

Applied Neuromonitoring and Improving Central Nervous System Outcomes

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Abstract: This article will review the pathogenesis of perioperative neurological injury in patients undergoing coronary revascularization. The high percentage of such patients with diabetes or concomitant cerebrovascular disease renders this population particularly susceptible to injury as a consequence of both hypoperfusion and atheroemboli. The role of transesophageal echocardi-

graphy for assessment of ascending aortic atherosclerosis and the use of noninvasive cerebral oximetry to detect cerebral hypoperfusion are discussed with respect to their impact on patient outcomes. **Key Words:** Atheroemboli—Neurological injury—Coronary revascularization—Cerebrovascular disease—Transesophageal echocardiography—Atherosclerosis.

In spite of a relative decrease in risk-adjusted perioperative mortality over the past decade (1), evidence of some degree of central nervous system (CNS) dysfunction associated with coronary artery bypass graft (CABG) surgery—with or without usage of cardiopulmonary bypass (CPB)—persists. While many patients may have clinically undetectable CNS sequelae, for a significant minority, the results can be devastating. In one large series, 6.1% of 2100 patients undergoing conventional CABG surgery evidenced clinically apparent CNS injury postoperatively (2). This was associated with a significant risk of perioperative death. Twenty-one percent of patients with type I outcomes (e.g., stroke) died while there was a mortality rate of 10% in those with type II outcomes (e.g., seizures), versus a mortality rate of 2% in those with no adverse cerebral outcome. In a longitudinal study, Newman et al. have further demonstrated that a significant number of surviving CABG patients exhibit ongoing cognitive dysfunction years after

their surgery (3). It has also been demonstrated that persistent postoperative cognitive decline may diminish improvements in quality of life associated with coronary revascularization, thus offsetting some of the physical improvements associated with surgery (4).

CEREBROVASCULAR DISEASE

In addition to procedural risks, patient-specific factors also have a fundamental impact on the likelihood of developing brain injury after CABG surgery. From preoperative studies of CABG patients, it is apparent that over 50% of patients who present for cardiac surgery have evidence of either extracranial or intracranial atherosclerotic disease (ECAD, ICAD) (5,6).

In a prospective study of 151 patients prior to CABG surgery, carotid and intracranial arteries were examined for occlusive lesions with magnetic resonance angiography (5). Cervical carotid artery stenoses of more than 50% narrowing were detected in 16.6% of the subjects, and intracranial artery stenoses of more than 50% narrowing were detected in 21.2% of the subjects (5). In a similar study of 201 patients presenting for CABG surgery, over 50% of patients had evidence of either ECAD or ICAD, while 13% of patients had evidence of both (6). In this series, 25.4% of patients had single or multiple

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postoperative CNS complications, and ICAD was found to have a strong independent association with the development of CNS complications. The presence of both ECAD and ICAD was even more strongly associated with adverse CNS outcomes than was ICAD alone (6).

It has been estimated that in patients with significant carotid stenoses, only about 40% of postoperative strokes (at most) can be directly attributable to ipsilateral carotid artery disease and, as such, there is no compelling evidence that concomitant carotid endarterectomy will reduce risk of stroke in such patients undergoing CABG (7). As will be discussed, intracerebral and aortic atheromatous disease may well be of equal or greater significance than carotid stenosis in the context of perioperative stroke.

Cerebral autoregulation has been shown to be impaired in patients with cerebrovascular disease. Studies of diabetic patients undergoing CPB have also demonstrated impaired cerebral autoregulation and depressed CO₂ responsiveness among this group, which in most areas comprise one-third or more of all patients presenting for coronary revascularization (8). Accordingly, mechanisms other than carotid stenosis including aortic atheroemboli and unrecognized cerebral hypoperfusion also have an important role in the genesis of perioperative cerebral injury. Perioperative monitoring strategies should thus be designed to detect and minimize cerebral hypoperfusion and atheroemboli.

ASSESSMENT OF AORTIC ATHEROSCLEROSIS

It is well established that palpation of the aorta is insensitive for detection of noncalcific plaque in the ascending aorta (9,10), with between 23.5 and 62% of all significant aortic atheroma being undetected (11,12). The use of epiaortic scanning (EAS) provides accurate images of the aortic wall and lumen, and allows for optimization of cannulation and clamp sites with a decrease in atheroembolic load and risk of stroke (13,14). In a study of 102 patients in whom EAS was performed directly after conventional aortic assessment by surgical palpation, in 23.5% of these patients aortic scanning resulted in a change in surgical management of aortic instrumentation by relocation of clamp or cannulation sites (11). This was also associated with a significantly lower incidence of cerebral emboli associated with cannulation and release of aortic cross clamp and partial clamp (15).

