

Cerebral Emboli During Cardiopulmonary Bypass: Effect of Perfusionist Interventions and Aortic Cannulas

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Presented at Perfusion Innovations in Cardiac Surgery Outcomes 2000—The Key West Meeting, May 2000, Key West, Florida

Abstract: Neuropsychological impairment is a very common complication of cardiopulmonary bypass (CPB). The principal cause of postoperative cognitive impairment is thought to be cerebral microemboli during CPB. We recently investigated the effects of perfusionist interventions and aortic cannulation techniques on cerebral emboli production during coronary bypass (CABG) surgery. Patients undergoing isolated CABG were monitored with continuous transcranial Doppler ultrasonography of the middle cerebral artery. Perfusionist interventions were defined as injections of drugs into the CPB circuit or acquisition of blood samples from the CPB circuit. Patients were randomized to receive either standard cannulation of the ascending aorta or cannulation of the distal aortic arch. Cerebral emboli were detected in all patients. The number of emboli per minute

was markedly higher during perfusionist interventions than during other time periods. Patients with increased perfusionist interventions had worse neuropsychological outcomes. Cannulation of the distal aortic arch, with placement of the cannula tip beyond the cerebral vessels, resulted in significantly less cerebral emboli than cannulation of the ascending aorta. Perfusionist interventions are a common source of cerebral microemboli during CPB, and may contribute to postoperative neuropsychological impairment. Care should be taken to minimize the introduction of air into the bypass circuit during CPB. Provided it is performed safely, distal aortic arch cannulation is a useful technique for reducing cerebral emboli during cardiac surgery. **Keywords:** cerebral emboli, neurologic complications, cardiopulmonary bypass, coronary bypass. *JECT. 2002;34:29–33*

It has been long recognized that neurological complications are a significant cause of morbidity and mortality in cardiac surgery (1). Such complications range from subtle neuropsychological deficits to overt stroke and brain death. Cardiopulmonary bypass (CPB) is thought to be a significant contributor to these complications (2–7). CPB may cause cerebral injury by: (i) macroembolization—atherosclerotic emboli from manipulation of the ascending aorta; (ii) microembolization—gaseous and particulate emboli from the CPB circuit; or (iii) hypoperfusion—inadequate cerebral blood flow secondary to carotid stenosis / occlusion, or low cardiac output pre- or post-CPB.

The prevalence of severe neurologic injury is low in coronary artery bypass grafting (CABG) patients, with the majority of studies quoting a perioperative stroke rate of 1.5% to 3% (8, 9). Atherosclerotic macroemboli from the ascending aorta are generally regarded as the major cause of stroke during coronary bypass surgery (8–10), even in

patients with concomitant carotid stenosis (11). The risk of stroke is higher in patients undergoing valvular surgery, with an incidence of 3% to 6% (12, 13). Stroke during valvular procedures probably involves several different etiologies including septic emboli, cardiogenic shock, and atherosclerotic emboli (12).

In contrast to the low incidence of stroke post-cardiac surgery, a large proportion of patients develop cognitive impairment. The incidence of neuropsychological impairment is approximately 50% to 70% one week postoperatively, and 30% to 40% three months postoperatively (3, 4, 6, 7, 14). Postoperative cognitive dysfunction is clinically important because most patients are aware of their deficits, often affecting their daily activities (15, 16).

CEREBRAL MICROEMBOLI AND COGNITIVE IMPAIRMENT

The predominant etiology of postoperative cognitive dysfunction is thought to be diffuse cerebral microischemia from microemboli during cardiopulmonary bypass. Cerebral microemboli have been described in virtually 100% of patients undergoing CPB, being detected by

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Received December 10, 2001; accepted January 15, 2002.

transcranial Doppler ultrasonography (TCD) (17–19), retinal fluorescein angiography (20, 21), and postmortem histology (22). Moody et al. used alkaline phosphatase histochemical staining to study the cerebral microvasculature in 29 patients who died shortly after CPB (23). These investigators described small capillary and arteriolar dilations (SCADs) throughout the brain and upper spinal cord in all patients, with a negative correlation between number of SCADs and time since operation. The SCADs are thought to represent “footprints” of previous emboli. Barbut et al. have demonstrated cerebral microemboli by TCD in 82 of 82 CABG patients (24). Similarly, we have recently used intraoperative TCD to detect microemboli during CPB in 34 of 34 CABG patients studied, with a range of 17 to 627 emboli per patient (25).

Several investigators have demonstrated an association between cerebral microemboli and neuropsychological impairment. Hammon et al. assessed 395 CABG patients and demonstrated that 100 or more cerebral emboli is an important predictor of cognitive dysfunction (26). Pugsley and colleagues found 43% of patients with more than 1,000 emboli had neuropsychological impairment eight weeks postoperatively, compared to only 9% of patients with less than 200 emboli (27). Sylvris et al. recently demonstrated a higher mean embolic rate (number of cerebral emboli per minute of CPB) in patients with cognitive impairment compared to those without impairment (28).

