Coronary artery disease (CAD) is common in the surgical population, with up to 50% of postoperative deaths due to cardiac events. Most of these events are ischemic, with some being exacerbations of underlying congestive heart failure (CHF). Recent data indicate that acute perioperative β-adrenergic blockade can reduce ischemia and ischemic events. Postoperative monitoring should focus on myocardial ischemia, with preparation for rapid treatment using IV therapy. A few studies suggest that elderly patients with known CAD undergoing major procedures might benefit from perioperative treatment guided by information from a pulmonary artery catheter. Postoperative CHF, which is likely to present early after surgery, may need aggressive management with diuretics, vasodilators, and inotropic drugs. Mechanical ventilation should be considered. When the patient develops severe or refractory dysrhythmias, serum magnesium levels should be supplemented and consideration given to IV use of amiodarone. Postoperative hypertension is common and can precipitate ischemia, CHF, and arrhythmias as well as cause bleeding. Newer IV drugs are arterial specific and can lower BP in a smooth and predictable manner. All acute cardiac disorders can be precipitated or exacerbated by inadequate pain control, hypoxemia, and fluid or electrolyte disorders.

It has been estimated that more than one half of postoperative deaths are caused by cardiac events. Not surprisingly, a large percentage of elective postoperative admissions to the ICU are for “cardiac monitoring,” and many unplanned ICU admissions are for treatment of acute cardiovascular changes that occur intraoperatively. For preexisting cardiac conditions, one of the most valuable aspects of ICU admission is the ability to reinstate preoperative treatment regimens in a timely fashion. Acute disorders are managed with IV medications while the patient is intensively monitored.

Cardiac management is closely related to other aspects of postoperative care in the ICU. Fluid and electrolyte status and oxygen content of arterial blood, for example, are vitally important in maintaining adequate cardiac function. Activation of the sympathoadrenal system by pain and perturbations in other organ systems place major stress on the heart. Therefore, assessment of cardiac function must be closely coupled with a complete physical examination, history of prior status and intraoperative events, and general assessment of blood chemistry, oxygenation, and analgesic regimen. When an ICU admission is the result of intraoperative events, direct communication between the anesthesiologist and the ICU caregiver is essential. The following discussion focuses on ischemic heart disease, with a brief consideration of heart failure, dysrhythmias, and hypertension.

CORONARY ARTERY DISEASE

In patients with known or suspected coronary artery disease (CAD), perioperative ischemia is common and is most prevalent in the postoperative period (Fig 1). This ischemia is associated with adverse cardiac outcomes during the hospital admission and for up to 2 years later. Many studies indicate that myocardial infarction (MI) occurs most frequently in the first few days after noncardiac surgery; a recent study documented the incidence of MI in patients with known CAD was 5.6%, with almost half occurring on the day of surgery. In vascular patients, the incidence of CAD may be as high as 70%, with perioperative MI occurring at three times this rate.

Diagnosis

Postoperative ischemia has been studied by the use of continuous ECG monitoring. Modern ICU monitors have the capacity for continuous ST segment trending, and at least one manufacturer of ambulatory ECG monitors has incorporated an alarm triggered by ST segment changes. These devices have not been validated for realtime use in
ischemia detection; clinicians usually rely on patients to complain of chest discomfort or on “routine” sequential ECG recordings and enzyme levels. In the study referred to above, only 17% of the patients who developed an MI complained of chest pain; however, 56% developed significant clinical findings (dysrhythmia, hypotension, pulmonary edema). Frequent cardiac enzyme determinations (creatinine phosphokinase, myocardial band [CK-MB]) are costly and may not add to the information gained from the 12-lead ECG in postoperative patients with clinical findings. Troponin-t and troponin-i levels appear to be more cardiac specific, peak at a similar time as CK-MB, and stay elevated for days. Studies are currently underway evaluating continuous 12-lead ECG monitoring in postoperative patients, with the possibility that this might be done in a telemetry or surgical floor setting.

**Prevention**

Prevention of myocardial ischemia is the main goal of ICU management in this population. Recent reports of reduction in postoperative ischemia and MI with the use of prophylactic β-blockade (using atenolol) are compelling. These studies extend to the surgical period the recognized benefit of β-blockade in prevention of ischemia and reinfarction in nonsurgical patients. Oral or IV β-blockade can be initiated the morning of surgery and continued into the postoperative period. Other therapy used in the treatment of ischemic heart disease either has not shown benefit consistently (e.g., prophylactic infusion of IV nitroglycerin) or has not been adequately evaluated in the perioperative setting (calcium blockers).

