Risk factors for stroke in cardiac surgery patients

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Key words: cardiac surgery, complications, cerebral injury, stroke, risk factors.

Summary. The modern reparative procedures are highly successful in terms of the cardiac outcome; they can be detrimental in regard to the central nervous system (CNS). Perioperative stroke is one of the most serious complications of cardiac surgery. Refinements and advances in surgical techniques, myocardial preservation and anesthesia have led to a decline in morbidity and mortality for cardiac surgical patients. Adverse cerebral outcomes, however, are increasing, largely because of a trebling of deaths caused by neurologic injury.

Complications involving the brain are increasing substantially because older patients with advanced atherosclerotic vascular disease now have surgery, suggesting that advances in surgical and anesthetic techniques proven to provide better myocardial protection have not had an impact on reducing the incidence of ischemic brain injury. Careful preoperative evaluation process must be undertaken to identify patients who are at the highest risk of having perioperative stroke.

This article provides a concise summary of a very important problem in contemporary cardiac surgery. The authors have concentrated on review of the predictive factors for perioperative stroke, identified by multivariate analysis in the recent studies. These factors taken together can identify patients, who are at high risk for perioperative focal cerebral ischaemic injury. Recognition of the high-risk group will facilitate prevention of stroke by modification of surgical procedures or pharmacologic intervention. Prevention is the most effective way of managing neurologic disorders.

Introduction

More than 800,000 patients a year throughout the world undergo myocardial revascularization procedures (1). Complications involving the brain account for the major adverse sequelae after cardiac surgery operations. Refinements and advances in surgical techniques, myocardial preservation and anesthesia during the past 2 decades have led to a decline in morbidity and mortality for cardiac surgical patients. Adverse cerebral outcomes, however, are increasing, largely because of a trebling of deaths caused by neurologic injury. As many as 6.1% of patients having heart surgery suffer the perioperative stroke (1,3). Neuropsychological impairment occurs more often, affecting up to 80% of patients soon after surgery. Cognitive abnormalities have been shown to persist in 17-35% in the long-term follow-up (3,4). The great variability in the incidence of postoperative neuropsychologic dysfunction is associated with the neuropsychologic tests used, the severity of the abnormalities considered significant, and the timing of the testing.

High incidence of postoperative neuropsychological dysfunction suggests that advances in surgical and anesthetic techniques proven to provide better myocardial protection have not had an impact on reducing the incidence of brain injury. Careful preoperative evaluation process must be undertaken to identify patients who are at the highest risk of having perioperative stroke.

Classification of the brain complications

Central nervous system complications have been divided into three different clinical syndromes:
stroke, neuropsychological impairment, and encephalopathy. Patients with focal (motor, sensory, or visual) neurologic signs are classified as having strokes. Other patients who have no obvious motor, sensory, or visual complaints but who show abnormalities in their thought processes and behavior are categorized as having neuropsychological complications. Patients who are obtunded, sleepy, or delirious are categorized as having encephalopathy. These three syndromes overlap, and all probably share causative mechanisms.

The authors have concentrated on review of the predictive factors for perioperative stroke, identified by multivariate analysis in the recent studies.

**Stroke rate after cardiac surgery**

Stroke occurs after coronary artery bypass grafting with the reported incidence ranging between 1.2% and 6.1% (1,5-10). The majority of studies, which investigated perioperative stroke, have been performed only at one center, have enrolled a limited number of patients, or have been retrospective (all of which has resulted in substantial variability among findings). Among the studies there is a more than 10-fold variation in the reported incidence of perioperative stroke (1).

There is no significant difference in neurological outcomes between patients undergoing valve and coronary operations (11-13). Combined procedures (intracardiac surgery combined with coronary revascularisation) however, are associated with substantially more cerebral injury than coronary artery bypass grafting (CABG) alone, indicating a 2.5-fold increase in the incidence of adverse neurological outcomes (14,15).

The risk of neurological injury in cardiovascular surgery reaches its apex during reconstruction of the aorta. In this procedure, the potentially damaging factors are numerous, and they act concomitantly: interruption of cerebral blood flow, advanced age, presence of hypertensive and atherosclerotic vasculopathy. Risk is further compounded by the fact that these operations are commonly performed in emergency situations and when neurologic impairment has already occurred.

