ANAESTHESIA FOR PATIENTS WITH CORONARY ARTERY DISEASE

J. L. WALLER AND J. A. KAPLAN

Much has been written during the past decade regarding the anaesthetic management of patients with coronary artery disease (CAD). The early literature on this topic focused upon care of patients undergoing cardiopulmonary bypass for surgical correction of their cardiac conditions. However, more recent discussions have turned toward the management, during non-cardiac surgery, of patients whose underlying cardiac disease has not been corrected. This review concerns the latter group of patients.

The goals to be achieved in the management of patients with CAD may be divided into two broad categories: the preservation of myocardial performance (ventricular function), and prevention or treatment of myocardial ischaemia. Accomplishment of these goals is a complex task requiring coordination of anaesthetic care, monitoring and pharmacological intervention.

EVALUATION BEFORE OPERATION

The presence of CAD modifies not only the management of a patient while he is undergoing surgery, but also requires additional steps in preoperative evaluation and preparation for operation. In addition to the information routinely obtained from a medical history and physical examination, the patient's cardiovascular status should be evaluated in considerable detail. Information regarding the anatomical diagnosis, predominant symptoms, the clinical course and complications should be obtained. An effort should be made to quantitate the patient's disability resulting from CAD, in terms of reduced exercise tolerance. The specific date of the most recent myocardial infarctions should be obtained, since Tarhan and others (1972) and Steen, Tinker and Tarhan (1978) have shown a clear relationship between recent infarctions and perioperative mortality. Precise information as to the patient's current drug treatment, the doses and the response to therapy should be noted, with particular attention to digitalis preparations, diuretic, anti-arrhythmic and antihypertensive agents, nitrates and beta-adrenoceptor blocking drugs. Data from nursing notes, treatment schedules and other physician's consultations, as well as from haematological, biochemical, radiological and e.c.g reports supplement the medical history and physical examination.

In evaluating a patient's cardiac status, two interrelated but separate aspects of heart function are considered individually. These are the myocardial oxygen supply–demand relationship and the function of the heart as a pump. The acquisition and review of the above data allow for the preanaesthetic classification of patients into categories useful in their subsequent care. The New York Heart Association Classification and Goldman's Cardiac Risk Index are two such schemes (table I). We have found that categorizing the extent of CAD and the state of left ventricular function are more helpful than either of the above schemes or the American Society of Anesthesiologists' Physical Status Classification. We have previously classified these patients into two categories (Waller, Kaplan and Jones, 1979):

(I) Those with signs and symptoms of ischaemic heart disease and good left ventricular function

(II) Those with signs and symptoms of ischaemic heart disease with poor left ventricular function

While such a scheme has proved helpful, we now believe it fails to call attention to another important sub-group, namely those with ischaemic heart disease who have intermittent signs and symptoms of left ventricular dysfunction (IA). The majority of patients with symptomatic CAD presenting for elective operations fit into groups I
or IA (table II). The major differences between patients in groups I and II relate to their response to stress or exercise. Both groups of patients give historical evidence of good left ventricular function at rest. These patients frequently have angina as their primary problem. They may also have a history of hypertension, but do not have classic findings of chronic left ventricular dysfunction. With exercise, however, patients in group IA become identifiable. Historically, they report the

TABLE II. Classification of patients with coronary artery disease. 
= Usually absent; ± = variable; + = usually present. 
ETT = exercise tolerance test.

<table>
<thead>
<tr>
<th>Symptoms</th>
<th>Group I</th>
<th>Group IA</th>
<th>Group II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angina</td>
<td>±</td>
<td>±</td>
<td>±</td>
</tr>
<tr>
<td>Dyspnoea:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At Rest</td>
<td>–</td>
<td>–</td>
<td>+</td>
</tr>
<tr>
<td>Exercise</td>
<td>–</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Findings</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hypertension</td>
<td>±</td>
<td>±</td>
<td>–</td>
</tr>
<tr>
<td>E.c.g. change</td>
<td>±</td>
<td>±</td>
<td>±</td>
</tr>
<tr>
<td>ETT</td>
<td>±</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>LV dysfunction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At rest</td>
<td>–</td>
<td>–</td>
<td>+</td>
</tr>
<tr>
<td>Exercise</td>
<td>–</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