Another class of drugs that holds promise for the prevention of perioperative ischemia is the α2-adrenoceptor agonists. These drugs act centrally to reduce sympathetic nervous system output, and are associated with mild sedation and reductions in heart rate and BP. A single oral dose of clonidine preoperatively reduced the incidence of perioperative ischemia in vascular patients; the newer drug mivazerol was found to significantly reduce myocardial ischemia when given as an infusion for 72 h perioperatively.

Reduction of the sympathoadrenal response to surgery by intraoperative epidural anesthesia fol-
Perioperative Cardiopulmonary Evaluation and Management

When myocardial ischemia or infarction is suspected in the postoperative period, short-term therapy is similar to that in the medical setting, with the exception of heparinization or thrombolytic agents. While the latter will be contraindicated, depending on the nature of the surgical procedure and the time between surgery and the ischemia, cautious heparinization may be possible. Short-term therapy with IV agents to control abnormal hemodynamics (especially tachycardia) should be initiated, along with specific anti-ischemic therapy such as IV nitroglycerin. Surgical pain, anxiety, and fluid/hemoglobin deficits must be treated. Table 1 lists some therapies useful in this setting. Intervention in the cardiac catheterization laboratory should be considered, as should use of an intra-aortic balloon pump, in cases of severe refractory ischemia.

**Congestive Heart Failure**

It has long been recognized that congestive heart failure (CHF) is a major risk factor in the development of perioperative cardiac morbidity and mortality; one clinical series suggested that 95% of perioperative acute CHF occurs within 1 h of the end of surgery. In patients with little or no cardiac reserve, or where there is a new cardiac event, activation of the sympathetic nervous system with awakening and pain may put intolerable stress on the left ventricle. Resumption of spontaneous breathing can unmask inadequate cardiac function that was concealed by positive pressure ventilation.

**Diagnosis**

The presence of unusually poor oxygenation associated with dyspnea or the appearance of a new dysrhythmia should alert the clinician to the diagnosis, which is confirmed by the chest radiograph. Review of the intraoperative course with the anesthesiologist may identify precipitating events or conditions, such as the patient being in the head-down position for an extended period. Nonanesthesiologists often remark on the large volumes of fluid given intraoperatively; most patients undergoing major or lengthy procedures require this fluid, and many require additional fluid resuscitation postoperatively. While fluid overload must be part of the differential diagnosis, underlying heart disease or a new ischemic event should be investigated. Echocardiography can provide diagnostic information and help guide the therapy.

**Prevention**

Identification of heart failure in the preoperative period should result in cancellation of elective surgery. Medical treatment to optimize the cardiac status should reduce the risk of perioperative CHF, and patients should continue to receive their medications through the perioperative period. This is one group of patients in whom use of a PAC to help guide perioperative fluid management may be indi-
cated, although this has not been evaluated in a prospective study. Prophylactic inotropic infusions are probably not indicated in patients with histories of heart failure; however, use of PAC will help the clinician know when such intervention is indicated.

As in CAD, close attention to electrolyte status, hematocrit, oxygenation, and analgesia will reduce the stress on the heart, and the patient must be closely observed during withdrawal of positive pressure ventilation. Hypertension and tachycardia should be prevented (adequate analgesia, resumption of preoperative therapy) and rapidly treated when they occur.

Treatment

As in the medical setting, treatment of acute postoperative heart failure includes oxygen, diuretics, preload, and afterload reduction where possible, and positive inotropic agents. There should be a low threshold for intubation to remove the work of breathing and provide the preload and afterload reduction associated with positive intrathoracic pressure. Pulmonary congestion can be relieved rapidly by the venodilating effects of IV nitroglycerin and loop diuretics. If there is any delay in response to treatment or if hypotension develops, insertion of a PAC should be considered to guide administration of potent vasoactive drugs and inotropes. Whereas for long-term medical management of CHF, angiotensin-converting enzyme inhibitors are of proven benefit, IV enalaprilat is difficult to use in the acute setting (slow onset and offset, unpredictable effect on BP). Similarly, digoxin has a slow onset of action and a very modest inotropic effect. Other vasodilators and inotropic drugs are much easier to use in the ICU. In chronic heart failure, there is a relative insensitivity or “down regulation” of the β-receptor, and use of a phosphodiesterase-3 inhibitor such as milrinone should be considered. Table 2 summarizes some IV therapies for acute postoperative CHF.