**Radiologic features of strokes**

Many strokes are noted after the patient has awakened from anesthetic sedation, but an important number also develop later during the first few days. From neuroimaging data, infarcts are multiple in 65% of patients (2). In patients who have intraoperative stroke, the cerebellar hemispheres are almost always affected. These infarcts are typically small and numerous, giving the cerebellum a “salt-and-pepper” appearance. The occipital lobes (territory of the posterior cerebral arteries), and the territories that lie between the middle cerebral arteries and posterior cerebral arteries also are involved in a majority of cases. Multiple small infarcts are frequently present in the territory of the middle cerebral artery branches but almost never in the anterior cerebral artery territory (Table 1).

Border-zone infarcts have most often been attributed to hypoperfusion. However, microemboli also seem to come to rest in these regions (2).

In one third of patients, infarcts are single and involve generally the territory of the middle cerebral arteries. These infarcts within the heart of vascular territory are often referred to as territorial infarcts.

The multiplicity of lesions in a majority of patients and the predominance of infarcts in recipient sites for emboli suggest that embolisation is the most important causative mechanism. Given that only one fifth of cerebral blood flow goes through the posterior circulation, the reason for preferential localisation of infarcts within the vertebrobasilar arterial supply is unclear. The predilection of emboli for the posterior circulation also has been noted in patients who have neurologic complications during cardiac catheterization and in patients with paradoxic embolism through patent foramen ovale.

In a recent study (17) a strong preponderance of left hemispheric strokes in coronary artery bypass surgery by a ratio of 3:1 was noted. If aortic clamping, cannulation, or manipulation were responsible for most strokes, then right-sided strokes should predominate, as the innominate artery is closest to the source of such emboli. In contrast, end-hole aortic cannulas direct a high-velocity jet at the left carotid orifice and may be responsible for a large proportion of perioperative strokes. That the jet from end-hole aortic cannulas is directed at both the left carotid and left subclavian arteries may also explain the posterior distribution of strokes: emboli in the proximal left subclavian ar-
tery may travel up the left vertebral artery and enter the posterior circulation. Use of side-hole aortic cannulas may significantly reduce the perioperative stroke rate (17).

Risk factors for perioperative stroke
Several large scale multiinstitutional prospective studies (1,2,5-10,15,18) are available on the incidence and the multivariate predictors of the postoperative stroke (Table 2).

In the following chapters we review the clinical aspects of the most important risk factors and discuss in detail recent studies, analysing the predictors of postoperative stroke.

Carotid arterial disease
Extracranial carotid artery stenosis is one of the most important predictors of perioperative stroke (1,5-7,9,10,19). More than 70% of the patients who had hemispheric events were found to have a significant (50% or greater) stenosis or occlusion of the internal carotid artery ipsilateral to the hemispheric stroke, as reported by Schwartz and associates (18). The authors observed direct relationship between severity of internal carotid artery stenosis and rate of hemispheric stroke (Table 3).

Similar conclusions were made by some other investigators. Mickleborough and associates (5) found the carotid occlusion with or without contralateral stenosis the most important predictor for stroke by stepwise logistic regression analysis.

Carotid stenosis is rarely an isolated finding; rather it is one of many manifestations of common atherosclerotic disease that influence the dynamics of intracranial blood flow. Significant carotid stenosis is a marker of aortic atheromatous disease (2). Some patients with carotid disease have strokes during cardiac surgery that are unrelated to the carotid lesion but are due to aortic embolisation. Therefore, assessing general atherosclerotic disease some authors (19) use total atherosclerotic score derived from brain, carotid arteries, and ascending aorta and group the patients undergoing CABG as having low (group L), intermediate (group I), and high (group H) score. The incidence of stroke was significantly higher in group H (14.3%) than in groups I and L (7.8% and 0.9%).

Evaluation of the extracranial internal carotid artery (ICA) alone using Doppler ultrasonography alone may provide an incomplete estimate of risk for ischemia. Transcranial Doppler may be required to supplement the extracranial Doppler evaluation preoperatively to determine which subgroup of patients with high grade carotid stenosis have significant compromise to blood flow to ipsilateral cerebral hemisphere (2).

