The Heart Surgery Forum #2010-1065
14 (1), 2011 [Epub February 2011]
doi: 10.1532/HSF98.20101065

Online address: http://cardenjennings.metapress.com

Monitoring Brain Oxygen Saturation During Coronary Bypass Surgery Improves Outcomes in Diabetic Patients: A Post Hoc Analysis

John M. Murkin, MD, FRCPC,[1] Sandra J. Adams, RN,[1] Elaine Pardy, BScN,[1]
McKenzie Quantz, MD, FRCPS,[2] F. Neil McKenzie, MD, FRCPS,[2] Linrui Guo, MD[2]

Departments of [1]Anesthesiology and Perioperative Medicine, and [2]Surgery, University Hospital – LHSC, University of Western Ontario, London, Ontario, Canada

ABSTRACT

Background: Having previously demonstrated in a prospective study of 200 coronary artery bypass (CAB) patients that by using the brain as an index organ, interventions to improve cerebral oxygenation would have systemic outcome benefits, we undertook a post hoc analysis of the diabetic subset (n = 57) of the overall study group to determine whether the outcomes of these patients were similarly improved.

Methods: Case-report forms for the 200 CAB patients study patients with a preoperative diagnosis of diabetes mellitus were stratified to intraoperative cerebral regional oxygen saturation (rSO_2) monitoring with active display and a treatment intervention protocol (intervention group, n = 28) or to blinded rSO_2 monitoring (control group, n = 29) and analyzed.

Results: There were no significant differences between the 2 groups in overall risk factors, although there were trends toward a higher body mass index, a worse angina score, a worse grade of ventricle, and greater use of off-pump coronary revascularization in the control group of patients. The 2 groups were similar with respect to overall insulin dosage and perioperative blood glucose concentrations. Significantly more diabetic patients in the control group demonstrated profound cerebral desaturation, with an area under the curve of <50%/min (P = .043; d = 0.55), longer intensive care unit (ICU) stays (P = .045; d = 0.58), and longer overall postoperative hospital stays (P = .036; d = 0.47), compared with patients in the intervention group. Compared with the intervention group, the control group had a significantly higher incidence of sternal wound infection (P = .028; φ = 0.31) and a significantly greater number of diabetic patients with >2 postoperative complications (P = .006; φ = 0.37). An analysis after removing the patients who underwent off-pump surgery revealed that the control group had significantly more patients with sternal wound infections (5 versus 0; P = .047) and ≥2 postoperative complications (6 versus 0; P = .008) than the intervention group, as well as a trend toward longer ICU and postoperative hospitalization stays in the control group.

Conclusion: Monitoring and management of cerebral rSO_2 in diabetic CAB patients avoid profound cerebral desaturation and are associated with significantly lower incidences of complications and shorter postoperative lengths of stay.

Implication Statement: A post hoc analysis of the diabetic cohort of a prospective, randomized, and blinded study of CAB patients revealed that those in whom cerebral oxygen saturation was actively monitored and maintained demonstrated significantly lower incidences of complications, resulting in shorter ICU and postoperative hospital stays compared with an unmonitored control group.

This work was presented in part at Outcomes Barbados, Accra Beach, Barbados, West Indies, May 2007.

Received May 3, 2010; received in revised form July 8, 2010; accepted July 27, 2010.

Correspondence: Dr. J. Murkin, Rm C3-112, University Hospital Campus LHSC, 339 Windermere Rd, London, Ontario, N6A 5A5 Canada; 519-663-3384; fax: 519-663-3260 (e-mail: john.murkin@lhsc.on.ca).

INTRODUCTION

Approximately 30% of patients presenting for cardiac surgery have a preoperative diagnosis of diabetes mellitus (DM), putting them at increased risk of postoperative complications, including stroke, myocardial infarction, wound infection, prolonged intensive care unit (ICU) stay, and other complications that can lead to prolonged postoperative hospitalization [Cho 1998; Bucerius 2003; Khan 2005; Ouattara 2005]. In a recent randomized prospective study of patients undergoing coronary artery bypass (CAB) surgery, we demonstrated significant improvements in major-organ morbidity and mortality (stroke, death, surgical reexploration, prolonged ventilation, dialysis, deep sternal infection [Shroyer 2003]) associated with cerebral oximetry monitoring [Murkin 2007].

