Intraoperative anaesthetic management
The objectives of anaesthetic management include an intensive preoperative assessment of risk factors and management of coexisting disease states; the utilization of monitoring techniques to detect promptly signs of myocardial ischaemia and impaired myocardial contractility; maintenance of adequate intravascular volume, optimal cardiac output and tissue oxygenation; avoidance or prompt pharmacological amelioration of untoward haemodynamic or metabolic changes associated with aortic clamping and unclamping; and intensive postoperative care.

Monitoring
Extensive monitoring of patients presenting for aortic vascular surgery is mandatory. Standard monitoring practice should include the patient’s exposed hand to check colour, capillary filling and radial pulse palpation; continuous electrocardiographic display — lead II for dysrhythmia detection and a precordial V5 lead,180 modified bipolar CM3 lead181 or oesophageal lead182 to detect S-T segment changes associated with myocardial ischaemia; oesophageal stethoscope with thermal probe for heart/breath sounds auscultation and temperature monitoring; neuromuscular function monitoring and bladder catheterization for urine output determination. Direct intramerial pressure monitoring should be standard practice to permit beat to beat recognition of arterial pressure and any adverse haemodynamic response to aortic clamping procedures and for frequent blood gas determinations (Table IV). Occasional complications may be anticipated in patients with severe vascular disease in the cannulated extremity, prolonged low cardiac output states, particu-
Changes in right and left ventricular compliance are common in patients presenting for aortic vascular surgery. Wide variations have been reported in the prediction of a change of PCWP value based on a known change in CVP and preoperative resting left ventricular ejection fraction does not identify a subgroup of patients in whom CVP and PCWP correlate consistently throughout surgery. Recent reports have cited improved left ventricular and renal performance, with lower morbidity and mortality, following pulmonary artery catheterization and appropriate therapy based on the haemodynamic data obtained.

**MYOCARDIAL PERFORMANCE**

Pulmonary artery catheterization is especially indicated in patients with a history of previous myocardial infarction, angina pectoris or signs of cardiac failure; in patients demonstrating diminished ejection fraction or abnormal ventricular wall motion on preoperative resting or exercise radionuclide or echocardiographic studies and in patients with evidence of redistribution on dipyridamole-thallium imaging. In addition to measurement of pulmonary artery and capillary wedge pressure, pulmonary artery catheterization facilitates calculation of derived cardiac indices (stroke volume, cardiac index, left ventricular stroke work index) systemic and pulmonary vascular resistance and intrapolmonary shunt (Table V). The appearance of an abnormal V wave on the PCWP trace may indicate the onset of myocardial ischaemia before surface ECG S-T segment changes occur. The incorporation of fibreoptic oximetry into pulmonary artery catheters has enabled the perioperative monitoring of mixed venous oxygen saturation (SvO2). When employed in conjunction with other indicators of tissue oxygenation, SvO2 may serve as a useful assessment of cardiac output and the response to pharmacological interventions during aortic vascular surgery.

The incorporation of intraoperative transoesophageal two-dimensional echocardiography into anaesthetic practice has provided a practical means of estimating left ventricular dimensions and myocardial performance in addition to the detection of wall motion abnormalities. Radionuclide cardiology monitoring techniques will evolve from investigative research tools to intraoperative clinical monitoring techniques. Measurement of end-diastolic volume and end-diastolic area allows a more precise definition of left ventricular preload, compared with central venous and pulmonary capillary wedge pressure measurements. Left ventricular ejection fraction changes associated with induction of anaesthesia and critical events during surgery may be monitored and treated. Favourable initial comparisons between intraoperative cardiac output determination with transoesophageal echocardiography and thermodilution techniques have been reported. In addition, the development of regional wall motion abnormalities is an earlier and more sensitive method of detecting myocardial ischaemia, compared with surface ECG S-T segment changes. Less reduction in coronary blood flow is required to produce hypokinesia compared with ECG changes and contraction abnormalities appear first in the endocardium, preceding S-T segment changes from epicardial leads.