Other factors, in addition to microemboli, may be involved in the etiology of cognitive dysfunction post-CPB. A systemic inflammatory response has been well described during CPB and may be involved in postoperative neurologic dysfunction (29, 30). Intracerebral shunts during CPB, with resultant mismatch of tissue oxygen supply and demand, have been implicated in cerebral injury (31, 32). Hyperglycemia may also worsen neurologic outcome post-CPB (33).

PERFUSIONIST INTERVENTIONS AND CEREBRAL MICROEMBOLI

The exact composition of cerebral microemboli during CPB is not known, but possible constituents include air, fat, atherosclerotic debris, and CPB tubing (10, 28, 34). Several previous studies (35–38) have identified a correlation between “surgical interventions” (eg., cannulation or crossclamping of the ascending aorta) and microemboli production, suggesting that these emboli are particulate in nature. Each of these studies, however, had a large proportion of emboli during CPB that were unexplained. We recently hypothesized that these unexplained emboli were related to perfusionist interventions, defined as the injection of drugs or blood into the venous reservoir (18).

Our study consisted of patients undergoing isolated, nonemergent coronary bypass surgery. Patients were ex-

cluded if they had a history of neurologic disease, carotid stenosis, or atherosclerosis of the ascending aorta. Cardiopulmonary bypass (CPB) was established with arterial inflow through either the ascending aorta or the aortic arch and venous drainage via a single two-stage right atrial cannula. Our CPB circuit consisted of a collapsible soft-shell venous reservoir, a hollow-fibre membrane oxygenator and nonpulsatile roller pumps. A 32- μ m filter was used in the arterial perfusion line in all patients. Perfusionists administered drugs into the bypass circuit using a manifold directly connected to the bottom of the soft-shell venous reservoir, directly adjacent to where the venous line enters the reservoir.

Using transcranial Doppler, we continuously monitored the middle cerebral artery during the entire operative procedure. Automated software and manual off-line analysis were used to discriminate between emboli and artifact. We calculated the mean embolic rate for three time periods: 1) during surgical interventions; 2) during perfusionist interventions; and 3) during baseline. Surgical interventions were defined as the two-minute time period following aortic cannulation/decannulation, crossclamp application/removal, CPB start/end, and start of cardiac ejection. Perfusionist interventions were defined as the two-minute time period following acquisition of blood samples and administration of drugs into a manifold directly attached to the soft-shell venous reservoir. Baseline was defined as all other time periods during cardiopulmonary bypass.

Our study revealed that the number of emboli per minute was significantly ($p < 0.001$) higher during perfusionist interventions (6.9 ± 4.5 emboli/min, mean \pm SD) than during surgical interventions (1.5 ± 1.5) or during baseline (0.4 ± 0.5). Approximately 75% of all emboli during CPB were directly associated with perfusionist interventions, a result that was consistent amongst all perfusionists who participated in the study. Drug injections resulted in more cerebral emboli production than blood sample acquisitions. We noted that careful deairing of the syringe prior to the injection of drugs led to a marked decrease in the number of detected emboli.

Two important conclusions can be made from our findings. First, our results suggest that the majority of microemboli that occur during cardiopulmonary bypass consist of air. Small bubbles of air within the syringe are injected into the soft-shell venous reservoir via the manifold, thus entering the reservoir at the same point of entry as the CPB venous line. These bubbles are then transported to the oxygenator before they are able to rise to the top of the collapsible venous reservoir. Acquisition of blood samples results in embolus production because of the practice of injecting blood into the venous reservoir, to clear the manifold of stagnant blood, prior to acquiring the sample. Indeed, we observed that when the perfusionists discarded the stagnant blood rather than injecting it, em-

boli did not occur. We recommend careful deairing of the syringe before drug administration, as well as discarding stagnant blood before sampling, in order to decrease the number of cerebral microemboli during CPB. Although gaseous microemboli may not cause as much cerebral injury as atherosclerotic emboli, we believe that the minimization of emboli of any type is important.

The second important observation from our study is that gaseous emboli are able to traverse the arterial filter. We used a 32 μm filter in the arterial line for all patients, and yet air was able to be transported from the venous reservoir to the aorta. On two separate occasions, we observed a massive number of cerebral microemboli occurring without obvious cause. Shortly thereafter, the surgeon realized that the venous line was sucking air from the right atrium. When the venous cannula was repositioned, the microemboli immediately stopped. The method by which air traverses the arterial filter is not entirely clear, but may involve distortion of the bubbles into a "sausage" shape in order to fit through the pores, or by coalescence of fragmented bubbles distal to the filter. Although arterial filters have been demonstrated to reduce the number of cerebral emboli and their use is standard, it is obvious that these devices do not remove all emboli.

