Clinical Findings and Mechanisms

1. CABG
   a. Signs and symptoms can be divided into (1) cerebrovascular events, (2) encephalopathy or coma, (3) early or delayed cognitive impairment (4) peripheral nervous system injury, and (5) other neurologic events (Table 1).
   b. Table 1: Etiologies and Potential Mechanisms of Neurologic Complications Following CABG

<table>
<thead>
<tr>
<th>Condition</th>
<th>Etiology/Mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ischemic infarction of the brain or spinal cord</td>
<td>Thromboembolism, air embolism, atherosclerosis, vasospasm, vessel trauma, hypotension, underlying coagulopathy or factors related to use of IABP</td>
</tr>
<tr>
<td>Hemorrhagic stroke</td>
<td>Mechanism unknown</td>
</tr>
<tr>
<td>Pituitary apoplexy</td>
<td>Proposed mechanisms include: factors related to the extracorporeal bypass apparatus, anticoagulation, low cerebral blood flow, anesthetic agents or presence of subclinical pituitary tumor</td>
</tr>
<tr>
<td>Seizure</td>
<td>Medication toxicity, cerebral thromboembolism, cerebral air embolism</td>
</tr>
<tr>
<td>Hypoxic-ischemic encephalopathy (HIE)</td>
<td>Acute low cardiac output, hypotension, shock, hypoglycemia</td>
</tr>
<tr>
<td>Encephalopathy</td>
<td>Sedatives, analgesics, showers of microemboli</td>
</tr>
<tr>
<td>Delayed cognitive dysfunction</td>
<td>Mechanism unknown</td>
</tr>
<tr>
<td>Visual loss</td>
<td>Optic nerve ischemia, retinal artery embolism</td>
</tr>
<tr>
<td>Subclavian steal syndrome</td>
<td>Atherosclerotic disease of the proximal subclavian artery</td>
</tr>
<tr>
<td>Horner syndrome</td>
<td>Injury to the cervical sympathetic chain</td>
</tr>
<tr>
<td>Brachial plexopathy</td>
<td>Stretching, direct trauma or compression</td>
</tr>
<tr>
<td>Phrenic nerve injury</td>
<td>Stretching, direct trauma, ischemia or topical hypothermia</td>
</tr>
<tr>
<td>Ulnar nerve injury</td>
<td>Compression</td>
</tr>
<tr>
<td>Recurrent laryngeal nerve injury</td>
<td>Stretching, direct trauma or hypothermia</td>
</tr>
<tr>
<td>Saphenous nerve injury</td>
<td>Direct trauma</td>
</tr>
<tr>
<td>Common peroneal nerve injury</td>
<td>Ischemia due to stretching or compression</td>
</tr>
</tbody>
</table>

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2. Cardiac Catheterization and PCI
   a. Signs and symptoms can be divided into (1) ischemic and hemorrhagic cerebrovascular events, (2) global cerebral anoxic ischemic insults, (3) seizures, (4) transient global amnesia, (5) peripheral nervous system injury including brachial plexopathy, peripheral mononeuropathies, complex regional pain syndrome (CRPS), and (6) cortical blindness (Table 2).
   b. Table 2: Etiologies and Potential Mechanisms of Neurologic Complications Following Cardiac Catheterization and PCI
<table>
<thead>
<tr>
<th>Neurologic Complication</th>
<th>Etiologies and Potential Mechanisms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ischemic stroke</td>
<td>Thromboembolism, air embolism, atherosclerosis, vasospasm, vessel trauma, hypotension</td>
</tr>
<tr>
<td>Hemorrhagic stroke</td>
<td>Pharmacotherapy, vessel trauma, catecholamine surge</td>
</tr>
<tr>
<td>Seizure</td>
<td>Ischemic infarction, subdural hemorrhage, air embolism, contrast administration</td>
</tr>
<tr>
<td>Cortical blindness</td>
<td>Contrast</td>
</tr>
<tr>
<td>Hypoxic-ischemic encephalopathy</td>
<td>Acute low cardiac output, hypotension, shock, hypoglycemia</td>
</tr>
<tr>
<td>Transient global amnesia</td>
<td>Mechanism unknown</td>
</tr>
<tr>
<td>Brachial plexus injury</td>
<td>Direct compression, or hematoma or pseudoaneurysm formation with axillary angiography</td>
</tr>
<tr>
<td>Median nerve injury</td>
<td>Direct injury, hematoma formation</td>
</tr>
<tr>
<td>Lateral femoral cutaneous nerve injury</td>
<td>Trauma</td>
</tr>
<tr>
<td>Femoral nerve injury</td>
<td>Direct injury, compression by groin hematoma, arteriovenous fistula or pseudoaneurysm, superficial or common femoral artery occlusion</td>
</tr>
<tr>
<td>Complex regional pain syndrome</td>
<td>With transradial approach</td>
</tr>
</tbody>
</table>

