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Optimizing Intraoperative Cerebral Oxygen Delivery Using Noninvasive Cerebral Oximetry Decreases the Incidence of Stroke for Cardiac Surgical Patients

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ABSTRACT

Background: A recent study demonstrated that almost 75% of strokes after coronary artery revascularization surgery occur in patients classified preoperatively as low to medium risk. Thus, despite the use of risk classification, most strokes can occur when not expected. We hypothesized that optimization of cerebral oxygen delivery variables by using noninvasive cerebral oximetry could reduce the incidence of stroke.

Methods: Cerebral oximetry was used by all surgeons to monitor cerebral oxygen saturation in all cardiac surgery patients from January 1, 2002, until June 30, 2003 (n = 1034; 18 months, treatment group). Cerebral oxygen delivery was optimized during surgery by modifying oxygen delivery and consumption variables to maintain oximetry values at or near the patient's preinduction baseline. Stroke was defined according to guidelines of the Society of Thoracic Surgeons. The incidence of stroke in the treatment group was compared with that for patients who underwent cardiac surgery between July 1, 2000, and December 31, 2001, (n = 1245; 18 months, control group) before cerebral oximetry was incorporated.

Results: Age and sex distribution were similar in the 2 groups. The study group had significantly more patients in New York Heart Association (NYHA) classes III and IV than the control group, and patients in the study group were sicker overall. Despite this difference, the study group overall had fewer permanent strokes (10 [0.97%] versus 25 [2.5%]; $P < .044$). This difference remained significant when the results were controlled for NYHA class and on-pump or off-pump surgery. When the patients were examined by NYHA class, the proportion of patients requiring prolonged ventilation was significantly smaller in the study group (6.8% versus 10.6%; $P < .0014$), as was the length of hospital stay ($P < .046$).

Conclusions: The treatment group, which underwent all cardiac surgeries with optimized cerebral oxygen delivery using cerebral oximetry monitoring, demonstrated a significantly lower incidence of permanent stroke. Because our study is retrospective, a prospective randomized trial is warranted.

BACKGROUND

Stroke remains a relatively common complication of cardiac surgery. Likosky and colleagues demonstrated that almost 75% of strokes after coronary artery revascularization surgery occurred in patients classified preoperatively as low to medium risk [Likosky 2003]. Thus, despite the use of preoperative risk classification, most strokes can occur when not expected. The avoidance of perioperative stroke carries the potential benefits of improvements in cost, facility use, and patient outcome.

The etiology of perioperative stroke has been debated and remains controversial. Although acceptance of the contribution of embolic phenomena on the circulation of the brain is widespread, some investigators believe that hypoperfusion is a significant factor. We previously showed that epiaortic scanning with a modification of operative technique could significantly reduce the incidence of perioperative stroke by reducing the potential embolic load [Duda 1995]. Quality-improvement initiatives have been implemented since that time, and they have typically focused on the reduction of embolic load. Various devices, including the cell saver, arterial line filter, dispersive aortic cannula, and others, have been implemented to reduce emboli. Despite these efforts, stroke incidence in our facility has remained at a level of 2% for all cardiac surgeries and at 1.44% for coronary artery bypass grafting (CABG) only, close to the incidence reported in the Society of Thoracic Surgeons (STS Database).

Recently, cerebral oximetry monitoring has been advocated as a means of reducing periods of hypoperfusion during cardiac surgery [Edmonds 2002]. It has been shown to be beneficial during off-pump cardiac surgery as well [Novitsky 2002]. The cerebral oximeter uses near-infrared spectroscopy

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to measure the oxygen saturation of capillary blood in a small region of the frontal cortex [Kim 2000]. Changes in regional brain oxygen saturation (rSO_2) reflect changes in the balance between oxygen delivery and consumption in the brain. We hypothesized that optimization of cerebral oxygen delivery variables with noninvasive cerebral oximetry could reduce the incidence of stroke.