development of dyspnoea, with or without angina, during exercise. Invasive and non-invasive studies of left ventricular function, performed during exercise, often reveal startling impairment of the heart in these patients, whose resting studies are normal or near normal (Bailey et al., 1977; Borer, Bacharach and Green, 1977; Okada et al., 1979). It is little wonder then that resting studies of left ventricular performance often fail to indicate a patient's left ventricular functional response to the stress of exercise or the noxious stimuli of surgery. Patients in group II classically have had one or more myocardial infarctions, and often have signs and symptoms of chronic congestive heart failure and decreased cardiac output. Invasive and non-invasive ventricular function tests may reveal numerous areas of abnormal ventricular wall motion. These patients are likely to have received digitalis, diuretics and even vasodilator drugs before operation to manage their heart failure.

Myocardial oxygen balance

The maintenance of the balance between myocardial oxygen supply and myocardial oxygen demand is the sine qua non of anaesthetic management for the patient with CAD. The pendulum of
emphasis upon either the supply side or the demand side of the oxygen balance equation has swung full cycle during the past decade. Earlier discussions of anaesthetic management of coronary patients stressed the maintenance of oxygen supply,—“avoid hypoxia and hypotension". Subsequent emphasis upon the avoidance of excessive myocardial oxygen demand by controlling heart rate, preload, afterload and contractility gained popularity in the late 70's. The most recent data have refined our understanding of myocardial oxygen demand, and in fact suggest that heart rate and diastolic ventricular volume exert their most important influences on the myocardial oxygen supply side of the balance. This is especially true of the heart rate. A number of investigators have demonstrated that the myocardial oxygen consumption per beat remains constant over a wide physiological range of heart rates if preload and afterload are constant (M. B. Laver, 1980, personal communication). Therefore, rapid heart rates exert their primary deleterious effect upon the myocardial oxygen balance by reducing the duration of diastole, and therefore coronary arterial perfusion time. Recently Boudoulas, Rittgers and Lewis (1979) have shown that the relationship between heart rate and the percent of diastole in each cardiac cycle is non-linear. Most perfusion of the coronary arteries distal to significant, partially obstructing lesions occurs after the cessation of electromechanical systole. Therefore, the percent diastole (determined by subtracting the period of electromechanical systole (Q-S₂) from the total R-R interval) decreases exponentially with increasing heart rates. Likewise, increased diastolic heart volume (preload) not only increases the myocardial oxygen demand by increasing ventricular wall tension, but also impairs perfusion in the coronary microcirculation since this transmitted tension compresses microscopic intramyocardial and subendocardial vessels. This reduces perfusion (Ellis and Klocke, 1979). In summary, a rapid heart rate and an abnormally high diastolic heart volume are the two aberrations of the determinants of myocardial oxygen supply and demand most likely to produce myocardial ischaemia. Increase in afterload or contractility, the other major indices of oxygen demand, may offset to some degree their own tendency to increase myocardial oxygen demand by simultaneously increasing the arterial pressure and thus the myocardial oxygen supply (Barash and Kopriva, 1980). In the patient with CAD and good left ventricular function, hypertension and tachycardia as a result of inadequate attenuation of the responses to noxious stimuli during surgery and anaesthesia are the most likely mechanisms for upsetting the myocardial oxygen balance. Conversely, in patients with ischaemia and poor left ventricular function, tachycardia and increased ventricular filling pressure without hypertension are likely to accompany noxious stimulation (Waller, Kaplan and Jones, 1979).

Drug therapy before surgery

The preoperative drug therapy of patients with CAD is based upon all these considerations. It is now generally accepted that patients with CAD should continue their long-term drug therapy until the time of surgery. In fact, many of these same drugs are now administered during operation.

Glyceryl trinitrate (nitroglycerin) has been a mainstay in the management of angina pectoris for more than a century. By its primary effect of increasing venous capacitance and causing peripheral pooling of blood and reduction of venous return, this drug markedly decreases heart size, wall tension and ischaemia (Mason, Zelis and Amsterdam, 1971). Larger doses also produce arteriolar vasodilatation (Hill, Antman and Green, 1981). Nitroglycerin also has been shown to cause a favourable redistribution of coronary blood flow via collateral circulation to subendocardial areas of ischaemia (Mehta and Pepine, 1978).