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3. Valvular Surgery
   a. Complications include (1) both ischemic and hemorrhagic strokes, (2) seizures, (3) coma, (4) cognitive dysfunction, (5) migraine-like phenomena, (6) brachial plexopathy and peripheral mononeuropathies (Table 3).
   b. Table 3: Etiologies and Potential Mechanisms of Neurologic Complications Following Valvular Surgery

<table>
<thead>
<tr>
<th>Neurologic Complication</th>
<th>Intraoperative</th>
<th>Postoperative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ischemic stroke</td>
<td>Atherosclerotic emboli</td>
<td>Valve thrombosis</td>
</tr>
<tr>
<td></td>
<td>Hypoperfusion</td>
<td>Left-atrial thrombi</td>
</tr>
<tr>
<td></td>
<td>Air embolism</td>
<td>Septic emboli</td>
</tr>
<tr>
<td></td>
<td>Fat embolism</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Vessel clamping</td>
<td></td>
</tr>
<tr>
<td>Intracranial and spinal hemorrhage</td>
<td>Anticoagulation</td>
<td></td>
</tr>
<tr>
<td>Seizure</td>
<td>Cerebral air embolism</td>
<td></td>
</tr>
<tr>
<td>Coma</td>
<td>Cerebral air embolism</td>
<td></td>
</tr>
<tr>
<td>Cognitive dysfunction</td>
<td>Possibly due to showers of microemboli to the bilateral subcortical white matter.</td>
<td></td>
</tr>
<tr>
<td>Migraine-like phenomena</td>
<td>Mechanism unknown</td>
<td></td>
</tr>
<tr>
<td>Brachial plexopathy</td>
<td>Stretching, direct trauma or compression</td>
<td></td>
</tr>
<tr>
<td>Peripheral nerve injury (see above with CABG)</td>
<td>Stretching, direct trauma or compression</td>
<td></td>
</tr>
</tbody>
</table>

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4. Patent Foramen Ovale/Atrial Septal Aneurysm Surgery  
a. Rarely transient ischemic attacks occur following percutaneous PFO closure  

5. Surgery for Cardiac Tumors  
a. Complications include (1) ischemic or hemorrhagic stroke, (2) delayed intracerebral or subarachnoid hemorrhage, or rarely (3) ischemic oculopathy  
b. Pathophysiology  
i. Myxomas account for 40% to 50% of primary cardiac tumors, and they typically arise from left-sided cardiac structures, predominantly the left atrium.  
ii. Ischemic and hemorrhagic strokes may occur in the peri-procedural period as a result of embolism of myxomatous material or thrombus.  
iii. Intracerebral or subarachnoid hemorrhage may develop in a delayed manner as a result of tumor recurrence after embolization, aneurysm formation and rupture or parenchymal metastasis  

6. Mechanical Circulatory Devices  
a. Signs and symptoms may be divided into (1) cerebrovascular events including ischemic stroke, HIE, transient ischemic attack (TIA) and intracranial hemorrhage, (2) seizures, (3) delirium, (4) visual loss, (5) hearing loss, (6) neuropsychological deficits, and (7) peripheral neurologic deficits (Table 4).  
b. Table 4: Etiologies and Potential Mechanisms of Neurologic Complications Following Implantation of Mechanical Circulatory Devices  