The optimal treatment of patients with both carotid and coronary artery disease has not been resolved finally yet. Carotid endarterectomy was proven to be highly beneficial in patients with recent hemispheric transient ischemic attacks or non-disabling stroke and ipsilateral high-grade stenosis

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Table 1. Radiologic features of strokes (Barbut et all, 1997)

<table>
<thead>
<tr>
<th></th>
<th>Apparent &lt;24 h (91% ligonių)</th>
<th>New onset &gt;24 h (9% ligonių)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single infarct</td>
<td>25%</td>
<td>100%</td>
</tr>
<tr>
<td>Multiple infarcts</td>
<td>75%</td>
<td>0%</td>
</tr>
<tr>
<td>Posterior circulation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>– cerebellum</td>
<td>90%</td>
<td>0%</td>
</tr>
<tr>
<td>– posterior cerebral artery</td>
<td></td>
<td>0%</td>
</tr>
<tr>
<td>– posterior watershed</td>
<td></td>
<td>–</td>
</tr>
<tr>
<td>Middle cerebral artery branch</td>
<td></td>
<td>45%</td>
</tr>
<tr>
<td>– parasagittal watershed</td>
<td></td>
<td>40%</td>
</tr>
<tr>
<td>– entire middle cerebral artery</td>
<td></td>
<td>20%</td>
</tr>
</tbody>
</table>

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The North American symptomatic carotid endarterectomy trial showed that patients with transient ischemic attacks and an internal carotid artery stenosis of \(\geq 70\%\) have a 65% reduction in the risk of ipsilateral stroke and an 81% reduction in the risk of major or fatal ipsilateral stroke with carotid endarterectomy. Controversial remains the management strategy for asymptomatic carotid artery stenosis. When trying to decide about the value of carotid endarterectomy in asymptomatic patients the important question is: what proportion of patients with asymptomatic internal carotid artery stenosis develops a major ipsilateral ischemic stroke without warning transient ischemic attacks? A comparison of the frequency of stroke without antecedent transient ischemic attack with the frequency of stroke resulting from carotid angiography and endarterectomy should indicate the value of the procedure in asymptomatic patients.

According to the Asymptomatic Carotid Atherosclerosis Study (ACAS), the aggregate risk for patients with asymptomatic carotid artery stenosis (60% or greater) over 5 years for ipsilateral stroke and any perioperative stroke is 5.1% for surgical patients and 11.0% for patients treated medically (aggregate risk reduction of 53%) (20).

### Advanced age

Aging is associated with atherosclerosis and an increased risk of embolic phenomena, as well as with alterations in cerebral vasculature and the autoregulation of blood flow, all of which may increase the incidence of perioperative stroke (1). The great majority of the reported studies (1,5-10,22) identified advancing age (\(>60 / >70\)) as the single most significant risk factor for perioperative

### Table 2. Risk factors for perioperative stroke after CABG, identified by multivariate analysis

<table>
<thead>
<tr>
<th>Risk factors</th>
<th>Mickleborough LL</th>
<th>D’Agostino RS</th>
<th>Roach GW</th>
<th>Mc Khann GM</th>
<th>Almassi GH</th>
<th>John R</th>
<th>Puskas JD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1631 cases</td>
<td>1835 cases</td>
<td>2108 cases</td>
<td>456 cases</td>
<td>4941 cases</td>
<td>19224 cases</td>
<td>10860 cases</td>
</tr>
<tr>
<td></td>
<td>POS – 1.2%</td>
<td>POS – 2.5%</td>
<td>POS – 0.1%</td>
<td>POS – 5.7%</td>
<td>POS – 3.4%</td>
<td>POS – 1.4%</td>
<td>POS – 2.2%</td>
</tr>
<tr>
<td>Carotid artery disease</td>
<td>+</td>
<td>+</td>
<td>–</td>
<td>+</td>
<td>–</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Advanced age*</td>
<td>+</td>
<td>–</td>
<td>+</td>
<td>+</td>
<td>–</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>History of prior stroke / TIA</td>
<td>–</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Aortic atheromatosis</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>–</td>
<td>+</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>CPB-time</td>
<td>–</td>
<td>+</td>
<td>–</td>
<td>+</td>
<td>+</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Peripheral vascular disease</td>
<td>+</td>
<td>+</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>History of diabetes</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>+</td>
<td>–</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>Inotropics after CPB</td>
<td>–</td>
<td>–</td>
<td>+</td>
<td>–</td>
<td>–</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>Low ejection fraction (&lt;30%)</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>History of hypertension</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>+</td>
<td>+</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Renal insufficiency</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>+</td>
<td>+</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Intracardiac thrombus</td>
<td>+</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Postoperative myocardial infarction</td>
<td>+</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Perioperative atrial fibrillation</td>
<td>–</td>
<td>+</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