Cardiac Dysrhythmias

The occurrence of a new cardiac dysrhythmia in the postoperative period is most commonly due to electrolyte disturbances and/or the increased sympathetic nervous system activity, although myocardial ischemia or CHF must be considered. Supraventricular tachydysrhythmias and ventricular extrasystoles are common, and many can be controlled by β-adrenergic blockade and correction of electrolyte disorders. Specific etiology and treatment of dysrhythmias is beyond the scope of this brief summary; only two relatively new treatments of dysrhythmias will be reviewed. The reader is referred to the excellent algorithms for acute dysrhythmias published by the American Heart Association.

Magnesium

In recent years, it has become apparent that major fluid shifts and losses are associated with hypomagnesemia, magnesium loss occurs with diuretic use, many postoperative patients are hypomagnesemic, and there is at least a functional deficit of magnesium associated with acute MI. Both atrial and ventricular dysrhythmias can be precipitated by hypomagnesemia, and many can be treated by magnesium administration; infarct size can be limited by administration of magnesium during or immediately after reperfusion, and survival after MI appears to be improved if magnesium levels are supplemented (although one large trial has failed to support this

Table 1—IV Drug Therapy for Postoperative Myocardial Ischemia*  

<table>
<thead>
<tr>
<th>Drug</th>
<th>Dosing</th>
<th>End Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitroglycerin infusion</td>
<td>50 μg/mL; titrate upwards as tolerated (BP)</td>
<td>Pain elimination, PAP/PAOP reduction, ST-segment normalization</td>
</tr>
<tr>
<td>β-Adrenergic blockade</td>
<td></td>
<td>Heart rate &lt;90 beats/min; while maintain BP &gt;75 mean; pain elimination; ST-segment normalization</td>
</tr>
<tr>
<td>Atenolol†</td>
<td>1–5 mg, incrementally; repeat as needed</td>
<td></td>
</tr>
<tr>
<td>Metoprolol†</td>
<td>1–5 mg, incrementally; repeat as needed</td>
<td></td>
</tr>
<tr>
<td>Propranolol†</td>
<td>1-mg increments repeat as needed</td>
<td></td>
</tr>
<tr>
<td>Esmolol</td>
<td>10–50 mg; infusion up to 200 g/kg/min</td>
<td></td>
</tr>
<tr>
<td>Calcium channel blocker†</td>
<td>100–200-g increments; infusion 1–5 mg/h</td>
<td>Control of hypertension; pain reduction; ST-segment normalization</td>
</tr>
<tr>
<td>Nicardipine</td>
<td>5–15-mg load; 1–10 mg/h</td>
<td></td>
</tr>
<tr>
<td>Diltiazem</td>
<td>2.5–5-mg increments</td>
<td></td>
</tr>
<tr>
<td>Verapamil</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Treat precipitating causes such as pain, anxiety, anemia, and intravascular volume disorders. PAP = pulmonary artery pressure; PAOP = pulmonary artery occlusion pressure.
† Duration of action of single small doses may be <1 h; repeated dosing will likely be necessary.
‡ IV calcium channel blockers are third-line drugs unless coronary spasm is suspected (where they may be first line). Diltiazem and verapamil may cause atrioventricular nodal blockade.
Amiodarone

This complex antidyssrhythmik drug has moved into the forefront for treatment of both supraventricular and ventricular tachydysrhythmias refractory to first-line drugs. Most studies have examined its use in the treatment of malignant ventricular rhythms, and amiodarone compares favorably to virtually all other drugs in terms of efficacy, safety, and adverse effect profile. While current algorithms place this drug as an alternative or next step to bretylium for acute refractory ventricular dysrhythmias, many practitioners are now turning directly to amiodarone if lidocaine is ineffective. Similarly, amiodarone appears to be at least comparable to quinidine and procaainamide in terminating and preventing atrial dysrhythmias. An excellent review of this drug in the perioperative setting suggests that its role will dramatically expand as safety studies in the surgical population become available. One undesirable feature of amiodarone is the need for a prolonged loading dose. Another precaution is the potential for ARDS, which has been observed in some patients after major pulmonary resections.

HYPERTENSION

Acute postoperative hypertension secondary to high sympathoadrenal tone is common, especially in patients with preexisting hypertension. Hypertension may cause excessive surgical bleeding (especially after cardiovascular procedures), and may precipitate myocardial ischemia, cardiac dysfunction, and/or pulmonary congestion. Analgesia and adequate gas exchange should be assured, and other potential causes of hypertension (e.g., bladder or gastric distention) should be evaluated before specific treatment of hypertension is initiated.