<table>
<thead>
<tr>
<th>IABP</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ischemic stroke and TIA</td>
<td>Cerebral air embolism due to IABP rupture Thromboembolism</td>
<td></td>
</tr>
<tr>
<td>Hemorrhagic stroke</td>
<td>Anticoagulation</td>
<td></td>
</tr>
<tr>
<td>Neurological deficits in one or both legs ranging from foot drop to complete paralysis</td>
<td>Obstruction to blood flow, or thromboembolism in the femoral artery</td>
<td></td>
</tr>
<tr>
<td>Ventricular assist devices</td>
<td>Ischemic stroke</td>
<td>Thromboembolism</td>
</tr>
<tr>
<td>Seizure</td>
<td>Secondary to stroke</td>
<td></td>
</tr>
<tr>
<td>Delirium</td>
<td>Multifactorial</td>
<td></td>
</tr>
<tr>
<td>Sciatic nerve injury</td>
<td>Compression due to posterior compartment syndrome of the thigh</td>
<td></td>
</tr>
<tr>
<td>ECMO</td>
<td>Ischemic stroke</td>
<td>Thromboembolism, air embolism, ligation of the carotid artery and internal jugular vein</td>
</tr>
<tr>
<td>Hemorrhagic stroke</td>
<td>Anticoagulation, thrombocytopenia, systolic hypertension</td>
<td></td>
</tr>
<tr>
<td>Hypoxic-ischemic encephalopathy</td>
<td>Changes in cerebral blood flow and arterial oxygen pressure</td>
<td></td>
</tr>
<tr>
<td>Seizure</td>
<td>Mechanism unclear</td>
<td></td>
</tr>
<tr>
<td>Sensorineural hearing loss</td>
<td>Mechanism unclear</td>
<td></td>
</tr>
<tr>
<td>Visual loss</td>
<td>Anterior ischemic optic neuropathy</td>
<td></td>
</tr>
<tr>
<td>Neuropsychological deficits</td>
<td>Mechanism unclear, probably related to hypoxia</td>
<td></td>
</tr>
<tr>
<td>ICU acquired weakness</td>
<td>Microvascular, electrical, metabolic, and bioenergetic alterations to nerve and muscle</td>
<td></td>
</tr>
</tbody>
</table>

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7. Atrial Ablation  
a. Signs and symptoms can be divided into (1) cerebrovascular events, (2) neuropsychological dysfunction, and (3) a combination of seizures, fever and stroke symptoms
b. Pathophysiology
   i. Thromboembolic events are rare and mostly occur within the 1st 48 hours
   ii. Subtle, global, neuropsychological dysfunction may occur but data is mixed
   iii. The constellation of symptoms including seizures, fevers and stroke symptoms should prompt an expedited search for atrio-esophageal fistula, a rare complication which allows air and food emboli to reach the brain

Natural History

1. Stroke
   a. Outcomes are affected by the underlying pathology, the type of procedure, the experience of the surgeon, differences in the surgery itself, and whether anticoagulation is used.
   b. Extensive follow-up data is not available for outcomes of patients with ischemic stroke following cardiac surgery however favorable recoveries can be expected in the majority of cases, with only a minority dying from cerebral edema or withdrawal of care in the acute period following stroke.
      i. ECMO is an exception, in which of patients who experienced neurological events, 59% die while on ECMO or within 7 days of discontinuation of ECMO

2. Seizures
   a. Seizures following cardiac surgery are typically self limiting or easily controlled with benzodiazepines.
   b. Rarely, status epilepticus has been reported with associated findings of diffuse cerebral edema on neuroimaging

3. Visual Loss
   a. Outcome is dependent on mechanism
      i. When induced by contrast administration with normal appearing optic nerves, the deficit is usually transient with return of vision within 24-48 hours
      ii. Visual loss due to anterior or posterior ischemic optic neuropathy following cardiac surgery is typically permanent.