Given that perioperative complications in diabetic patients are due in part to impaired cerebral autoregulation and generalized impairment of tissue vasoreactivity [Singleton 2003; Last 2007], we sought to determine whether cerebral oximetry monitoring was of benefit to diabetic patients—a group known to have increased susceptibility to microcirculatory dysfunction and end-organ ischemia. Because this group constituted approximately 30% of our initial study, we undertook a post hoc analysis of the subset of study patients with a preoperative diagnosis of DM to determine whether their clinical outcomes were similarly impacted by cerebral oximetry monitoring and protocol-directed interventions [Denault 2007].

Table 1. Preoperative Demographic and Morphometric Data in Diabetes Mellitus Patients*

	Control (n = 29)	Intervention (n = 28)	*P*
Age, y	64.7 ± 7.9	62.6 ± 7	.37
Age >70 y, n	8	8	.58
Age >80 y, n	0	0	1.0
Male/female sex, n	27/1	25/4	.187
Body mass index, kg/m^2	32.3 ± 5.2	29.8 ± 4.3	.085
CCS angina score	3.4 ± 0.6	3.1 ± 0.7	.086
Grade of ventricle	1.8 ± 1.0	1.5 ± 0.7	.083
Grade III or IV ventricle, n	7	4	.27
Recent MI, n	2	2	.68
CHF, n	2	3	.48
Type II DM (noninsulin), n	21	21	.53
Type II DM (insulin), n	8	7	.53
Renal insufficiency, n	4	4	.63
TIA, n	4	1	.187
CVA, n	2	4	.335
COPD, n	6	7	.47

*Data are categorical or presented as the mean ± SD. CCS indicates Canadian Cardiovascular Society angina score from 0 to 4, where a higher grade reflects increased severity of anginal symptoms; grade of ventricle, qualitative categorical clinical estimate of global ventricular function (grade I to IV), where a higher grade reflects increased severity of left ventricular dysfunction; recent MI, myocardial infarction within <30 days of acceptance for surgery; CHF, diagnosis of congestive heart failure; type II DM (noninsulin), diagnosis of non–insulin-dependent diabetes mellitus; type II DM (insulin), DM chronically treated with insulin; renal insufficiency, serum creatinine >120 mg/L; TIA, history of transient ischemic attack; CVA, history of cerebrovascular accident; COPD, history of chronic obstructive pulmonary disease.

Table 2. Perioperative Glucose Concentrations and Insulin Administration*

	Control (n = 29)	Intervention (n = 28)	*P*
Mean glucose, mmol/L			
Preoperative	9.0 ± 3.7	9.1 ± 3.4	.675
Intraoperative before CPB	12.5 ± 3.4	10.5 ± 0.4	.066
Intraoperative during CPB	11.4 ± 3.5	11.6 ± 3.1	.788
Initial 24 h in ICU	10.8 ± 2.3	11.6 ± 2.0	.157
Insulin administration, U			
Intraoperative (in OR)	23.8 ± 17.3	25.3 ± 22.2	.874
Initial 24 h in ICU	76.2 ± 41.6	80.3 ± 57.1	.758

*Data are presented as the mean ± SD. CPB indicates cardiopulmonary bypass; ICU, intensive care unit; OR, operating room.

METHODS

After Institutional Review Board approval, patients were recruited and enrolled from July 2000 through April 2004. From the comprehensive database established for the overall study [Murkin 2007], the case-report forms and source documents for all patients with a preoperative diagnosis of DM treated with insulin, diet, or oral hypoglycemic agents were collected, stratified into either the intervention group or the control group, and analyzed. Table 1 summarizes the demographic and morphometric data. Specific areas of analysis included perioperative blood glucose concentrations, cumulative insulin doses, cerebral oximetry values, clinical outcomes (including major-organ morbidity and mortality), overall incidence of postoperative complications, and postoperative lengths of stay.

All patients were anesthetized with a narcotic-inhalational technique using 10 to 30 μg/kg fentanyl, isoflurane, and rocuronium for neuromuscular blockade, with the goal of early postoperative extubation. Anesthetic management of clinical variables, including heart rate, blood pressure, ventilation, systemic oxygen saturation, temperature, depth of anesthesia, glucose management, and related parameters, was at the discretion of the attending anesthesiologist.