CABG – coronary artery bypass grafting; TIA – transitory ischemic attacks; CPB – cardiopulmonary bypass; POS – perioperative stroke.

* – advanced age (older than 60 - 70 years).

### Table 3. Relationship between severity of internal carotid artery stenosis and incidence of hemispheric stroke (Schwartz et all, 1995)

<table>
<thead>
<tr>
<th>Internal carotid artery (ICA)</th>
<th>Incidence of the stroke</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without significant ICA stenosis</td>
<td>0.34%</td>
</tr>
<tr>
<td>50 % or greater stenosis of one ICA</td>
<td>3.8%</td>
</tr>
<tr>
<td>80 % or greater stenosis of one ICA</td>
<td>4.3%</td>
</tr>
<tr>
<td>50 % or greater bilateral ICA stenosis</td>
<td>6.0%</td>
</tr>
<tr>
<td>80 % or greater bilateral ICA stenosis</td>
<td>8.3%</td>
</tr>
</tbody>
</table>

(>60–70%) of the internal carotid artery(2,9,19). The North American symptomatic carotid endarterectomy trial showed that patients with transient ischemic attacks and an internal carotid artery stenosis of \(>/=70\%\) have a 65% reduction in the risk of ipsilateral stroke and an 81% reduction in the risk of major or fatal ipsilateral stroke with carotid endarterectomy. Controversial remains the management strategy for asymptomatic carotid artery stenosis. When trying to decide about the value of carotid endarterectomy in asymptomatic patients the important question is: what proportion of patients with asymptomatic internal carotid artery stenosis develops a major ipsilateral ischemic stroke without warning transient ischemic attacks? A comparison of the frequency of stroke without antecedent transient ischemic attack with the frequency of stroke resulting from carotid angiography and endarterectomy should indicate the value of the procedure in asymptomatic patients.

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### Advanced age

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stroke. In Gardner’s series, patients 60 years of age or younger had a 3% stroke rate, which increased to 7.1% for patients 75 years or older (21). In a more recent study (8) the reported incidence of stroke was 1.6% for patients below 60 years of age that increased to 5.25% for patients above 70 years. These data suggest that older patients with arteriosclerotic disease of the aorta, especially with a prior history of cerebrovascular disease are at significant risk for a postoperative stroke after coronary revascularization.

History of prior stroke / previous transitory ischemic attack

History of cerebrovascular disease has been shown to be an independent predictor of perioperative stroke (1,6-10). Redmond and colleagues (22) compared the incidence of perioperative stroke in study group (patients who had previously documented stroke) versus control group (no history of stroke). There was a higher incidence of focal neurologic deficit among study patients (43.7% vs. 1.4%). These deficits included new stroke (8.5%), reappearance of previous deficits (26.8%) or worsening of previous deficits (8.5%), without new abnormalities on head computed tomography or magnetic resonance imaging. A history of neurologic disease suggests existing pathologic cerebrovascular conditions, such as impaired cerebral blood flow and autoregulation or inadequate collateral vessels, which may predispose patients to perioperative stroke after CABG surgery. The new neurologic deficit in such cases is commonly an extension of the previous infarct rather than a new infarct in a different vascular territory (2).