METHODS

All patients who underwent cardiac surgery for any reason at the Lankenau Hospital and Institute for Medical Research, Wynnewood, Pennsylvania, from July 1, 2000, to June 30, 2003, were included in a retrospective data analysis and were divided into 2 groups. The control group of patients underwent surgery during the 18 months before cerebral oximetry monitoring was introduced, between July 1, 2000, and December 31, 2001. Cerebral oximetry was introduced on January 1, 2002, and was used by all surgeons to monitor cerebral oxygen saturation until June 30, 2003 (18 months, treatment group). Operative techniques were modified in the study group to maintain cerebral oximetry values at or near the preoperative baseline throughout the surgery.

Intraoperative methods, including anesthesia and surgical techniques, were similar for the 2 groups. After January 1, 2002, cerebral oximetry was used on all patients to monitor rSO_2 bilaterally in a small region of the frontal lobe cortex (INVOS 5100; Somanetics Corporation, Troy, MI, USA). After the patient's skin was thoroughly cleaned, 2 disposable sensors were applied bilaterally to the patient's forehead and connected to the oximeter. Near-infrared light entered the forehead, and reflected and scattered light was measured by 2 detectors at 3 cm and 4 cm from the light source. The oximeter uses spatial resolution by calculating the difference between the 2 detectors corresponding to 2 depths of penetration to suppress signals from the scalp and skull that are common to both detectors [Kim 2000].

Cerebral oxygen delivery was optimized during surgery by modifying oxygen delivery and consumption variables to maintain oximetry values at or near the patient's preinduction baseline. When rSO_2 began to decline, we used a treatment algorithm that incorporated increases in cerebral oxygen delivery, reductions in cerebral oxygen consumption, or increases in blood oxygen-carrying capacity [Edmonds 2002]. Table 1 lists the interventions performed in the sequence that we used.

Demographic, preoperative, perioperative, and postoperative data were entered and maintained by the staff in a database over the study period according to STS recommendations. These data were analyzed to determine whether there were major differences in the composition or treatment of the 2 groups. Stroke was defined according to STS guidelines. The incidence of stroke in the treatment group was compared with that in the control group before cerebral oximetry was incorporated. These data were also analyzed after controlling for comorbidities and type of surgery.

Categorical variables were analyzed with the chi-square test except when an expected value was less than 5, when the Fisher exact test was used. For noncategorical variables, group means were compared by means of the Student *t* test; for nonnormal distributions, the Wilcoxon rank sum test was used. When controlling for the effects of other categorical variables, we analyzed differences in the proportions of patient groups with Cochran-Mantel-Haenszel statistics. When examining differences in continuous variables, such as length of hospital stay, in the presence of other categorical data, we used a 2-way unbalanced analysis of variance. A probability value <.05 was considered statistically significant.

RESULTS

The control and study groups were compared with regard to preoperative risk factors and morbidities as well as to type of surgery and operative parameters. As shown in Table 2, the 2 groups were dissimilar with regard to risk factors, comorbidities, and type of surgery. Although the 2 groups were similar with regard to age, sex, history of tobacco abuse, diabetes, and previous cerebral vascular accident, other factors, such as family history of coronary artery disease, hypercholesterolemia, renal failure, hypertension, chronic lung disease, and peripheral vascular disease incidence, were all significantly greater in the study group. Echoing the differences in comorbidities, the New York Heart Association (NYHA) class at admission was significantly worse in the study group than in the control group (Table 2). Most of the patients in the control group had a preoperative NYHA class of I or II, whereas most of the patients in the study group presented in

Table 1. Sequence of Interventions Used to Maintain Cerebral Oxygen Saturation at or near Preoperative Baseline*

Interventions	On-Pump	Off-Pump
1	Increase FiO_2 to 100%	Increase FiO_2 to 100%
2	Adjust head or cannula position	Adjust head or heart position
3	Increase $PaCO_2$ by reducing fresh gas flow rate	Increase $PaCO_2$ by reducing respiration rate
4	Increase mean arterial pressure	Increase mean arterial pressure
5	Increase pump flow	Increase cardiac output
6	Increase anesthetic depth	Increase anesthetic depth
7	Administer nitroglycerin to dilate cerebral vessels	Administer nitroglycerin to dilate cerebral vessels
8	Administer packed red cells if hematocrit is <23%	

*FiO_2 indicates fraction of inspired oxygen.