After administration of the initial heparin bolus (300-400 IU/kg) to maintain an activated coagulation time >480 seconds, cardiopulmonary bypass (CPB) was instituted with a 40-μm arterial line filter (Pall Biomedical, East Hills, NY, USA) and a non–surface-modified membrane oxygenator with a CAPIOX SX18® integrated venous and cardiotomy reservoir (Terumo Cardiovascular Systems Corporation, Ann Arbor, MI, USA), a nonocclusive roller pump (Cobe Stockert®; Lakewood, CO, USA), and in-line monitoring of venous saturation and hematocrit. Flow rates of 2.0 to 2.5 L/m^2 per minute were used, with the rectal temperature maintained in the tepid range (32°C-35°C) during alpha-stat pH management and the PaO2 level maintained between 150 and 200 mm Hg. Combinations of antegrade and retrograde cold blood cardioplegia were used for myocardial protection after application of the aortic cross-clamp. A minimum concentration of 0.5% isoflurane (range, 0.5%-2.5%) was titrated continuously by vaporizer during CPB to maintain the bispectral index (BIS®; Aspect Medical Systems, Framingham, MA, USA) between 40 and 60 for anesthesia; the mean arterial pressure (MAP) was maintained between 50 and 90 mm Hg.

As per our routine clinical practice, we measured blood glucose values perioperatively as clinically indicated and administered insulin at the discretion of the attending physician. Preoperative, intraoperative, and postoperative glucose concentrations and the cumulative amount of insulin administered were recorded and analyzed. Results are displayed in Table 2. For all patients, best clinical practices aimed at maintaining the blood glucose concentration within the institutional reference interval (3.4-11 mmol/L), the hematocrit at ≥20%, the MAP at >50 mm Hg, and the central venous pressure at <10 mm Hg were used specifically during CPB and throughout the intraoperative period.

The specifics of the cerebral oximetry monitoring and intervention protocol have previously been detailed [Murkin 2007] but are summarized here. On arrival in the operating room (OR), patients were randomly assigned via sealed envelopes containing a random-number sequence to either an active-treatment group (intervention group) or a control group that used cerebral oximetry monitoring with bilateral near-infrared spectroscopy (INVOS 5100; Somanetics Corporation, Troy, MI, USA). In the intervention group, resting baseline regional oxygen saturation (rSO_2) values were obtained as follows: The quietly resting patient was administered 3 to 5 L/min of oxygen by nasal cannula, sensors were placed, and the rSO_2 level was monitored until values stabilized. Data were obtained and digitally stored not less than 1 minute after values had stabilized. In the control group, adequate signal strength was verified, the screen was electronically blinded, and data were recorded continuously. Baselines were calculated post hoc by averaging the data obtained over a 1-minute period 3 minutes after recording was begun. For the intervention group, we established an audible alarm threshold at 75% of the resting baseline rSO_2 value. rSO_2 values were stored on a floppy disc and updated continuously every 15 seconds for the duration of the intraoperative period. The data were then transferred to a digital spreadsheet (Excel; Microsoft, Redmond, WA, USA) and subsequently analyzed with statistical software (Statistical Package for the Social Sciences; SPSS, Chicago, IL, USA). Upon application of the chest dressing and before the patient left the OR, we discontinued monitoring and removed the optodes.

A decrease in cerebral saturation values to <70% of baseline was previously shown to be correlated with adverse neurologic outcomes [Higami 1999]. We therefore used a prioritized intraoperative management protocol in the intervention group to maintain rSO_2 values at ≥75% of the baseline threshold. Profound desaturation was defined as a saturation level <50% of baseline. To minimize the probability of patients reaching these levels, we applied interventions to improve cerebral oxygenation when the rSO_2 value decreased to <75% of baseline for >15 seconds. These interventions included a check of patient head position, modification of ventilation to achieve a $PaCO_2$ value ≥40 mm Hg, administration of phenylephrine in 40-µg increments to achieve a MAP >60 mm Hg, repositioning of the heart or increasing the MAP to maintain a cerebral perfusion pressure >50 mm Hg if the jugular venous pressure was >10 mm Hg during distal anastomoses, an increase in the pump flow to 2.5 L/m^2 per minute, an increase in the fraction of inspired O_2, initiation of pulsatile perfusion, administration of a propofol bolus (50-100 mg), and red cell transfusion if the hematocrit was <20%.