The beta-adrenergic blocking drugs have been used with increasing frequency in the management of patients with ischaemic heart disease, since they reduce heart rate, arterial pressure and myocardial contractility and also protect against arrhythmias (Ahlquist, 1977). Earlier fears of adverse interactions between beta-adrenergic blocking drugs and anaesthetic agents have proved largely unfounded (with the possible exception of methoxyflurane). Most major cardiovascular centres now recommend the maintenance of patients on beta-blockers until immediately before the surgery, the administration of beta-blockers at the time of premedication, and their further use during operation when anaesthetic drugs fail to control tachycardia (Kaplan and Dunbar, 1976).

Calcium channel blocking drugs represent a relatively new class of drug. They have been used
in the treatment of arrhythmia, hypertension, coronary artery disease, and in the protection of the heart from ischaemic damage (Ellrodt, Chew and Singh, 1980). While the exact site of action of these drugs is not established clearly, they appear to block the transit of calcium through the slow channel of the cell membrane and inhibit the release of calcium from various intracellular pools (Henry, 1980). 

In vitro studies have demonstrated dose-related decreases in myocardial contractility which are much greater with some of the calcium antagonists than with others. In vivo, however, the primary effect of most of these drugs is a decrease in vascular resistance which occurs in the coronary, systemic, and pulmonary vascular beds (Zsoter, 1980). Nifedipine, a prototype of this class of drug, has produced its most striking results in the treatment of variant angina (Antman et al., 1980). This can be explained by its ability to prevent coronary vasospasm. While it is also effective in the management of classical angina, it has not been proven to be superior to the standard treatment with beta-blocking drugs and nitrates in prevention of anginal attacks. However, it may be a useful additional drug in patients with this condition.

**E.C.G. MONITORING**

E.c.g. monitoring for detection of myocardial ischaemia is now standard practice in the operating room. Earlier studies of e.c.g. monitoring during operation referred primarily to standard limb lead II (Cannard, Dripps and Helwig, 1960). Lead II was chosen because its axis parallels the P-wave vector, thus making identification of the P-wave easier and aiding in the differentiation of supraventricular from ventricular arrhythmias. Although cardiologists have long recognized that precordial leads are the most likely to detect ST-segment changes during conventional exercise electrocardiography (Mason, Likar and Biern, 1967), it was not until the 70's that this information was widely applied to the operating room setting. Foëx and Prys-Roberts (1974), Dalton (1976) and Kaplan and King (1976) recommended various systems which include a precordial lead for the detection of ischaemia during operation in patients with CAD. A system allowing the simultaneous observation of a precordial lead (V₅ or CM₅) and lead II, using two separate e.c.g. channels, permits the detection of both anterior and inferior myocardial ischaemia. ST–T wave changes seen in a precordial lead usually correspond to ischaemia of the left ventricle. With the e.c.g. standardized to 1 mV per 10 mm, a 1-mm horizontal or down-sloping ST segment depression from baseline represents significant myocardial ischaemia, and greater magnitudes of depression are generally thought to represent increased ischaemia. Up-sloping ST segment depression (J-point depression) and various T-wave changes may reflect ischaemia, but are not specifically diagnostic. ST segment elevations of greater than 1 mm usually represent transmural myocardial ischaemia (Belic and Gardin, 1980).

In several centres there has been a recent renewal of interest in e.c.g. tracings obtained from endocardial or oesophageal electrodes (Kistin and Bruce, 1957). Positioning of these electrodes to maximize P-wave amplitude can greatly simplify the diagnosis of supraventricular arrhythmias (fig. 1). It is not yet clear if important information regarding subendocardial ischaemia can also be obtained from these electrodes.

Various invasive and non-invasive monitoring devices have been used to detect the changes in global or regional myocardial performance which are often associated with myocardial ischaemia. Sudden reductions in ejection fraction, new ventricular wall motion abnormalities and the sudden onset of papillary muscle dysfunction have been detected by echocardiography (Elliot et al., 1980) or real-time radionuclear techniques (Barash et al., 1980) during anaesthesia. Additionally, increases in the amplitude of the A or V waves, or both, in a pulmonary capillary wedge pressure tracing have been observed to occur with, or even precede, the development of ST segment depression on the e.c.g. during stimulation in these patients (Wells and Kaplan, 1980) (fig. 2).