Cold, volume-depleted patients often are hypertensive until they warm to above 36.5°C, at which time they vasodilate and the hypovolemia becomes apparent. Intermittent doses of vasodilating drugs produce unpredictable responses, both in terms of effect and duration; the nitrodilators (nitroprusside and nitroglycerin) are potent venodilators and can cause major swings in BP due to their preload reducing effect. β-Adrenergic-blocking drugs may be effective, and considering the cause of most postoperative hypertension, they should be the drug of first choice. Newer drugs that are arterial specific (nicardipine, fenoldopam) are now available for continuous infusion and provide a real benefit in achieving smooth control of the BP. These latter drugs should be considered if β-blockers are either not tolerated or ineffective. Table 3 summarizes some IV therapies for acute postoperative hypertension.

Nicardipine

Nicardipine is a dihydropyridine calcium channel-blocking drug with a similar structure to nifedipine. Unlike the latter drug, however, it is relatively vascular specific with little effect on the myocardium and capacitance vessels, and it is water soluble. Postoperatively, in a direct comparison to nitroprusside, nicardipine was found to control the BP more rapidly, with fewer changes in dose and low incidence of need to stop the drug treatment. In addition, calcium-blocking drugs have antispasmodic, anti-inflammatory, and cytoprotective effects.
Table 3—IV Drug Treatment for Postoperative Hypertension

<table>
<thead>
<tr>
<th>Drug</th>
<th>Dosing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial dilators</td>
<td></td>
</tr>
<tr>
<td>Nicardipine</td>
<td>100–200-µg increments; 1–5 mg/h</td>
</tr>
<tr>
<td>Nitroprusside</td>
<td>50 µg/mL; begin at lowest dose (1–2 mL/h) and titrate upwards; usual dose 0.5–10 µg/kg/min</td>
</tr>
<tr>
<td>Fenoldopam</td>
<td>0.025–0.15 µg/kg/min</td>
</tr>
<tr>
<td>β-Adrenergic blockers</td>
<td></td>
</tr>
<tr>
<td>Atenolol</td>
<td>1–10 mg in incremental doses; repeat as necessary</td>
</tr>
<tr>
<td>Metoprolol</td>
<td>1–5 mg in incremental doses; repeat as necessary</td>
</tr>
<tr>
<td>Propranolol</td>
<td>1 mg in incremental doses; repeat as necessary</td>
</tr>
<tr>
<td>Esmolol</td>
<td>10–50 mg; infusion of 50–200 g/kg/min</td>
</tr>
<tr>
<td>Labetalol</td>
<td>5–20-mg incremental doses; repeat as necessary</td>
</tr>
<tr>
<td>Hydralazine</td>
<td>5–20-mg incremental doses</td>
</tr>
<tr>
<td>Enalaprilat</td>
<td>0.625–2.5 mg; repeat as needed (usually 4–6 hr)</td>
</tr>
</tbody>
</table>

*Treat pain, hypoxemia, and other underlying physiologic disturbances.

Fenoldopam

Fenoldopam is a selective dopamine_1-agonist that is approved for the treatment of hypertension. Postsynaptic dopamine_1-receptors are found in multiple vascular beds where their stimulation causes arterial vasodilation, and also in the distal renal tubule where sodium excretion is modulated. Infusion of this drug causes a lowering of systemic BP in association with an increase in renal blood flow and sodium excretion. In comparison to nitroprusside, cardiac filling pressures and cardiac output are better maintained with fenoldopam owing to a lack of pulmonary and systemic venodilation. It also appears that intrapulmonary shunt is not affected with this drug. Although there are extensive laboratory data, relatively few clinical trials have been conducted in surgical patients. There is, however, great interest in a drug that can maintain or improve renal perfusion and sodium excretion and not affect intrapulmonary shunt fraction, while lowering BP with efficacy comparable to that of nitroprusside.

Conclusions

This brief overview has highlighted some current trends in the short-term cardiovascular treatment of postoperative patients. As CAD is the most prevalent underlying cardiovascular disease in surgical patients, and as it is associated with considerable morbidity and mortality in this setting, a major focus of postoperative care must be on monitoring for ischemia and on therapy designed to reduce or prevent ischemia and MI. While less common, acute CHF in the postoperative setting is associated with mortality and may be the consequence of underlying CAD. Perioperative invasive monitoring in high-risk patients may reduce adverse outcome; however, studies supporting this practice are not compelling. Newer drugs to treat perioperative dysrhythmias, reduced cardiac performance, and arterial hypertension may provide the clinician with valuable tools to prevent and treat adverse cardiac outcomes.

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