**Anaesthetic technique**

No single anaesthetic agent or technique is ideal for all patients presenting for aortic vascular surgery. The anaesthetic agents and techniques chosen should ensure a smooth induction of anaesthesia, a favourable cardiovascular dose–response relationship which preserves the delicate myocardial oxygen supply/demand balance, adequate muscle relaxation with intraoperative analgesia and amnesia. The choice of anaesthetic techniques includes nitrous oxide/oxygen with incremental volatile agent or opiate supplementation; opiate-oxygen or an opiate-oxygen-volatile agent combination with or without regional anaesthesia.

With the development of inert gas and labeled microsphere techniques for measuring coronary blood flow and metabolic indices for detecting myocardial ischaemia, it is now accepted that an anaesthetic technique which produces low-pressure, low-myocardial oxygen demand...
provides better preservation of myocardial oxygenation compared with a high-pressure, high-myocardial oxygen demand technique.197 Only limited data are available in the literature on the effect of anaesthetic technique on cardiac performance during aortic vascular surgery. A "balanced" nitrous oxide-oxygen-opiate-relaxant technique198 and a nitrous oxide-oxygen-volatile agent-relaxant technique199 have been associated with depressed left ventricular performance following induction of anaesthesia which persisted following aortic cross-clamp application. The addition of 50 per cent nitrous oxide to anaesthesia with halothane, enflurane or fentanyl in patients with coronary artery disease was associated with depressed left ventricular performance and metabolic evidence of subtle myocardial ischaemia.200,201 Hence the use of opioid analgesics as sole anaesthetic agents with oxygen and muscle relaxants for patients undergoing cardiac and major vascular surgery has achieved widespread popularity in recent years. Advantages cited include stable cardiovascular dynamics in patients with ischaemic heart disease,202 with suppression of the humoral and metabolic (catecholamine, cortisol, antidiuretic and growth hormone) responses to anaesthesia and surgery,203 and prolonged postoperative analgesia. High-dose fentanyl (100 μg·kg⁻¹) oxygen-relaxant anaesthetic technique has been evaluated for elective abdominal aortic surgery. Such an unsupplemented anaesthetic technique may be associated with an unacceptably high incidence of hyperdynamic circulatory responses to surgical stimuli before, during, and after aortic cross-clamping.204,205 Moreover, a prolonged elimination half-time was observed, which may be associated with prolonged postoperative respiratory depression, especially in patients with pre-existing pulmonary disease.206

Enflurane or halothane with oxygen consistently depresses myocardial contractility and oxygen demand and early postoperative hypertension has been frequently observed with these techniques.207 A combination of an opiate (fentanyl 30 μg·kg⁻¹ induction with maintenance infusion) with a volatile agent halothane208 or enflurane209 in oxygen maintains a reduced myocardial contractility, unchanged systemic vascular resistance, and preserved myocardial oxygenation in patients with good left ventricular function undergoing coronary artery by-pass grafting. The volatile agent may be titrated to prevent autonomic responses to stressful surgical stimuli. Theoretically, isoflurane is the volatile anaesthetic agent of choice for aortic vascular surgery. Despite its direct myocardial depressant effects, isoflurane administration is associated with preserved cardiac output due to increased heart rate and reduced systemic vascular resistance.210 In experimental studies performed with intact myocardial tissue and using equipotent concentrations, a lesser direct negative inotropic effect was observed with isoflurane than with either halothane or enflurane.211 A low concentration of isoflurane with nitrous oxide has been reported to protect against pacing-induced myocardial ischaemia in patients with documented ischaemic heart disease.212 Improved hepatic artery blood flow with comparable renal and cerebral blood flow has been reported with isoflurane compared with halothane.213 Unfortunately, in patients with coronary artery disease, isoflurane administration may be deleterious if a vasodilatory or coronary steal effect is produced. Moffitt et al.214 studied ten patients with good left ventricular function presenting for coronary artery by-pass surgery following isoflurane-oxygen administration for induction and maintenance of anaesthesia. Despite stable cardiac index and coronary blood flow, coronary vascular resistance decreased by 23 per cent and metabolic indices of global myocardial ischaemia were noted in three of ten patients studied. No such adverse effects were reported by the same authors in similar patient populations given halothane or enflurane.207 A higher incidence of postoperative congestive heart failure and renal insufficiency has been reported in patients following aortic surgery with isoflurane anaesthesia than with a sufentanil-based anaesthetic technique.215