Table 2. Patient Demographics and Risk Factors*

	Study Group (n = 1034)	Control Group (n = 1245)	*P*
Age, y†	65.9 ± 11.44 (20-90)	66.9 ± 11.52 (17-90)	NS
Female patients, n (%)	319 (30.9)	380 (30.5)	NS
Smoking history, n (%)	591 (57.2)	719 (58.0)	NS
Family history of CAD, n (%)	600 (58.0)	642 (51.6)	<.01
Diabetes, n (%)	300 (29.0)	332 (26.7)	NS
Hypercholesterolemia, n (%)	693 (67.0)	526 (42.2)	<.0001
Renal failure, n (%)	86 (8.3)	74 (5.9)	<.035
Hypertension, n (%)	758 (73.3)	783 (62.9)	<.0001
Previous CVA, n (%)	82 (7.9)	84 (6.7)	NS
Chronic lung disease, n (%)	177 (17.1)	89 (7.1)	<.0001
Peripheral vascular disease, n (%)	195 (18.9)	131 (10.5)	<.0001
NYHA class, n (%)			<.0001
I	85 (8.2)	506 (40.6)	
II	286 (27.7)	326 (26.2)	
III	283 (27.4)	239 (19.2)	
IV	379 (36.7)	143 (11.5)	

*NS indicates not significant; CAD, coronary artery disease; CVA, cerebral vascular accident; NYHA, New York Heart Association.
†Data are presented as the mean ± SD (range).

class III or IV. Figure 1 illustrates the temporal changes in the composition of preoperative NYHA class for all patients who underwent cardiac surgery during the study period.

There was no difference in the incidence of mortality or in cause of death between the 2 groups. There was also no difference between the groups in the combined incidence of stroke and transient ischemic attack. However, the incidence of permanent stroke in the study group was less than 1%, significantly less than in the control group (2%) despite the higher NYHA class of the study group ($P < .044$). Figure 2 illustrates the reduction in the incidence of permanent stroke in the study group by preoperative NYHA class. Table 3 tabulates the incidences of stroke for all procedures, CABG only, and valve procedures. After we controlled for the proportion of off-pump surgeries and preoperative NYHA class, the reduction in stroke rate remained significant ($P < .023$). All of the reduction in stroke occurred in NYHA classes I through III, those patients with low to medium preoperative risk.

Length of hospital stay, measured from the day of surgery to discharge, was similar overall in the 2 groups but became