Aortic atheromatosis

The incidence of aortic atheromas increases sharply with age, from 20% in the fifth decade at necropsy, to 80% at older than 75 years (23). Aortic atheromatosis is considered by many investigators (1,2,5,10,15,20,25-27) as the single most important risk factor for stroke. The correlation between aortic atheromatosis and stroke in patients having CABG was first shown in a study involving 221 patients (23). Atheroemboli were present in 37% of patients with severe disease of the ascending aorta but in only 2% of patients without significant disease in the ascending aorta. Mizuno and associates (24) reported in a more recent study that patients who have an aortic arch intima thickened to more than 5mm are at a significantly high risk for perioperative stroke.

With the advent of transesophageal echocardiography (TEE), aortic atherosclerosis can now be visualized and quantitated more accurately. Each segment is graded according to severity from I to V, grade I representing normal aorta, and grade V, intraluminal protrusion of atheromatous plaque of greater than 5mm and associated with mobile components. Large protruding mobile aortic atheromas, especially those near the orifices of the innominate, carotid, and subclavian arteries, are particularly prone to cause strokes (27).

Bar-El and associates (25) distinguish five surgical pathology groups (Table 4). The stroke rate was 0.63% in patients in whom precautions were taken.

Some cardiac surgery clinics use a high-frequency epicardial ultrasound probe that is placed directly over the ascending aorta at the time of surgery to identify large atheromas. Images that are obtained are used to guide aortic cannulation, aortic cross clamping when performed, and the optimal identification sites for placing the proximal anastomoses of coronary bypass grafts. Dislodgment of atherosclerotic plaques from the aorta may occur as a result of various maneuvers, such as overly aggressive aortic palpation, cannulation, cross-clamping, and lateral occlusion clamping, as detected intraoperatively by using transcranial Doppler ultrasonography (TCD) in the middle cerebral artery. Atheroma avoidance can be facilitated by use of the exclusive Y graft technique, which has no aortic coronary anastomoses (26). Complete avoidance of aortic manipulation combined with avoidance of cardiopulmonary bypass (CPB) may theoretically represent the best strategy capable of preventing dislodgment of atheroemboli, thereby reducing the rate of perioperative stroke (“off-pump, no touch” technique).

Repeated aortic cross clamping, which is not an uncommon practice, is also a risk factor for perioperative stroke (15). Anew intra-aortic filtration method has been developed with the objective to capture particulate emboli before they enter the central circulation (28). Visual inspection revealed hard or soft particles or both in 96% of the filters.
Histology samples of filters were examined, and 66% showed evidence of atheromatous material. In conclusion, intra-aortic filter captures particulate emboli, the predominant origin of which is atheromatous and can be an important measure for prevention of perioperative stroke.

Reconstruction of the aorta

In this procedure, the potentially damaging factors are numerous, and they act concomitantly: interruption of cerebral blood flow, advanced age, presence of hypertensive and atherosclerotic vasculopathy. Risk is further compounded by the fact that these operations are commonly performed in emergency situations and when neurologic impairment has already occurred. Several risk factors for neurologic damage during aortic surgery are common with other cardiac surgery procedures, some are however specific (Table 5).

When surgery requires the interruption of blood flow through epiaortic vessels, the temporary cessation of cerebral blood flow places the brain in serious jeopardy, and makes a complete revision of neuroprotective strategies mandatory.

As far as surgical repair of the aortic arch is concerned, the last 40 years have produced several surgical and perfusion techniques that aim to guarantee adequate surgical conditions and an effective neuroprotection (33):

- Deep hypothermic circulatory arrest (DHCA)
- Deep hypothermia with selective antegrade cerebral perfusion
- Deep hypothermia with retrograde cerebral perfusion

The introduction of DHCA, represented a significant improvement, since surgeons could operate with looser time constraints, in a bloodless field. However DHCA does not guarantee optimal neuroprotection since research has not yet defined what period of circulatory arrest may be considered safe. The limit of time has not been clearly defined to date. Ceriana and colleagues (33) reported a 100% rate of persistent neurologic deficit in cases in which DHCA alone was carried out, while other investigators (2,30,31) recorded “safe” period for stroke not developing to be limited to approximately 40-60 minutes of circulatory-arrest time.

In an effort to extend the limits of safe circulatory arrest, alternative perfusion techniques have been developed as adjuncts to deep hypothermia. These include selective cannulation of all three cerebral vessels with antegrade perfusion (SCP) (30,38,39) and continuous retrograde cerebral perfusion (RCP) through the superior vena cava during the period of circulatory arrest (34,36).