The coronary arteriolar vasodilating properties of isoflurane are now well documented in experimental and clinical studies.216,217 The clinical implications of isoflurane-induced coronary arteriolar dilatation in patients with coronary artery disease remain controversial.218 Comparisons between isoflurane and halothane are difficult because studies have been performed using two markedly different coronary perfusion pressures. The adverse coronary steal effects associated with one per cent end-tidal isoflurane administration have been highlighted by Reiz et al.219 in patients with coronary artery disease presenting for aortic vascular surgery. With decreased coronary vascular resistance, myocardial oxygen consumption and extraction, ten of 21 patients developed ECG and metabolic changes associated with myocardial ischaemia. In contrast, the same authors noted decreased cardiac index, systemic vascular resistance, coronary sinus blood flow, myocardial oxygen consumption and no myocardial lactate production in aortic vascular surgery patients with coronary artery disease and evidence of heart failure using one per cent end-tidal halothane in 30 per cent oxygen.220 The authors suggested that unloading of the left ventricle by systemic vasodilatation predominates over the cardiac-depressant action of halothane in this patient population.

MANAGEMENT GUIDELINES

Guidelines for clinical practice based on data from patients with coronary artery disease and good left ventricular function presenting for coronary artery by-
pass grafting and limited information on patients with normal and impaired ventricular function undergoing abdominal aortic surgery would suggest that a combined opiate-oxygen-volatile anaesthetic agent will best ensure a hypodynamic circulation with preservation of myocardial oxygenation. Adequate premedication is required to avoid adverse haemodynamic responses to the placement of monitoring catheters before induction of anaesthesia. 221 Induction with fentanyl 30–50 μg·kg⁻¹ followed by maintenance fentanyl infusion in combination with oxygen-enflurane or oxygen-halothane should provide optimal myocardial supply-demand conditions. Based on current information, nitrous oxide and isoflurane should be used with caution in this patient population because of the reported risks of insidious global or regional myocardial ischaemia.

The prophylactic or specific use of vasodilatory agents to prevent haemodynamic changes associated with surgical interventions during aortic vascular surgery remains controversial. Evidence from experimental studies suggests that nitroglycerin infusion during aortic cross-clamping maintains cardiac index by preventing an increased systemic vascular resistance 222 while producing a transmural distribution of coronary blood flow which favours the endocardium. 223 In a clinical study low-dose (0.25 μg·kg⁻¹·min⁻¹) nitroglycerin infusion was reported to sustain myocardial contractility at pre-clamp levels, while preserving peripheral tissue blood flow. Sodium nitroprusside infusion may maintain normal intrarenal blood flow distribution and may preserve splanchic blood flow during infrarenal aortic cross-clamping. 224 However, nitroglycerin administration may decrease intestinal blood flow and shunt blood from the distal colon during aortic occlusion. 172 Sodium nitroprusside administration may produce myocardial ischaemia when administered in doses sufficient to reduce mean arterial pressure to 80 mmHg or less, presumably due to decreased coronary perfusion pressure, metabolite-induced toxicity 226 or a direct coronary vasodilatory steal effect. 227 The balance of evidence currently available would support the administration of 1–2 μg·kg⁻¹·min⁻¹ nitroglycerin infusion if hypertension, impaired myocardial contractility and tissue oxygenation or signs of myocardial ischaemia develop following aortic cross-clamping. 228 This therapy should decrease arterial pressure, systemic vascular resistance and myocardial oxygen consumption. Dobutamine intravenous infusion may also be administered to sustain myocardial contractility if evidence of impaired contractility develops following aortic cross-clamping. 229

**Intraoperative fluid and blood transfusion therapy**

Patients undergoing abdominal aortic surgery usually experience major functional extracellular fluid and blood loss. Functional extracellular fluid loss into a non-functional or "third-space" may follow extensive tissue trauma, manipulation, exposure and retraction. 230 Sequestration of fluid within the lumen wall of the intestine and major retroperitoneal oedema account for most of the fluid shift from the circulation. The issue of whether a crystalloid or colloid intravenous fluid regimen better preserves circulatory homeostasis and renal function during major vascular surgery has not been resolved. Restoration of normal intravascular and interstitial fluid volumes is a primary objective in intravenous fluid administration.