We discontinued cerebral oximetry monitoring in the OR and maintained postoperative blinding by including no study-group identifiers with the patient or in the patient's charts. Postoperatively, all patients were transferred to an autonomous, protocol-driven "closed" ICU under the exclusive care of ICU physicians without direct reference to the attending surgeons or anesthesiologists.

An independent blinded observer compiled and concomitantly registered data for the perioperative complications listed in Table 3. These variables are the same as those modeled after the Society of Thoracic Surgeons database registry [Shroyer 2003].

Table 3. Thirty-Day Postoperative Morbidity and Mortality in All Diabetic Patients*

	Control (n = 29)	Intervention (n = 28)	*P*
Myocardial infarction, n	1	1	.745
Postoperative IABP use, n	2	2	.681
New-onset stroke, n†	1	0	.508
Sternal infection, n	5	0	.028
Mediastinitis, n†	1	0	.508
Arrhythmia requiring treatment, n	1	0	.508
Reoperation for bleeding, n†	0	1	.491
Surgical reintervention, n†	1	0	.508
Renal failure requiring dialysis, n†	0	0	1.0
Death, n†	0	0	1.0
Ventilation time, min	1096 ± 1778	649 ± 313	.097
Ventilation time >24 h, n	2	0	.254
Ventilation time >48 h, n†	2	0	.254
ICU time, d	2.8 ± 4.1	1.4 ± 1.0	.045
ICU time >2 d, n	6	1	.056
ICU time >5 d, n	2	0	.254
Total no. of ICU days	80	39	
Length of stay, d	8.2 ± 6.1	5.7 ± 1.7	.036
Length of stay ≥7 d, n	8	2	.044
Length of stay ≥10 d, n	5	2	.225
Readmission to hospital within 30 d, n	4	3	.520
Patients ≥1 complication, n	13	6	.055
Patients ≥2 complications, n	7	0	.006
MOMM, n†	4	1	.187
No. of events/patients, n	34/13	9/6	

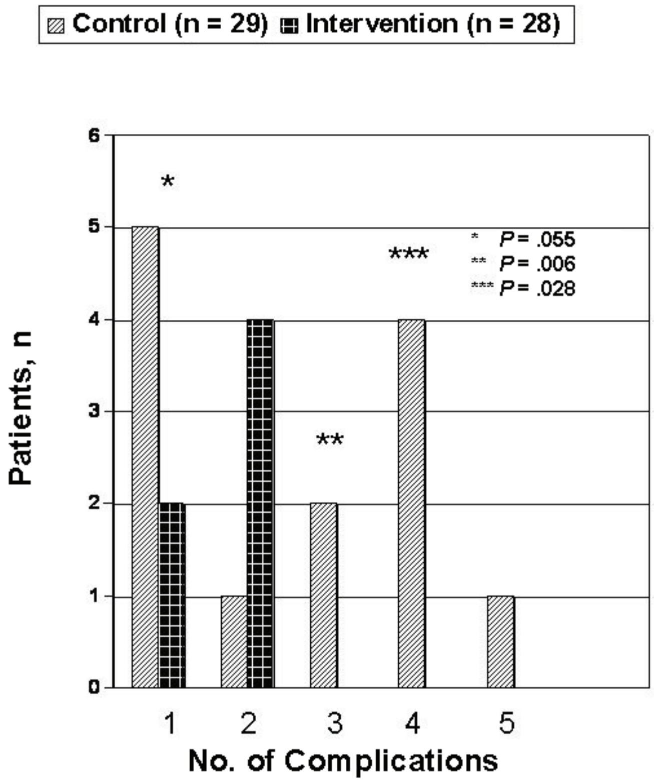
*Data are categorical or presented as the mean ± SD. IABP indicates intra-aortic balloon pump; ICU, intensive care unit; MOMM, major-organ morbidity and mortality.

†Indicates variables comprising MOMM, as derived from Society of Thoracic Surgeons database analysis [Shroyer 2003].