EAS AND MODIFICATIONS OF SURGICAL TECHNIQUE

In a large study, EAS of the ascending aorta was performed in 500 patients of mean age 68 years who underwent a variety of cardiac surgical procedures (12). Sixty-eight patients (13.6% of the total) with a mean age of 72 years (range 55–85 years) had significant atheromatous disease in the ascending aorta and were considered to be at increased risk for embolization. Palpation identified atheromatous disease in only 26 (38%) of these patients and underestimated its severity. A total of 168 modifications to the standard techniques for cannulation and clamping of the aorta were implemented in the 68 patients (mean 2.5 per patient) and included alterations in the sites of aortic cannulation (50 patients), aortic clamping (54 patients), attachment of the vein grafts (35 patients), and cannulation for infusion of cardioplegic solution (29 patients). Ten patients with severe diffuse atheromatous disease underwent graft replacement of the ascending aorta with hypothermic circulatory arrest without aortic clamping. Permanent neurologic deficits occurred in five (1.0%) of the patients in the entire group but in none of the 68 patients with significant atheromatous disease in whom modifications in technique were used (12). Others have similarly reported on the utility of EAS and reviewed various other surgical strategies to manage the atherosclerotic aorta (16).

Instrumentation of an atheromatous ascending aortic plaque has also been identified as pathogenic in the development of aortic intimal disruptions (17). Using intraoperative pre- and postcannulation transesophageal echocardiography (TEE) examination of ascending aorta in 472 patients, an association was demonstrated between new lesions created by surgical maneuvers and postoperative stroke (17). Embolic strokes were more likely to occur if new lesions were complicated with intimal disruption, especially of the mobile type. They recommended that modifications in surgical procedures will be needed if thick plaque (especially >4 mm) is noted near the manipulation site—identification that can only be made intraoperatively by use of TEE or EAS. Parenthetically, such aortic intimal disruptions with subsequent thrombus formation and later cerebral embolization may well be the pathogenesis in those patients in whom, after having made an initially uneventful recovery from surgery, CNS injury or overt stroke presents after a “lucid interval” of several days.

Intraoperative assessment of ascending aorta using TEE and/or EAS is thus one important step in

the detection of otherwise nonpalpable plaque and is recommended as one of several important management strategies to decrease perioperative CNS injury (18,19).

CEREBRAL HYPOPERFUSION

Given the high incidence of occult or overt cerebrovascular disease in adult patients presenting for cardiac surgery (5,6), unrecognized ischemic cerebral hypoperfusion can be implicated in a significant number of perioperative CNS events. Gold et al. have reported a lower incidence of morbidity, including stroke, in patients undergoing conventional CABG in whom mean arterial pressure (MAP) was maintained greater than 80 mm Hg (20). This may imply a requirement for higher MAP to better optimize collateral cerebral perfusion during CPB, but cerebral venous hypertension from superior vena caval (SVC) obstruction may be another unrecognized yet equally injurious contributor to cerebral hypoperfusion. In a clinical study of adult patients undergoing CPB, transcranial Doppler was used to measure cerebral blood flow velocity (CBFV) as an index of CBF during dislocation of the heart for distal revascularization (21). An inverse correlation was demonstrated between SVC pressure and CBFV, despite unchanged MAP. This study graphically illustrated that cerebral perfusion pressure (CPP) is the difference between inflow (or MAP) and outflow (or SVC) pressures such that CPP can be significantly decreased not only by lowered MAP but also by increased SVC pressure, a phenomenon that is not always clinically apparent. Interestingly, the original report of intraoperative SVC occlusion was made over 40 years ago in the context of applied intraoperative electroencephalographic (EEG) monitoring (22).

It has been shown experimentally that cerebral oximetry monitoring using noninvasive transcutaneous near infrared spectroscopy (NIRS—see below) can detect such elevated cerebral venous outflow pressures and that such SVC cannula obstruction causes clinically silent cerebral ischemia with no change in blood pressure or mixed venous oxygen saturation (23).