Larger volumes of crystalloid solution will be required to restore the intravascular volume compared with colloid solutions. Advocates of a crystalloid regimen claim greater urine output and a reduction in the incidence of oliguric renal failure following abdominal aortic surgery which they attribute to the use of balanced salt solution. 10 Despite the large volumes infused and the lower colloid osmotic pressures, similar extravascular lung water and pulmonary shunt fractions have been reported in studies 232, 233 comparing crystalloid with colloid infusions during major vascular surgery. Conflicting data have been published showing improved postoperative respiratory function following colloid administration. 234, 235 A combination of balanced salt and colloid solutions, guided by appropriate venous pressure monitoring, will ensure adequate intravascular volume, optimal cardiac output, satisfactory renal and end-organ blood flow, and minimal extravascular losses into the pulmonary interstitium and traumatized tissues.

A balanced salt solution, with or without a colloid solution, should be infused in volumes sufficient to maintain a PCWP of 10–15 mmHg during the cross-clamp period and to ensure a urine output greater than 60 ml·hr⁻¹. If urine output is unsatisfactory, despite PCWP measurement of 15 mmHg or greater, diuretic therapy with mannitol or furosemide should be considered. Low-dose dopamine (2 μg·kg⁻¹) following surgery has been reported to increase renal blood flow, glomerular filtration rate, urine output and sodium excretion. 236 The PCWP should be increased to 3–5 mmHg above the preoperative value before cross-clamp release to prevent declamp hypotension and cardiac output reduction.

The presence of a preoperative coagulation or bleeding diathesis should be established on direct questioning of the patient concerning family history, drug ingestion, the presence of bruising or easy bleeding and the detection of abnormalities on physical examination and laboratory investigation. Partial thromboplastin time (PTT), prothrombin time (PT), thrombin time, platelet count and bleeding time will help determine the nature of any haemostatic defect encountered. Up to 40 per cent of patients presenting for abdominal aortic surgery will have
significant elevation of fibrin split products. Overt disseminated intravascular coagulation will be detected only in a small minority of cases. 237

The greatest blood loss during elective abdominal aortic aneurysm resection usually occurs when the aneurysm is opened and the lumbar arteries are back-bleeding. Extensive blood loss may also arise at proximal and distal graft anastomoses, following graft flushing or secondary to inadequate surgical haemostasis, excess heparinization or bleeding diathesis. Blood transfusion should be commenced when blood loss exceeds 15 per cent of the patient's estimated blood volume. Homologous blood transfusion requirements have ranged from 1.5 to 5.5 units depending on surgical skill, the extent of grafting procedures and the duration of surgery. 238 The potential complications of multiple homologous blood transfusions during elective aortic vascular surgery are well known, especially the risk of transfusion-transmitted diseases such as acquired immune deficiency syndrome, hepatitis and syphilis. 239

The techniques currently available to minimize homologous blood transfusion during elective aortic vascular surgery include multiple pre-deposit autologous collection, storage and retransfusion; immediate preoperative phlebotomy, haemodilution and autologous transfusion; intraoperative blood salvage and reinfusion. Intraoperative autotransfusion may be an economic method of significantly reducing homologous blood transfusions. Initial reports 240 suggested a 40–50 per cent avoidance of homologous blood transfusions, which has increased up to 80 per cent in recent studies. 241 The initial application of autotransfusion was complicated by haemolysis and coagulation disorders; air and fat emboli; platelet and leucocyte microaggregation and sepsis. 242 Technological advances have virtually eliminated the problems of air and particulate embolization. No significant haemolysis or coagulopathies have been noted with autotransfusion techniques in recent studies. 243 Because autotransfused blood is, in essence, a preparation of washed, packed red blood cells suspended in saline solution without platelets or clotting factors, fresh frozen plasma and platelet concentrate transfusion may be necessary. Autotransfusion, by providing fresh warm blood with optimal pH and 2–3 DPG content, 244 may prevent some of the adverse cardiovascular effects associated with extensive stored homologous blood therapy. 244