Statistical Analysis

All enrolled substudy patients were included in an intent-to-treat data analysis. Mean rSO_2 values, minimum rSO_2 values, the area under the curve (AUC) for rSO_2 values <75% of baseline, and the AUC for rSO_2 values less than absolute 50% were determined.

Data for categorical variables are presented as the number (percent) and analyzed with the Fisher exact test or with the chi-square and Wilcoxon rank sum tests as appropriate; effect size was determined as φ. Data for continuous variables are presented as the mean ± SD and were analyzed with the unpaired Student *t* test or by analysis of variance. *P* values <.05 were considered statistically significant, and effect size was computed as the Cohen *d* statistic. For estimating effect size,



Post hoc analysis of incidence of complications in diabetic patients in the control and intervention groups.

a Cohen d value of 0.2 to 0.3 was considered a small effect, a d value of approximately 0.5 was considered a medium effect, and a *d* value ≥0.8 was considered a large effect [Cohen 1988]. A Bonferroni correction was applied to a *P* value when multiple comparisons of the data were made. A second subanalysis was made after the patients who underwent off-pump CAB (OPCAB) surgery were removed.

RESULTS

There were no significant differences between the diabetic intervention group and the control group in demographic or morphometric characteristics (Table 1). This diabetic subset of the larger study exhibited a nonsignificant trend (P = .112) for more patients in the control group to undergo OPCAB procedures, likely because of the smaller sample size. There were also trends toward higher body mass index, worse Canadian Cardiovascular Society angina score, and worse ventricle grades in the control group, but these differences also were not statistically significant. The 2 groups showed no significant differences with respect to the number of coronary anastomoses, CPB duration, or aortic clamp time (Table 4), nor were there any differences in direct cardiovascular outcomes, including myocardial infarction or intra-aortic balloon pump (IABP) use (Table 3). There were also no significant differences between the 2 groups with respect to the clinical management of DM; preoperative, pre-CPB, CPB, post-CPB, and cumulative 24-hour postoperative plasma glucose concentrations; or intravenous insulin administration (Table 2).

The 2 groups showed major differences in the incidences of complications, with significantly more patients in the control group experiencing >2 complications (P = .006; φ = 0.37) and >3 complications (P = .028; φ = 0.31) (Figure). After correction for multiple comparisons (P = .05/4 = .01), there were still significantly more patients in the control group who had >2 complications. In addition, significantly more patients in the control group (P = .028; φ = 0.31) required antibiotic therapy for sternal wound infection (Table 3), and the control group had significantly longer ICU stays (P = .045; d = 0.58), significantly longer overall postoperative stays (P = .036; d = 0.47), and more patients with prolonged postoperative

Table 4. Intraoperative Variables and Cerebral Oximetry Parameters in Diabetes Mellitus Patients*

	Control (n = 29)	Intervention (n = 28)	*P*†
Concomitant procedures, n	2	1	.51
OPCAB, n	4	0	.112
No. of grafts	2.96 ± 0.98	3.21 ± 0.74	.29
CPB time, min	90.4 ± 37	93.2 ± 41	.791
Clamp time, min	53.4 ± 23	59.3 ± 26	.663
Hematocrit, %‡	23.6 ± 3.1	24.2 ± 2.7	.473
Hematocrit <20%, n	2	1	.513
Aprotinin use, n	19	23	.130
Packed RBCs, n	5	2	.226
Packed RBCs, units/patient	2	3	.483
Phenylephrine use, n	21	26	.616
Phenylephrine, µg	3094 ± 2355	2880 ± 2556	.768
rSO_2, %			
Baseline	66.2 ± 8.2	68.7 ± 4.3	.205
Mean	60.7 ± 7.5	68.1 ± 5.5	.204
Minimum	43.9 ± 6.6	43.9 ± 9.6	.989
rSO_2 AUC <75% baseline, %/min	98.2 ± 132.4	74.9 ± 132.3	.073
rSO_2 AUC <50%, %/min	164.2 ± 275.3	52.7 ± 96.6	.043

*Data are categorical or presented as the mean ± SD. Concomitant procedures indicates patients who underwent an additional procedure coincident with coronary revascularization; OPCAB, off-pump coronary artery bypass surgery; CPB, cardiopulmonary bypass; aprotinin, patients receiving 2 × 10^6 kallikrein inhibitor units (KIU) of aprotinin during CPB; packed RBCs, patients receiving ≥1 unit of packed red cells; phenylephrine, no. of patients administered phenylephrine while on CPB; rSO_2, regional oxygen saturation; AUC, area under the curve of cumulative rSO_2 values less than the threshold;

†*P* value indicates results of Student *t* test, Wilcoxon rank sum test, or Fisher exact test.