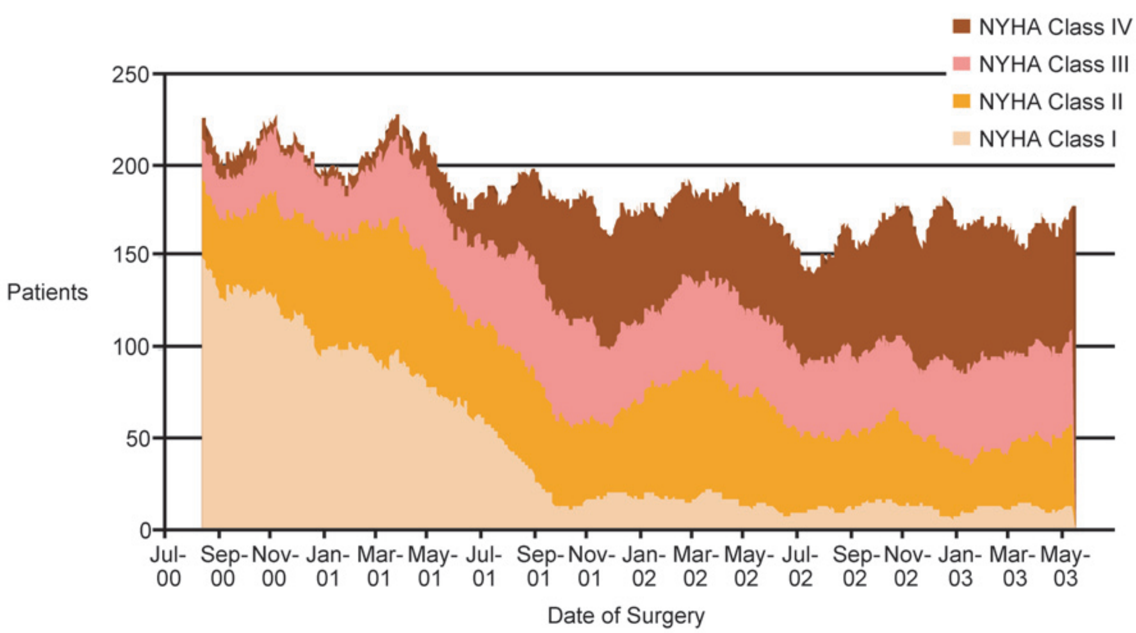

Figure 1. Changes in the proportion of admission New York Heart Association classes over time.

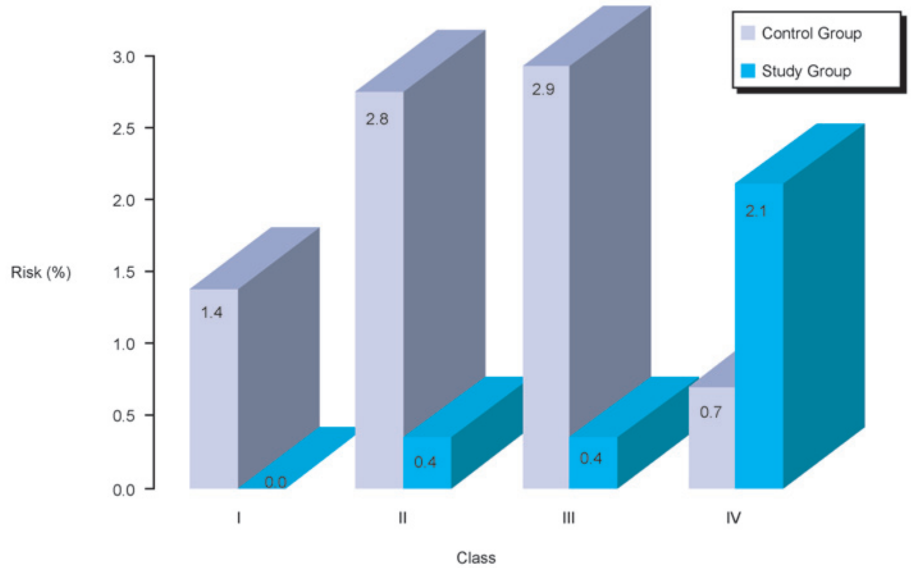

Figure 2. Incidences of permanent stroke in the control and study groups by New York Heart Association (NYHA) class. Stroke was reduced in the study group in all NYHA classes except class IV.

significantly shorter in the study group when it was analyzed by preoperative NYHA class (Figure 3). Total ventilator time was significantly shorter in the study group (median of 4 hours versus 5 hours in the control group; $P < .0016$). In addition, the proportion of patients who required prolonged ventilation was significantly smaller in the study group (6.8% versus 10.6%; $P < .0014$). This relationship remained statistically significant when it was controlled for type of surgery (on-pump versus off-pump; $P < .0112$) and preoperative NYHA class ($P < .0014$), as shown in Figure 4.

DISCUSSION

Likosky et al [2003] have shown that most strokes occur in those patients with low to moderate preoperative risk, making it difficult to reduce stroke risk simply through preoperative screening. However, the same study shows that perioperative variables such as time on cardiopulmonary bypass and prolonged use of inotropes can also contribute to the stroke risk of these patients. These data point to a combination of preoperative risk and intraoperative factors as contributing to permanent stroke risk, opening the possibility that perioperative improvements can be made.