Regional anaesthesia

Continuous epidural anaesthesia has been frequently used in association with general anaesthesia and, on occasion, as the primary anaesthetic technique for patients undergoing aortic vascular surgery. 245 Proponents of regional anaesthesia claim reduction in volatile anaesthetic and narcotic requirements and significant alleviation of postoperative pain. Elevation in skin temperature, increased graft blood flow and reduced muscle blood flow have been observed. 246 Combined regional and general anaesthetic techniques may attenuate the increased systemic resistance with aortic cross-clamping 247 and may produce stable cardiovascular dynamics following cross-clamp release if intravascular volume is maintained. 248 Experimental studies suggest that cervico-thoracic epidural blockade may redistribute coronary blood flow, favouring the endocardium, in both the normal and infarcted heart. 249 Recent randomized prospective data from mostly major vascular surgical patients comparing general and epidural–general anaesthetic techniques noted fewer postoperative cardiovascular complications in the group receiving regional anaesthesia. 250

Despite the well known and accepted advantages of regional anaesthesia alone, or in combination with general anaesthesia and tracheal intubation, these techniques have not been universally adopted, partly due to the lingering controversy surrounding epidural catheters and anticoagulant therapy. Occasional case reports have documented the occurrence of peridural haematomas leading to transient or permanent neurological impairment. 251,252 The relative safety of anticoagulation following epidural catheter insertion was impressively established by Rao et al. 253 in a study involving 3,164 patients. Utilizing proper patient selection, atraumatic techniques and appropriate heparin administration based on activated clotting time monitoring, these investigators noted no peridural haematoma leading to spinal cord compression. Notwithstanding Odorn et al.'s 254 report of no epidural haematoma formation or spinal cord compression in 1,000 lumbar epidural blocks in vascular surgery patients already anticoagulated, most authorities consider the use of epidural anaesthesia contraindicated in patients already anticoagulated. 255 The use of combined general anaesthesia and continuous lumbar epidural anaesthesia for major aortic vascular surgery has increased during the past decade. This technique has been associated with greater total perioperative fluid volume administration and reduced left ventricular function compared with general anaesthesia alone. 256 The merits of combined regional and general anaesthetic techniques, compared with conventional general anaesthesia alone for aortic vascular surgery, must await the publication of more extensive clinical investigations. 257

Postoperative management

Patients recovering from aortic vascular surgery are at risk of developing cardiac, respiratory and renal failure in the immediate postoperative period. Close monitoring of the patient's intravascular volume status, temperature, respi-
Hypertension is a common and potentially serious complication in the immediate postoperative period following abdominal aortic surgery. Postulated mechanisms include overzealous hydration during anaesthesia and exaggerated replacement of blood loss; re-bound hypertension following vasodilator therapy; pre-existing hypertension and vascular hyper-reactivity. Conflicting findings have been reported by different groups studying plasma renin activity during experimental and human aortic vascular surgery. Depending on the extent of intraoperative hydration, plasma renin activity may increase or remain unchanged following aortic cross-clamping. Renal renin response could be reduced by volume infusion and blocked by the prior administration of propranolol. A consistent feature of recent studies is the lack of correlation between postoperative hypertension and plasma renin activity or angiotensin II levels in the recovery room. Preoperative propranolol administration inhibited the renin response to anaesthesia, surgery and aortic cross-clamping but postoperative hypertension still remained a problem in this group.