‡Hematocrit is mean lowest hematocrit value during CPB; hematocrit <20%, no. of patients with hematocrit values <20% during CPB.

Table 5. Thirty-Day Postoperative Morbidity and Mortality in On-Pump Diabetic Patients*

	Control (n = 25)	Intervention (n = 28)	*P*
Myocardial infarction, n	1	1	.745
Postoperative IABP use, n	2	2	.681
New-onset stroke, n†	1	0	.472
Sternal infection, n	4	0	.047
Mediastinitis, n†	1	0	.472
Arrhythmia requiring treatment, n	1	0	.472
Reoperation for bleeding, n†	0	1	.491
Surgical reintervention, n†	1	0	.472
Renal failure requiring dialysis, n†	0	0	1.0
Death, n†	0	0	1.0
Ventilation time, min	1164 ± 1911	649 ± 298	.165
Ventilation time >24 h, n	2	0	.218
Ventilation time >48 h, n†	2	0	.218
ICU time, d	2.8 ± 4.5	1.3 ± 0.52	.072
ICU stay >2 d, n	5	1	.0890
ICU stay >5 d, n	2	0	.218
Total no. of ICU days	73	39	
Length of stay, d	8.27 ± 6.4	5.7 ± 1.8	.050
Length of stay ≥7 d, n	6	2	.098
Length of stay ≥10 d, n	4	2	.420
Readmission to hospital within 30 d, n	4	3	.520
Patients ≥1 complication, n	11	6	.139
Patients ≥2 complications, n	6	0	.008
MOMM, n†	4	1	.187
No. of events/patients, n	29/11	9/6	

*Data are categorical or presented as the mean ± SD. IABP indicates intra-aortic balloon pump; ICU, intensive care unit; MOMM, major-organ morbidity and mortality.

†Indicates variables comprising MOMM, as derived from Society of Thoracic Surgeons database analysis [Shroyer 2003].

stays (>6 days) (P = .044; φ = 0.27). Consistent with these results were strong trends in the control group toward a greater overall incidence of complications (P = .055) and a longer postoperative ventilation time (P = .057). Of the 10 patients with a hospital length of stay >6 days, 8 were in the control group. Three of these patients had sternal infection, 1 had a cerebrovascular accident, and 1 had a low output requiring an IABP. One of the 2 patients in the intervention group had a low output requiring an IABP. The remaining patients in the 2 groups with prolonged stays had a variety of nonspecific factors that extended their hospitalization.

To minimize confounders associated with the nonuse of CPB, we removed the 4 patients who underwent OPCAB procedures from the cohort and reanalyzed the data (Table 5). This analysis demonstrated outcome trends similar to those of the data sets for the complete study population, with significantly higher incidences in the control group for sternal wound infections (5 versus 0; P = .047) and patients having ≥2 postoperative complications (6 versus 0; P = .008). These findings were associated with a trend in the control group for longer ICU stays (2.8 ± 4.5 days versus 1.3 ± 0.52 days; P = .072) and longer overall postoperative stays (8.27 ± 6.4 days versus 5.7 ± 1.8 days; P = .050).

The 2 groups showed no significant differences with respect to baseline, mean, and minimum rSO_2 values (Table 4), whereas the control group tended to have a greater degree of desaturation <75% of baseline (P = .073) and a significantly greater amount of profound desaturation <50% of baseline (P = .043; d = 0.55).