The mean preoperative NYHA class of our patients became progressively higher over the period of the study, as shown in Figure 1. This progressive increase in morbidity is partially explained by a significant increase in the study group in the number of patients presenting after a failed previous percutaneous coronary intervention such as angioplasty or stent placement, compared with the control group. Whereas at the beginning of the study period CABG surgery was considered the primary response to coronary artery disease, CABG has progressively become more of a secondary procedure after the failure of less invasive procedures. A secondary explanation may be due to an increase in cardiac surgery programs in the area, which have tended to attract patients with less comorbidity. Even though the patients in the study group were sicker, we saw a significant decrease in the incidence of permanent stroke and prolonged ventilation.

We previously demonstrated a significant reduction in the incidence of permanent stroke by using perioperative epiaortic scanning [Duda 1995]. Although the benefit of this tech-

Table 3. Incidences of Permanent Stroke in All Surgeries and in Coronary Artery Bypass Grafting (CABG) and Valve Procedures*

	Incidence of Permanent Stroke		
	Study Group (n = 1034), % (n_0/n_T)	Control Group (n = 1245), % (n_0/n_T)	*P*
All surgeries	0.97 (10/1034)	2.01 (25/1245)	<.044
CABG	0.61 (5/825)	2.21 (23/1040)	NS
Valve	1.32 (4/303)	3.05 (10/328)	NS

*Some patients underwent a combination CABG and valve surgery. n_0 indicates number of patients with permanent stroke; n_T, total number of patients in category; NS, not significant.

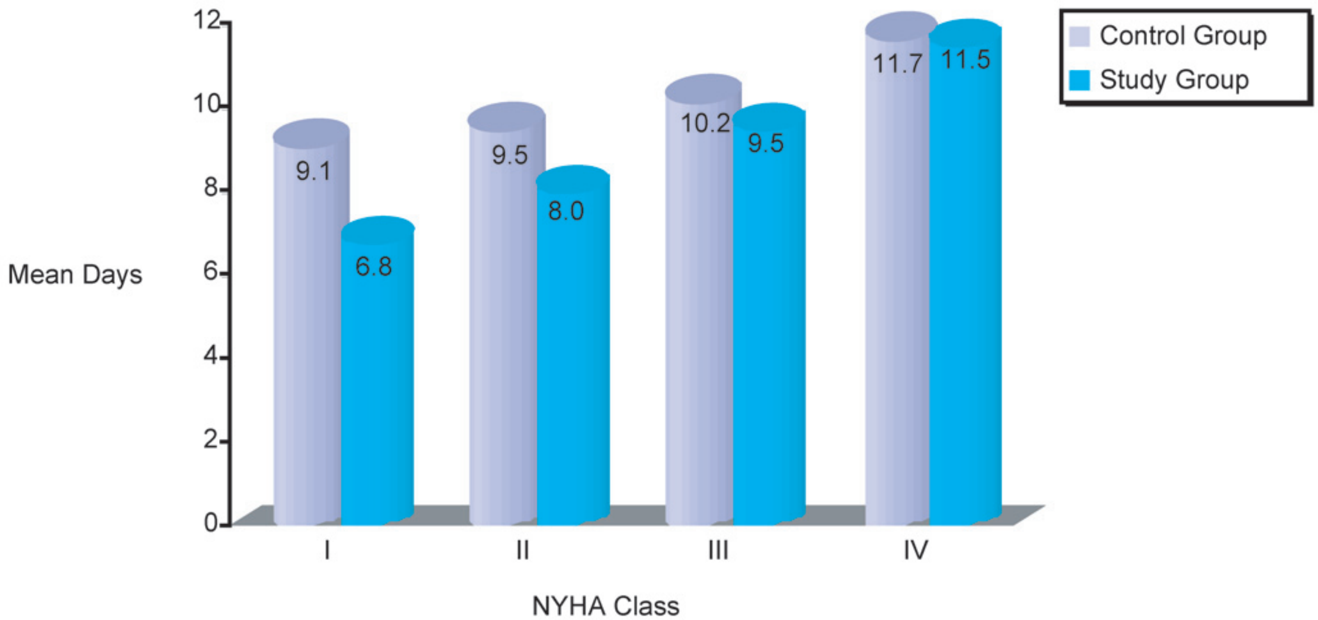

Figure 3. Length of hospital stay after surgery adjusted by preoperative New York Heart Association class.

nique was attributed to lower rates of embolism, it was not considered to be 100% effective in preventing stroke, and other factors such as the conduct of cardiopulmonary bypass, including the modification of pressure and flow rates, were implicated as causative factors.