It should be noted that our findings may be specific to our CPB circuit, in particular to the collapsible soft-shell venous reservoir. The hard-shell reservoir is more commonly used in North American cardiac surgical centers. However, an important study by Mitchell et al revealed that cerebral embolization also occurs with hard-shell venous reservoirs (39), and that the number of emboli increases exponentially when the venous reservoir level falls below 700 mL. Further studies are required to determine if our findings are generalizable to other types of venous reservoirs and CPB circuits. Until the results of these studies are known, however, we feel it is reasonable to suggest the minimization of air in any venous reservoir in order to decrease the risk of cerebral embolization.

PERFUSIONIST INTERVENTIONS AND NEUROPSYCHOLOGICAL IMPAIRMENT

To determine if there is an association between perfusionist interventions and postoperative cognitive deficits, we examined a subset of CABG patients who underwent detailed neuropsychological testing. A battery of neuropsychological tests was administered preoperatively, one week postoperatively, and three months postoperatively. Our test battery assessed the cognitive domains of learning and memory (RAVLT, RVDLT), psychomotor skills (Grooved Pegboard, Trail Making A and B), attention and concentration (Mental Control, Digit Span, Visual Span), language (Verbal Fluency, SCOLP), and higher intellectual functioning (AMNART). Patients were consid-

ered to have neuropsychological impairment if they had a 20% decrease in scores (from preoperative testing) on 20% or more of the tests (40).

We divided patients into two groups according to the median number of perfusionist interventions during CPB. Patients with more than 10 perfusionist interventions tended to have a higher prevalence of postoperative cognitive impairment when compared to patients who had 10 or less interventions (80% versus 64% one week postoperatively; 42% versus 30% three months postoperatively). Patients with more perfusionist interventions also had lower group mean scores, i.e., more cognitive impairment, on 9 of the 10 neuropsychological tests. We can conclude from this data that there is an association between the number of perfusionist interventions and postoperative neuropsychological deficits. However, it should be noted that patients with more perfusionist interventions have longer CPB times, and that this may be partially responsible for the increase in cognitive impairment.

AORTIC ARCH CANNULATION VERSUS ASCENDING AORTA CANNULATION: A RANDOMIZED TRIAL

We recently performed a randomized clinical trial of different arterial cannulation techniques (25). We hypothesized that cannulation of the distal aortic arch, with placement of the cannula tip beyond the cerebral vessels, would result in less cerebral micro-embolization than cannulation of the ascending aorta.

Patients were randomized to conventional cannulation of the ascending aorta with a 24 French standard arterial cannula or to cannulation of the distal aortic arch with a 24 French flexible aortic arch cannula. Both cannulas had a single distal aperture for the exit of blood. Trendelenberg positioning of the patient was employed whenever possible. We found significantly less cerebral emboli in the arch cannulation group (152 ± 33 , mean \pm SEM) than in the conventional cannulation group (249 ± 35 , $p = 0.04$). Embolization rates were lower in distal arch patients than control patients during CPB (2.0 ± 0.3 versus 4.2 ± 0.9 per minute respectively, $p = 0.03$). Reduction in cerebral emboli by distal arch cannulation was most pronounced during perfusionist interventions, when emboli probably consisted of air.

We concluded from our study that cannulation of the distal aortic arch is an important surgical technique for the reduction of cerebral emboli during cardiac surgery. Distal arch cannulation may be most effective when performed in patients with diffuse atherosclerosis of the ascending aorta, in order to limit embolization of particulate debris. Although atherosclerosis of the aortic arch is more common than atherosclerosis of the ascending aorta, the disease process is often localized to the superior portion of

the arch (41). It is sometimes possible, therefore, to find a disease-free segment of the inferior aortic arch in patients with diffuse atherosclerosis of the ascending aorta. Furthermore, use of a long, straight arterial cannula, as used in the arch cannulation group, is associated with lower peak aortic flow velocities than conventional short, right-angled cannulas (42). A decrease in flow velocity may result in decreased embolization from an atherosclerotic aortic wall (known as the "sandblast effect").

Before concluding that arch cannulation should be performed in all cardiac surgery patients, however, it should be noted that this procedure is more technically challenging than standard cannulation of the ascending aorta. The posterior position of the aortic arch requires that the surgeon must perform the cannulation "in a hole". Although we have safely performed this procedure in a large number of patients, it may theoretically increase the risk of an aortic dissection during cannulation.

SUMMARY

In conclusion, perfusionist interventions are an important source of cerebral microemboli during CPB. The vast majority of emboli probably consist of air that is not removed by the arterial filter. Perfusionist interventions may also be an important cause of postoperative cognitive impairment. We suggest avoidance of injecting air into the venous reservoir, in particular during drug injections, to decrease cerebral injury associated with cardiopulmonary bypass. Distal arch cannulation may be an important technique for the reduction of cerebral embolization during CPB. Provided it is performed safely, arch cannulation may be the procedure of choice in patients with severe atherosclerosis of the ascending aorta.

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