OFF-PUMP CORONARY ARTERY BYPASS (OPCAB) SURGERY

Cerebral hypoperfusion may be implicated in CNS injury after OPCAB as well. The surprising lack of difference in the incidence of cognitive injury after OPCAB versus conventional CABG surgery—despite an exponential decrease in numbers of cerebral emboli detected—suggests that other mecha-

nisms independent of cerebral microemboli are at work (24). The recent demonstration that there was nearly double the incidence of profound cerebral venous desaturations in OPCAB patients during dislocation of the heart for revascularization in comparison to those undergoing CABG is suggestive that occult cerebral hypoperfusion may underlie a significant number of otherwise inexplicable perioperative CNS events, especially in a patient population with such a high incidence of concomitant cerebrovascular disease (25). Intraoperative cerebral monitoring can be employed to detect and ameliorate such otherwise silent ischemic events.

NIRS/CEREBRAL OXIMETRY

One of the most well-studied NIRS devices (INVOS Somanetics, Flint, MI, USA) employs two-channel monitoring using adhesive pads placed on the forehead over frontal eminences and containing one transmitting and two separately spaced receiving optodes, allowing measurement of oxygenated and deoxygenated hemoglobin in brain tissue. Differential spacing of the two receiving optodes enables correction for extracerebral tissues to be made, allowing an assessment of regional oxygen saturation (rSO_2) of cerebral tissue comprised of venous, capillary, and arterial blood. This device enables indices of cerebral oxygenation to be determined in a continuous manner in a variety of clinical circumstances, although a potential limitation is the fact that the cerebral sample volumes are on the order of 1 cc of tissue, thus rendering them highly localized in nature. It is also apparent that because it measures total tissue oxygenation, various factors including patient age, hemoglobin concentration at the measurement site, and sensor location can affect rSO_2 values (26). Recent studies in patients undergoing coiling of cerebral aneurysms has demonstrated a correspondence between changes in rSO_2 and onset of cerebral vasospasm as demonstrated in a series of 32 patients in whom episodes of angiographic spasm were strongly associated with reduction in trend ipsilateral NIRS signal; furthermore, the degree of spasm (especially more than 75% vessel diameter reduction) was associated with a greater reduction in same-side NIRS signal (27). This study provides further evidence of the validity of noninvasive transcutaneous cerebral oximetry to provide real-time information on the status of cerebral oxygenation and perfusion.

INTRAOPERATIVE CEREBRAL OXIMETRY

Previous studies have indicated a positive predictive value between low rSO_2 and adverse CNS

outcomes (28). The use of cerebral oximetry identifies a number of otherwise unrecognized causes of cerebral hypoperfusion both during conventional CPB (29) and during beating heart surgery (30). Various causes of cerebral hypoperfusion, including inadvertent positioning of the head turned to extreme left side, SVC cannula-obstructed venous outflow from brain, hypocapnia, low perfusion pressure, inadequate hemoglobin concentration, have all been detected and successfully treated by applied cerebral oximetry (31,32). Even during beating heart procedures, compromised cerebral perfusion can occur relatively frequently. Combined EEG and cerebral oximetry identified episodes of cerebral ischemia in 15% of a series of 550 beating heart patients; all were treated successfully by a combination of pharmacologically improved cardiac output, increased perfusion pressure, and cardiac repositioning (30). Murkin et al. have recently published results of a prospective, randomized, blinded study in 200 CABG patients demonstrating a significant reduction in major organ morbidity in patients with active rSO₂ monitoring (33). In addition, a decrease in intensive care unit length of stay of 60 days was seen in the NIRS monitored group compared with control patients (34).

Consistent with this result, in a large nonrandomized series of 1698 cardiac surgical patients reported by Goldman et al., a significant reduction in perioperative stroke rate, from 2.01% to 0.97%, was observed in patients in whom rSO₂ cerebral oximetry was used to optimize and maintain intraoperative cerebral oxygenation in comparison to an untreated comparator group of 2077 similar patients operated on in the immediately preceding 18-month interval (35).

SUMMARY

Perioperative CNS injury is multifactorial in nature involving both atheroemboli and hypoperfusion in a population predisposed to occult or overt cerebrovascular disease. Strategies to minimize perioperative CNS injury should accordingly be aimed at both decreasing the potential for aortic atheroemboli, primarily through TEE or EAS-guided assessment of ascending aorta and aortic arch prior to instrumentation, and employment of techniques designed to detect otherwise clinically silent episodes of cerebral hypoperfusion via cerebral oximetry monitoring. In addition, best clinical practice should utilize various other supportive measures, including avoidance of hyperglycemia, alpha-stat pH management, use of arterial line filtration, avoid-

ance of excessive hemodilution, and use of anti-inflammatory measures, all of which can be advocated as evidence-based recommendations for optimal management of patients undergoing coronary revascularization surgery (18).

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