Svensson and associates observed in the prospective randomised study no neurocognitive advantage with retrograde brain perfusion or antegrade brain perfusion for aortic arch operations. RCP patients were not significantly different from SCP patients with regard to any postoperative complication.

Duration of cardiopulmonary bypass

The strong association between prolonged cardiopulmonary bypass (CPB) time and major stroke has been found by some investigators (6-8,10). The longer the time, the higher the probability for stroke. The long pump time may denote technical difficulties in executing the planned operation, unfavorable anatomy, surgical inexperience, or intraoperative complications. The recent application of minimally invasive techniques, especially the avoidance of CPB, may decrease the incidence of postoperative stroke. The median number of high intensive transient signals (HITS), measured transtemporally by transcranial Doppler ultrasound (TCD) was significant lower in the off-pump group versus CPB-group, as reported by Diegeler and colleagues (41).

Both clinical and experimental studies have shown that CPB expose the central nervous system to a
Table 5. Risk factors for perioperative stroke after reconstruction of the aorta, identified by multivariate analysis

<table>
<thead>
<tr>
<th>Risk factors</th>
<th>Ehrlich MP</th>
<th>Shimizu H</th>
<th>Ueda Y</th>
<th>Wong CH</th>
<th>Okita Y</th>
<th>Ergin MA</th>
<th>Svensson L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced age*</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Operations on the aortic arch</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>and descending aorta</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urgency of the surgery</td>
<td>+</td>
<td>–</td>
<td>–</td>
<td>+</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>DHCA time</td>
<td>+</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Ruptured aneurysm/aortic dissection</td>
<td>+</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>+</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>CPB time</td>
<td>–</td>
<td>–</td>
<td>+</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>+</td>
</tr>
<tr>
<td>History of cerebrovascular disease</td>
<td>–</td>
<td>–</td>
<td>+</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

POS – perioperative stroke; CPB – cardiopulmonary bypass; DHCA - deep hypothermic circulatory arrest.
* – advanced age (older than 60 - 70 years).

A variety of potentially harmful effects. Their causes can be mechanical, temperature-related, hemodynamic, metabolic, infectious, or pharmacologic, each independently or in various combinations (41-43). Diegeler and colleagues (41) found postoperative cognitive impairment of 90% of the patients in the conventional group versus no impairment in the off-pump group. With this in mind, the advantages of off-pump operations on neurological and neurocognitive outcome appear to be promising.

Neurologic and neuropsychologic impairment in patients undergoing CPB may be associated with cerebral blood flow changes arising from different management protocols for carbon dioxide tension (pH-stat or alpha-stat acid-base management) during hypothermic bypass. Middle cerebral artery flow velocity was significantly reduced in the alpha-stat group to 87% of the prebypass value, whereas it was significantly increased 152% in the pH-stat group; hyperemia was significantly more pronounced in the pH-stat group, indicating greater disruption in cerebral autoregulation, as observed by Patel and associates (50). The authors conclude, that patients receiving alpha-stat management had less disruption of cerebral autoregulation during cardiopulmonary bypass, accompanied by a reduced incidence of postoperative cerebral dysfunction.

Stump and associates reported a reanalysis of the IMAGE Trial data (51), suggesting that full-dose aprotinin treatment has an apparent neuroprotective effect.

Aprotinin reduces bleeding during cardiac surgery procedures and avoids the reinfusion of shed blood. Shed blood is a major cause of neurologic insult. Therefore patients receiving aprotinin will have less shed blood returned and have less evidence of neurologic injury (51).

Atrial fibrillation and strokes caused by cardiac emboli

Atrial arrhythmias are the most common complication of cardiac surgical procedures today (52). Between 25% and 40% of CABG patients display atrial fibrillation (AF) during the postoperative period, the majority in the first 4 days afterward (53). The incidence of atrial arrhythmias requiring treatment for the most commonly performed operative procedures are as follows: CABG- 31.9%, CABG+ mitral valve replacement - 63.6%, CABG+ aortic valve replacement-48.8%, and heart transplantation-11.1% (54). Atrial fibrillation significantly increases (3-5 times) the incidence of perioperative stroke (6,53,54).