4. Delirium
   a. Mixed outcomes, reflecting the multifactorial nature of delirium
      i. Neurocognitive decline is common after cardiac surgery, varying from 7% - 49% at 3 months and up to 33% after 1 year

5. Peripheral Complications
   a. Patients with brachial or lumbosacral plexopathy can in the majority of cases expect full recovery with conservative management
   b. While the severity of mononeuropathies following cardiac surgery can range from mild transient sensory neuropathy to disabling paralysis, symptoms almost always resolve completely.

Laboratory and Neuroimaging Investigations

1. Coma, encephalopathy or seizures
   a. Laboratory evaluation should focus on ruling out a metabolic cause and should include at the minimum complete blood count, coagulation studies, chemistry panel, liver function tests, lactate and ammonia levels.
   b. An EEG is appropriate in patients suspected of having seizures.
   c. Those with seizures should be further evaluated for stroke or air embolism
   d. Lumbar puncture should be performed for CSF analysis in unexplained coma or encephalopathy or when the patient is known to be immunosuppressed.

2. Suspected Stroke
   a. Focal neurologic deficits raising concern for ischemic stroke or convulsions occurring during cardiac catheterization should alert the clinician to look for air in the tubing.
   b. Neuroimaging
      i. A non-contrast CT of the head should be obtained before considering thrombolysis or endovascular therapy. An MRI of the brain with diffusion-weighted images may be indicated if the CT scan does not show the suspected stroke
      ii. For most devices, if there is a good clinical indication for an MRI scan, then the benefits probably outweigh the risks. The exception is patients who have implantable cardiac defibrillators (ICDs) and pacemakers, in which MRI scanning should be performed only at a very experienced center and only when there is a strong indication for MRI (Levine 2007)
iii. Neuroimaging is undertaken to exclude hemorrhage and to identify the pattern of infarction. The most common pattern encountered is multiple embolic infarcts however large artery territorial or watershed infarcts can also occur.

c. Serum glucose, CBC, and coagulation studies

d. Trans-esophageal echocardiography may be indicated in selected cases, particularly those having undergone cardiac valve surgery to evaluate for the presence of left-atrial or valvular thrombus or infective vegetations.

e. ECG should be obtained and telemetry data reviewed to evaluate for arrhythmias.

3. Peripheral nervous system injury
   a. EMG/NCV may help to localize the lesion and to provide prognostic information
   b. Lumbosacral plexopathy or femoral neuropathy
      i. Exclude retroperitoneal hemorrhage with CT scan of the pelvis in cases of lumbosacral plexopathy or femoral neuropathy following administration of thrombolytic agents during cardiac catheterization and PCI procedures.

4. Generalized weakness with or without myalgia
   a. CK and aldolase should be obtained to assist in the evaluation of myopathy

Management

1. Perioperative ischemic stroke in the setting of cardiac surgery
   a. Similar to that in other settings except that use of intravenous r-tPA is contraindicated in patients within 2 weeks of cardiac surgery
   b. TPA may be considered after cardiac catheterization (head CT is still required prior to TPA administration in this setting even if the embolism is detected by angiography)
   c. Select patients may be considered for mechanical endovascular embolectomy
   d. If the etiology of the stroke is an air embolism, hyperbaric oxygen therapy should be administered early

2. Seizures
   a. Seizures can be managed acutely with benzodiazepines.
   b. Long term treatment with an anti-seizure drug if focal or if an associated structural lesion is identified no pharmacologic mechanism is identified

3. Peripheral nervous system injury
   a. Conservative management remains the mainstay of therapy for peripheral nerve or muscle injury associated with cardiac surgeries and procedures.
   b. Surgery is only recommended when there are coexisting complications (e.g., development of a large hematoma)

Conclusions

- Neurologic complications of cardiac surgery and cardiac procedures are not rare and remain an important cause of morbidity and mortality.
- Evaluation of these complications requires a systematic approach.
- Prompt identification of these deficits is important in order to plan appropriate evaluation and initiate possible treatments in a timely manner.
References