We found that monitoring and managing cerebral oxygen delivery during all types of cardiac surgery resulted in a lowering of the overall stroke rate, even though the monitored patients were in significantly higher NYHA classes. Figure 2 shows that all of the reduction in the incidence of permanent stroke occurred in those patients with low to moderate preoperative risk, ie, NYHA classes I through III. When the data were examined by type of surgery (on-pump versus off-pump), the reduction in stroke remained statistically significant. Because cerebral oximetry measures the oxygen saturation of predominantly venous blood in the brain, it provides

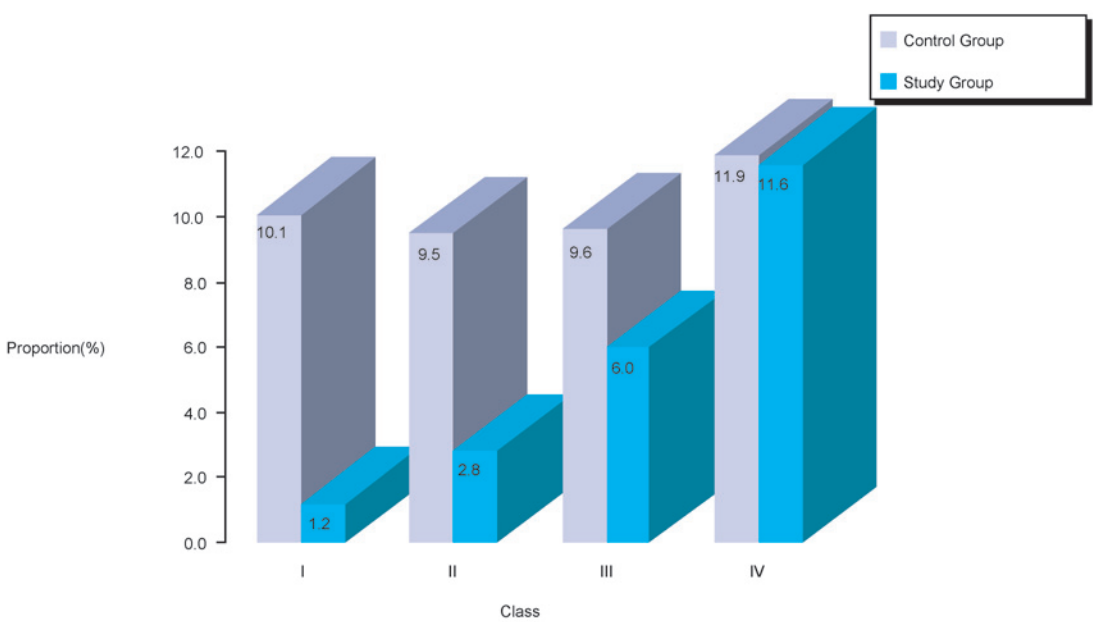

Figure 4. Proportions of patients requiring prolonged ventilation by New York Heart Association class.

an indication of the adequacy of cerebral oxygen delivery. Reductions in rSO_2 can be caused by reductions in cerebral blood flow, arterial oxygen content, or cerebral perfusion pressure. Maintaining rSO_2 values at or near preoperative levels reduced the incidence and duration of periods of hypoperfusion.

Although the use of cerebral oximetry had no effect on embolic reduction and might have negatively affected embolic delivery by maintaining higher blood flows to the brain at times, the increased perfusion may have ameliorated the negative effects of embolic delivery. Increased cerebral perfusion pressure can open collateral blood channels and thereby reduce the impact of small-vessel blockage. Recent research has shown that the risk of poor functional outcome following frank stroke increases almost 2-fold with every 10% decrease in systolic blood pressure [Oliveira-Filho 2003].

