D versus E groups (Figure 2A).

DISCUSSION

The need for perfusionists to monitor adequately blood gas status is not disputed and is well supported by the physiological consequences of its absence. According to Justison and Parsens, continuous, in-line blood gas management (CILBGM) facilitates more consistent management of perfusion parameters within physiological limits and increases safety margins on CPB (4).

Newer technologies may obviate many of the accuracy and reliability concerns that have precluded the use of in-line monitoring. The latest device offered was found to provide accuracy comparable to laboratory analysis for arterial pH, PCO_2, PO_2, and K^+ in a prospective, multicenter clinical evaluation and validated by the results of this study and others (2, 5, 6). The question of the cost-effectiveness of CILBGM is no longer centered on the inaccuracy of the devices. Instead, the focus is whether or not real-time, continuous monitoring of the patient's physiologic responses to CPB provides a tangible patient benefit. Part I of this study showed that improved blood gas control is provided by the use of CILBGM, but the impact of closely regulating blood gas parameters has not been explored previously.

The Physiological Basis for Precise Blood Gas Management

The implications of proper PO_2 management are more pronounced than believed previously. It is well recognized that PO_2 reflects the balance between oxygen content, local blood flow, and oxygen uptake. Significant metabolic disruption is associated with PO_2 values lower than 30 mmHg, and death typically results from tension lower than 20 mmHg (7). However, it is becoming increasingly clear that hyperoxemic conditions are also associated with significant physiological impairment. In a prospective investigation, Joachimsson et al. found signs of maldistributed capillary flow and decreased oxygenation in response to hyperoxia (PaO_2 > 185 mmHg), which remained irrespective of decline in perfusion pressure, temperature, non-pulsatile flow, and concomitant atherosclerosis (8). Paradoxically, they also reported that tissue oxygen levels in both the brain and skeletal muscle decreased during hyperoxemic conditions. Belboul et al. reported a prospective, randomized study that showed hyperoxia (PaO_2 = 190–300 mmHg) increased damage to red cell rheology and decreased postoperative organ performance (9). The increased blood trauma during CPB was related to increased use of blood products postoperatively, in the absence of differences in postoperative blood loss. Hyperoxia also increases the rate of formation of oxygen free radicals (superoxide, hydrogen peroxide, and hydroxyl radical) and lipid peroxides (10). Not surprisingly, Belboul et al. also found a higher frequency of arrythmias, which may be associated with oxygen derived free radicals (9).

The effects of acidemia upon the cardiovascular system are particularly pernicious and can include decreased cardiac output, decreased arterial blood pressure, decreased hepatic and renal blood flow, and centralization of blood volume (11, 12). Reentrant arrythmias and a reduction in the threshold for ventricular fibrillation can occur, while the defibrillation potential threshold remains unaltered (13, 14). Acidemia also decreases the uptake of glucose in tissues by inducing insulin resistance and inhibits anaerobic glycolysis by depressing 6-phosphofructokinase activity (15, 16). This effect can have grave consequences during hypoxia, since glycolysis becomes the major energy source. The uptake of lactate by the liver can become curtailed, and the liver can become the primary producer of lactate, rather than the primary consumer (11).

Acidemia also causes potassium to leave the cells, resulting in hyperkalemia (17, 18). Increased net protein breakdown and development of a catabolic state also occurs in patients with acidosis (19–21). Brain metabolism and the regulation of cerebral volume are impaired by severe acidemia, resulting in a progressive obtundation and eventually coma.

Alkalemia can compromise cerebral and myocardial perfusion by causing arteriolar constriction, an effect that is more pronounced in respiratory alkalosis then metabolic (22–24). Neurological abnormalities may ensue, including headache, tetany, seizures, lethargy, delirium, and stupor (22). The associated reduction in the plasma concentration of ionized calcium probably contributes to these manifestations. Although it exerts a positive inotropic effect on the isolated heart, alkalemia reduces the anginal threshold and predisposes patients to refractory supraventricular and ventricular arrythmias (23). This action is more pronounced in patients with underlying heart disease. Alkalemia also depresses respiration, causing hypercapnia and hypoxemia. Even a mild alkalemia can frustrate efforts to wean patients from mechanical ventilation (24).

Specific acid–base management strategies during hypothermic CPB have received much attention. The specific strategy employed does not alter cerebral metabolism, but does affect cerebral blood flow and neurologic outcome (25). Patel et al. have shown that patients receiving alpha-stat management had less disruption of cerebral autoregulation during CPB, accompanied by a reduced incidence of postoperative cerebral dysfunction (26). Changes in cerebral blood flow during CPB is intimately related to $PaCO_2$ maintained during hypothermia (27, 28). Temperature and pH management also influence microembolic phenomena, and modifications in these parameters

are increasingly being shown to reduce the incidence of post-operative neuropsychologic dysfunction (29).

Outcomes

From the physiological data available, it is clear that appropriate regulation of blood gas parameters is essential to avoid the diverse negative outcomes linked to sub-optimal blood gas parameter control. Cardiac function, electrophysiological disturbances, renal function, pulmonary function, cerebral function, transfusion requirements, and less defined parameters such as ventilator requirements, ICU stay, and post-operative hospital stay could be potentially improved by more precise and accurate control of blood gas parameters.