DISCUSSION

Cardiac surgery patients with DM tend to have a greater incidence of perioperative complications, such as wound infection and more prolonged hospitalization times, than nondiabetic patients [Bucerius 2003; Ouattara 2005; Talbot 2005]. Contributing factors include microcirculatory disturbances and impairment of cerebral autoregulation. As previously shown [Kadoi 2000] and demonstrated in the control group in the present study, unmonitored DM patients tend to have greater degrees of cerebral desaturation and a 3-fold greater amount of profound desaturation (AUC < 50%/min)—a metric that has previously been associated with profound cerebral vasospasm [Bhatia 2007] and cerebral ischemia of sufficient severity to decrease the amplitude of somatosensory evoked potentials [Cho 1998]—than patients with cerebral oximetry monitoring and an intervention protocol. A potentially important aspect of this study is thus the demonstration that use of an intervention protocol was able to significantly decrease the extent and duration of cerebral desaturation, even in this diabetic cohort. Although multiple previous studies have associated cerebral desaturation with adverse clinical outcomes [Yao 2004; Kazan 2009; Slater 2009; Vohra 2009], the ability to intervene effectively and mitigate brain desaturation has been questioned [Yao 2004; Slater 2009].

A recent study used cerebral oximetry in 265 patients undergoing primary CAB surgery and randomized to active cerebral oximetry monitoring or to a control group in which blinded monitoring was used [Slater 2009]. The investigators found a significant association between prolonged cerebral desaturation and adverse outcomes, including early cognitive decline, as well as a threefold-increased risk of a prolonged hospital stay, results that are consistent with those described here. In that study, however, the 2 groups had similar rates of cerebral desaturation (which were ascribed to poor compliance with the treatment protocol), leading to no difference between the groups in the incidence of cognitive dysfunction. To minimize the effects of noncompliance and facilitate treatment of cerebral desaturation, Denault et al [2007] recently published a physiological rationale underlying the current intervention protocol.

A potential confounder in the results of the present substudy is the trend toward higher body mass index, worse Canadian Cardiovascular Society angina score, and worse ventricle grade in the control group than in the intervention group. These factors may have combined to produce worse outcomes in the control group, although the 2 groups did not differ with respect to IABP use and the incidence of myocardial infarction and although the trend for a greater OPCAB incidence in the control group could equally have mitigated such adverse outcomes. Because OPCAB has been reported in some studies to decrease the incidence of prolonged ventilation [Lizak 2009] and has been associated with significantly shorter ICU and total hospital stays [Ivanov 2008], the trend for a higher OPCAB incidence in the control group could equally have biased against the improved outcomes observed in the intervention group.

In further support of this observation, an analysis without the patients who underwent OPCAB demonstrated a significantly higher incidence of sternal wound infection and a significantly larger number of patients having ≥2 complications in the control group than in the intervention group. This analysis also demonstrated trends for longer ICU and postoperative hospitalization stays in the control group.

The significant decrease in sternal wound infection associated with the use of cerebral oximetry is of interest and may reflect improved tissue perfusion and its attendant role in wound healing, as previously demonstrated in studies of healing of diabetic lower-extremity ulcerations [Pecoraro 1991]. What is also notable in the current study is that this decrease was not due to differences in glycemic management (Table 2).

Overall, our results demonstrating a decrease in the number of diabetic patients with multiple postoperative complications and associated reductions in ICU and overall hospital stays are further evidence of the positive impact of applied cerebral oximetry monitoring on perioperative patient outcomes. As noted in a recent meta-analysis of studies of cerebral oximetry [Vohra 2009], prolonged intraoperative cerebral desaturations are associated with adverse neurologic outcomes and prolonged hospital stays. Furthermore, interventions carried out with thoughtful use of the cerebral oximeter are associated with significant reductions in neurologic injury, major-organ morbidity and mortality, and hospital stay. Some studies have indicated decreases in ventilation times and ICU stays as well. Further randomized, prospective studies of cerebral oximetry in high-risk patient subsets are warranted.

ACKNOWLEDGMENTS

This research was supported in part by grant no. MOP37914 from the Canadian Institutes of Health Research. The authors acknowledge the support of the cardiac surgical, perfusion, respiratory technology and anesthesiology staff at University Hospital. Dr. Murkin has received lecture/travel fees from neuromonitoring companies, including Somanetics and Nonin Medical, but has no stock equity or other relevant financial interests.

REFERENCES

Bhatia R, Hampton T, Malde S, et al. 2007. The application of near-infrared oximetry to cerebral monitoring during aneurysm embolization: a comparison with intraprocedural angiography. J Neurosurg Anesthesiol 19:97-104.