Although the incidence of permanent stroke was reduced in the study group, the incidence of all neurologic dysfunction, including stroke and transient ischemic attack, was similar in the 2 groups. This finding suggests that patient management based on cerebral oxygen monitoring may reduce the effects of a potential stroke to the level of a transient deficit. More research is warranted to better understand whether more aggressive interventions have the potential to further reduce cerebral dysfunction.

One of the weaknesses of our study is that we have no way of verifying that all patients in the study group in which cerebral oximetry monitoring had been initiated also had their rSO_2 values carefully maintained at or near preoperative levels throughout the surgery. However, perfect compliance would mean potentially better results in the study group. Furthermore, we believe that the compliance level at our facility is similar to what would be encountered in any other facility, so our results should be representative of those of other facilities. Additionally, our study was neither prospective nor randomized and therefore may suffer from statistical errors. However, the large number of patients and the increased morbidity of the study group provide some assurance that the result represents a true event. The introduction of newer surgical equipment and techniques have the potential to explain some of the outcome improvement in the study group, although we do not have knowledge of any changes in equipment or techniques that may have occurred during the study.

Others have demonstrated similar improvements in stroke rate in smaller studies. Schmahl [2000] showed a reduction in stroke rate in a high-risk group, and Yao et al [2001] demonstrated a reduced incidence of stroke overall when the cerebral oximeter was used to manage patients during cardiac surgery. Both of these studies also used a historic control group and might be subject to the same errors as our study. Murkin [2004] recently published preliminary results of a prospective randomized blinded study in which the management of patients with similar risk resulted in a significant reduction in hospital stay of 2 days, on average. Our study also shows a risk-matched reduction in the length of hospital stay of between 0.2 days and 2.3 days, depending on NYHA class (Figure 3).

CONCLUSIONS

We compared cardiac surgical patients during the 18-month periods before and after the incorporation of cerebral oximetry monitoring and management of cerebral oxygen delivery and found that the patients in the later period were sicker and had more comorbidity. Despite this fact, the study group with cerebral oximetry had a lower incidence of permanent stroke, less need for prolonged ventilation, and a shorter hospital stay. Because our study is retrospective in nature, additional research in a prospective cohort is warranted.

REFERENCES

Duda AM, Letwin LB, Sutter FP, Goldman SM. 1995. Does routine use of aortic ultrasonography decrease the stroke rate in coronary artery bypass surgery? J Vasc Surg 21:98-109.

Edmonds HL Jr. 2002. Multi-modality neurophysiologic monitoring for cardiac surgery. Heart Surg Forum 5:225-8.

Kim M, Ward D, Cartwright C, Kolano J, Chlebowski S, Henson L. 2000. Estimation of jugular venous O_2 saturation from cerebral oximetry or arterial O_2 saturation during isocapnic hypoxia. J Clin Monit Comput 16:191-9.

Likosky DS, Leavitt BJ, Marrin CAS, et al. 2003. Intra- and postoperative predictors of stroke after coronary artery bypass grafting. Ann Thorac Surg 76:428-35.

Murkin JM. 2004. Perioperative multimodality by neuromonitoring: an overview. Semin Cardiothorac Vasc Anesth 8:167-71.

Novitsky D, Bowen TE, Larson A, Powe J, Ebra G. 2002. Aiming towards complete myocardial revascularization without cardiopulmonary bypass: a systematic approach. Heart Surg Forum 5:214-20.

Oliveira-Filho J, Silva SCS, Trabuco CC, Pedreira BB, Sousa EU, Bacellar A. 2003. Detrimental effect of blood pressure reduction in the first 24 hours of acute stroke onset. Neurology 61:1047-51.

Schmahl TM. 2000. Operative changes effecting incidence of perioperative stroke (IPS) using cerebral oximetry (CO) and aortic ultrasonography (AU) [abstract]. Anesthesiology 92:A-399.

Yao FSF, Tseng C-C, Woo D, Huang SW, Levin SK. 2001. Maintaining cerebral oxygen saturation during cardiac surgery decreased neurological complications [abstract]. Anesthesiology 95:A-152.