Cardiac function, which is influenced by both oxygen and pH management, was evaluated in terms of electrophysiology (via rates of cardioversion and pacing, required pharmacological support, and documented arrythmias), and mechanical function (via required inotropic support, mechanical assistance, and associated morbidities). No specific cardiac morbidities occurred in the study. However, differences were noted in the frequency of cardiac complications and events which required pharmacological support. In the perioperative period, the treatment group required significantly less antiarrythmic therapy, and tended to require cardioversion and pacing less frequently. These differences were noted in the postoperative period through discharge, with the frequency of cardiac glycoside, antiarrythmic, and beta-blocker use achieving significance.

Overall, patients in the treatment group spent less time on mechanical ventilation and less time in the ICU and hospital. This is particularly striking due to the fact that treatment patients were generally at a higher risk, with significantly more diabetic, renal failure, and COPD patients. However, most of the differences in outcome did not achieve statistical significance.

Outcomes Relative to Blood Gas Management Quality

The extremes in blood gas management are not composed of equivalent numbers of control and treatment patients. In fact, the most tightly controlled patients were predominately treatment patients, and the worst blood gas management occurred in control patients. However, patients receiving average blood gas management were equally distributed between the experimental groups. Therefore, to uncover the relative importance of blood gas control (rather than only control vs. treatment effect), select outcomes were evaluated in terms of relative blood gas control. The results of this analysis indicate that the patients receiving average blood gas management may have buffered the results of the treatment vs. control comparison, thus making statistical significance difficult to achieve. In every example, as blood gas parameters fell outside of normal range more often, outcomes worsened in a predictable manner (Figure 2A–F). The differences were significant between the extremes, demonstrating that blood gas management during CPB influences patient outcome. Thus, perfusionists should strive to maintain

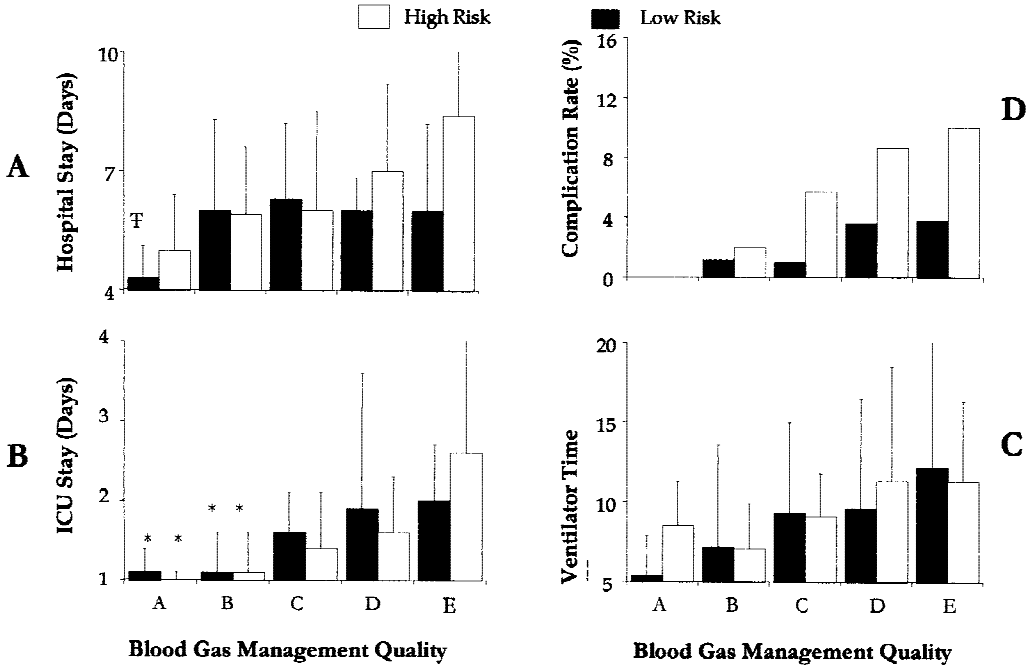

Figure 3: Outcome data by preoperative risk classification and blood gas management quality. (A) Hospital stay; (B) ICU stay; (C) ventilator time; (D) complication rates. Ave., Average; ICU, Intensive care unit. High risk: patients with a preoperative risk score >3, and low risk: ≤3 according to the Cleveland Clinic Clinical Severity Scoring System. Complication rate includes the occurrence of all perioperative and postoperative complications, morbidities, and mortalities. $p < 0.01$ vs. E blood gas management, high risk group; *$p < 0.05$ vs. E blood gas management, high risk group.

blood gas parameters within normal range, and tools that aid this process are well justified in terms of patient benefit.

Outcomes Relative to Preoperative Risk

To examine the possibility of higher risk patients benefiting more from CILBGM, the treatment and control groups were stratified according to preoperative risk status. Interestingly, the differences between control and treatment patients for ICU and hospital stay were equivalent between the high-risk and low-risk groups, but for ventilator time and complication rates only the high-risk group seemed to benefit from CILBGM. None of the differences achieved significance, and there was concern that the patients receiving average blood gas management may have buffered these results, as before. Therefore, the patients were examined in terms of blood gas management quality and risk stratification. The high-risk patients appeared to benefit more from improved blood gas control (in terms of ICU stay, complication rates, and hospital stay), but the low-risk patients also showed a decline in ICU stay, hospital stay, complication rates, and ventilator time with improved blood gas management (Figure 3).

CONCLUSIONS

As blood gas parameters fell outside of normal range more often, complications rates increased and more time was spent on mechanical ventilation, in the ICU, and in the hospital. When the data were examined relative to preoperative risk status, there was an indication that all patients benefit from improved blood gas control, but higher risk patients benefited more.

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