A positive correlation has been observed between elevated mean preoperative arterial pressure and postoperative hypertension. Adequate preoperative antihypertensive therapy may be the most important prophylaxis against postoperative hypertension, with its attendant risks of myocardial ischaemia and infarction. Antihypertensive medications should be administered until induction of anaesthesia and should be resumed as soon as possible in the postoperative period. An acute hypertensive response may be observed in the recovery room due to pain, apprehension, volume overload, hypoxaemia or hypercapnia. Treatment of postoperative hypertension involves excluding an underlying cause and prompt initiation of anti-hypertensive therapy. Nitroprusside, commencing at 0.5–1 μg·kg⁻¹·min⁻¹, or nitroglycerin, commencing at 1–2 μg·kg⁻¹·min⁻¹, may be chosen because of their prompt onset, titratable dose–response and rapid reversal on discontinuing drug administration. A more delayed onset of 15–30 minutes and frequent tachycardia may follow intravenous hydralazine administration. Incremental doses of 0.5–1 mg propranolol may effectively control postoperative hypertension, especially if the patient has been taking beta-adrenergic blocking drugs preoperatively. Labetalol, a combined alpha- and beta-adrenoceptor antagonist, may produce the desired blood pressure reduction without compensatory tachycardia. The preoperative administration of 200–300 mg clonidine, an alpha₂-adrenergic agonist, may prove a useful agent to prevent hyperdynamic responses in the postoperative period.

Summary
Patients presenting for abdominal aortic surgery have a high incidence of vascular disease elsewhere, manifested primarily by hypertension, coronary and cerebrovascular disease, as well as co-existing respiratory, renal and metabolic disorders. Routine clinical assessment, electro-
TABLE VI Abdominal aortic surgery—guidelines for anaesthetic management

1 Preoperative hydration
   Maintenance fluids IV overnight

2 Premedication
   Benzodiazepine ± opiate

3 General anaesthesia
   Induction
     - opiate: fentanyl 50 μg·kg⁻¹
     - relaxant: non-depolarizing
   Maintenance
     - O₂
     - Opiate: fentanyl 20–30 μg·kg⁻¹·hr⁻¹
     - Volatile: incremental enfluran/halothane
     - Ventilation: controlled normocapnia
   Nitroglycerin
     - Myocardial ischaemia
     - Hypertension > 20% baseline arterial pressure

4 Intravenous fluid management
   Crystalloid infusion ± colloid
   - PCWP 10–15 mmHg
   - Urine output > 60 ml/hr
   Blood
   - Loss > 15% estimated blood volume
   Mannitol
   - Urine output < 60 ml·hr⁻¹ + PCWP > 15 mmHg

5 Postoperative management
   Mechanical ventilation
   - Cardiac and respiratory homeostasis
   Regional anaesthesia
   - Postoperative analgesia

The haemodynamic consequences of aortic cross-clamping, especially in aneurysm patients, include a significant reduction in stroke volume, cardiac index, and myocardial oxygen consumption with an increased systemic vascular resistance. Patients with coronary artery disease may respond to aortic cross-clamping by increasing pulmonary capillary wedge pressure and by demonstrating ECG evidence of myocardial ischaemia. Pulmonary artery catheterization is especially indicated in patients with a history of previous myocardial infarction, angina or signs of cardiac failure and in patients with evidence of diminished ejection fraction, abnormal ventricular wall motion or myocardial redistribution on preoperative scanning. The more widespread application of intraoperative transoesophageal two-dimensional echocardiography and radionuclide cardiography monitoring techniques into anaesthetic practice will enable measurement of left ventricular dimensions, myocardial performance and wall motion. Suggested guidelines for anaesthetic management are presented in Table VI.

A combined opiate-oxygen-volatile anaesthetic agent technique will best ensure a hypodynamic circulation with preservation of myocardial oxygenation. Nitrous oxide and isoflurane should be avoided, if possible, in this patient population because of the risk of insidious global or regional myocardial ischaemia. Nitroglycerin infusion should be commenced if hypertension and signs of impaired myocardial contractility tissue oxygenation or myocardial ischaemia develop following aortic cross-clamp application. Preoperative replacement of extracellular fluid deficits; prompt and aggressive intravenous hydration and blood loss replacement, guided by appropriate monitoring techniques; a stable cardiac output and optimal surgical techniques are the best prophylactic measures to ensure adequate renal, spinal cord and intestinal blood flow and function during the perioperative period. Adequate preoperative antihypertensive therapy remains the most important prophylaxis against postoperative hypertension, with all its attendant risks of myocardial ischaemia and infarction. The relative safety of anticoagulation following epidural catheter insertion has been recently established. The merits of a combined general and regional anaesthetic technique await further detailed scrutiny.

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