Bucerius J, Gummert JF, Walther T, et al. 2003. Impact of diabetes mellitus on cardiac surgery outcome. Thorac Cardiovasc Surg 51:11-6.

Cho H, Nemoto E, Yonas H, Balzer J, Sciabassi RJ. 1998. Cerebral monitoring by means of oximetry and somatosensory evoked potentials during carotid endarterectomy. J Neurosurg 89:533-8.

Cohen J. 1988. Statistical power analysis for the behavioral sciences. 2nd ed. New York, NY: Routledge.

Denault A, Deschamps A, Murkin JM. 2007. A proposed algorithm for the intraoperative use of cerebral near-infrared spectroscopy. Semin Cardiothorac Vasc Anesth 11:274-81.

Higami T, Kozawa S, Asada T, et al. 1999. Retrograde cerebral perfusion versus selective cerebral perfusion as evaluated by cerebral oxygen saturation during aortic arch reconstruction. Ann Thorac Surg 67:1091-6.

Ivanov J, Borger MA, Tu JV, Rao V, David TE. 2008. Mid-term outcomes of off-pump versus on-pump coronary artery bypass graft surgery. Can J Cardiol 24:279-84.

Kadoi Y, Saito S, Kawahara F, Goto F, Owada R, Fujita N. 2000. Jugular venous bulb oxygen saturation in patients with preexisting diabetes mellitus or stroke during normothermic cardiopulmonary bypass. Anesthesiology 92:1324-9.

Kazan R, Bracco D, Hemmerling TM. 2009. Reduced cerebral oxygen saturation measured by absolute cerebral oximetry during thoracic surgery correlates with postoperative complications. Br J Anaesth 103:811-6.

Khan AH, Khilji SA. 2005. Neurological outcome after coronary artery bypass surgery. J Ayub Med Coll Abbottabad 17:18-21.

Last D, Alsop DC, Abduljalil AM, et al. 2007. Global and regional effects of type 2 diabetes on brain tissue volumes and cerebral vasoreactivity. Diabetes Care 30:1193-9.

Lizak MK, Nash E, Zakliczyński M, Sliwka J, Knapik P, Zembala M. 2009. Additional spirometry criteria predict postoperative complications after coronary artery bypass grafting (CABG) independently of concomitant chronic obstructive pulmonary disease: when is off-pump CABG more beneficial? Pol Arch Med Wewn 119:550-7.

Murkin JM, Adams SJ, Novick RJ, et al. 2007. Monitoring brain oxygen saturation during coronary bypass surgery: a randomized, prospective study. Anesth Analg 104:51-8.

Ouattara A, Lecomte P, Le Manach Y, et al. 2005. Poor intraoperative blood glucose control is associated with a worsened hospital outcome after cardiac surgery in diabetic patients. Anesthesiology 103:687-94.

Pecoraro RE, Ahroni JH, Boyko EJ, Stensel VL. 1991. Chronology and determinants of tissue repair in diabetic lower-extremity ulcers. Diabetes 40:1305-13.

Shroyer AL, Coombs LP, Peterson ED, et al. 2003. The Society of Thoracic Surgeons: 30-day operative mortality and morbidity risk models. Ann Thorac Surg 75:1856-64.

Singleton JR, Smith AG, Russell JW, Feldman EL. 2003. Microvascular complications of impaired glucose tolerance. Diabetes 52:2867-73.

Slater JP, Guarino T, Stack J, et al. 2009. Cerebral oxygen desaturation predicts cognitive decline and longer hospital stay after cardiac surgery. Ann Thorac Surg 87:36-44.

Talbot TR. 2005. Diabetes mellitus and cardiothoracic surgical site infections. Am J Infect Control 33:353-9.

Vohra HA, Modi A, Ohri SK. 2009. Does use of intra-operative cerebral regional oxygen saturation monitoring during cardiac surgery lead to improved clinical outcomes? Interact Cardiovasc Thorac Surg 9:318-22.

Yao FS, Tseng CC, Ho CY, Levin SK, Illner P. 2004. Cerebral oxygen desaturation is associated with early postoperative neuropsychological dysfunction in patients undergoing cardiac surgery. J Cardiothorac Vasc Anesth 18:552-8.