Over 90% of cardiac embolic strokes are from clots originating in the left atrial appendage. Johnson and associates (55) recommend therefore prophylactic appendage removal whenever the chest is open, as a method to prevent future strokes.

Prior myocardial infarctions, mural thrombi, cardiomyopathy, ventricular aneurysms (as source for embolization) are often present before and after heart surgery. Surgery itself increases the coagu-
lability of the blood and enhances thrombus formation and embolization. Most strokes, caused by emboli arising in the heart are territorial and occur later during the postoperative period (new onset >24 hr) (2).

**Valve surgery**

Are neurologic complications more frequent in valve operations than CABG procedures? Most of the reports involving valve procedures are from the 1970s, whereas the majority of CABG studies were published in the 1980s, by which time notably more sophisticated techniques had been developed. Patients undergoing intracardiac procedures are more likely to be at risk for atherosclerotic emboli and other solid emboli associated with valve calcification, vegetation, or intracardiac thrombus. Regarding air emboli, prevalence is increased with intracardiac procedures because air bubbles commonly remain trapped within the heart after its chambers are closed (15). Neville et all (11) have noted that in patients undergoing valve surgery, the number of embolic events measured in the middle cerebral artery with TCD even exceeds that associated with myocardial revascularization.

Herrmann et all (56), Taggart et all (57) reported a significantly greater elevation in S-100 and NSE values during the postoperative course after intracardiac operation than CABG. However, neither of these investigators found significant difference in neurobehavioral scores and neurological outcomes between patients undergoing either coronary artery bypass grafting or cardiac valve operations at any time. The current belief seems to be that CPB-related central nervous system injury is not a function of the cardiac disease (12).

**Conclusions**

This article provides a concise summary of a very important problem in contemporary cardiac surgery. The authors have concentrated on review of the predictive factors for perioperative stroke, identified by multivariate analysis in the recent studies. These factors taken together can identify patients, who are at high risk for perioperative focal cerebral injury. Recognition of the high-risk group will help for prevention of stroke by modification of surgical procedures or pharmacologic intervention. Prevention is the most effective way of managing neurologic disorders.

**Išeminis insultas ir jo rizikos veiksniai po kardiochirurgijos operacijų**

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**Raktažodžiai:** kardiochirurgija, komplikacijos, centrinės nervų sistemos pažeidimas, išeminis insultas, rizikos veiksniai.

**Santrauka.** Pastaraisiais metais pasaulioje kasmet atliekama per 800 tūkstančių kardiochirurgijos operacijų. Viena sunkiausių komplikacijų po ju – centrinės nervų sistemos pažeidimas. Per pastaruosius du dešimtmečius bendrasis pooperacinis sergamumas bei mirštamumas žymiai sumažėjo dėl kardiochirurgijos, dirbtinės kraujo apytakos ir anesteziologijos progreso, tačiau didėjant pooperacinių neurologinių komplikacijų skaičiui, paraleliai tris kartus didesnis ir mirštamumas, susijęs su centrinės nervų sistemos pažeidimu.

Didelis pooperacinių centrinės nervų sistemos komplikacijų dažnis gali būti siejamas su operuojamų ligonių vyresniu amžiumi bei įvairiai gretutine patologija, atsiradusia dėl išspėtusio aterosklerotinio proceso. Tai tarsi patvirtina, kad kardiochirurgijos ir anesteziologijos pasiekimai, užtikrinę geresnę miokardo apsaugą operacijos metu, yra nepakankami centrinės nervų sistemos atžvilgiu, todėl priešoperacine ligonių ištirimo metu būtina nuodugniai ir patikimai įvertinti pagrindinius neurologinės rizikos veiksniai.

Centrinės nervų sistemos komplikacijos po kardiochirurgijos operacijų yra skirstomos į tris klinikinius sindromus: išeminį insultą, neuropsichologinius sutrikimus ir encefalopatiją. Dauginis galvos smegenų pažeidimų pobūdis ir jų vyravimas smegenyse, į kurias dažniausiai patenka embolas, leidžia teigti, kad dažniausia pooperacine išeminio insulto priežastis yra embolia.


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