![Fig. 1. Progression of arrhythmia. An oesophageal e.c.g. tracing (oesoph) is compared with a precordial (V₅) tracing. The ease of P-wave identification facilitates diagnosis of the progression from normal sinus rhythm (left) to atrial flutter and fibrillation (centre and right) which is not clearly shown by the surface e.c.g.](image-url)
Although the meaning of such changes has not been elucidated fully, they may be an indication of the reduction in diastolic ventricular compliance, which appears to represent the earliest detectable change of myocardial ischaemia in the cardiac catheterization laboratory (Wiener, Dwyer and Cox, 1968). Therefore, whilst ECG monitoring remains the standard method of detecting ischaemic changes, various monitors which can detect early changes in regional ventricular performance may yield earlier and more precise information regarding the development and progression or regression of ischaemia (Barnard, Buckberg and Duncan, 1980).

ANAESTHESIA

The major goals of intraoperative care in patients with CAD are to prevent or treat myocardial ischaemia while preserving or improving left ventricular function. The methods of achieving these goals are fundamentally different in patients with good left ventricular function as opposed to those with very poor left ventricular function. In general, the major focus of therapy in patients with good ventricular function is to produce an anaesthetic state sufficiently deep to assure attenuation of the autonomic responses to noxious stimuli while still preserving adequate haemodynamic function. No one technique using single or multiple anaesthetic drugs, with or without the addition of vasoactive agents, has been shown to be superior to any other technique. Therefore, the approach to these patients varies widely among major cardiovascular centres. In patients with good left ventricular function, ischaemia is often the result of a hyperdynamic circulatory state in which heart rate, arterial pressure and, at times, ventricular filling pressures are increased. There-
fore, the use of anaesthetic drugs which produce controllable myocardial depression has become increasingly popular. The short-acting thio-barbiturates, such as thiopentone, enjoy wide use for the induction of anaesthesia in this group of patients. The barbiturates depress myocardial contractility, reduce ventricular filling pressures secondary to venous pooling of blood, and reduce the sympathetic nervous system outflow, tending to decrease myocardial oxygen demand (Seltzer, Gerson and Allen, 1980).

Large doses of the narcotic analgesics have also been recommended by Lowenstein and others (1969) as induction agents for patients with CAD. The failure of even very large doses of morphine to provide adequate amnesia and reflex attenuation in patients with good left ventricular function has been known for some time (Lowenstein, 1971). Recently, the suggestion has been made (Lunn et al., 1979) that use of large doses of fentanyl without the addition of the other anaesthetic drugs overcomes these problems. However, Waller and others (1981) have shown that this technique may also fail to provide adequate reflex blockade. Despite the limitations of narcotic anaesthetics as sole induction agents for these patients, they clearly have a role in augmenting other anaesthetic measures. The combination of narcotics with benzodiazepines or butyrophenones has also been recommended (Stanley, Bennett and Loeser, 1976). Diazepam is one of the benzodiazepines widely used for this purpose (Jones, Stehling and Zauder, 1979). It has become popular because of the profound amnesia produced and its relatively benign effects on the cardiovascular system, including a slight reduction in arterial pressure and little change in cardiac output and filling pressures (McCammon, Hilgenberg and Stoelting, 1980). In addition, a coronary vasodilator effect of diazepam has been suggested (Ibrahim, Ruben and Jewkes, 1973), and there is evidence that, in patients with increased left ventricular filling pressures, a small dose of diazepam can reduce this pressure (Côté, Campeau and Bourassa, 1976).

After the patient loses consciousness, inhalation drugs are commonly used as a part of the technique in the United States. Fifty percent nitrous oxide in oxygen, plus potent volatile agents such as enflurane, halothane or isoflurane may be administered to obtain an adequate depth of anaesthesia before the stimulus of tracheal intubation. The combined effect of these drugs produces some depression of left ventricular performance, which aids in preventing undesirable increases in arterial pressure and heart rate during laryngoscopy and intubation (Roy, Edelist and Gilbert, 1979). The potent volatile anaesthetics are especially useful during operation since they provide controllable, rapidly reversible, myocardial depression. Halothane has been shown to reduce myocardial work and oxygen consumption (Sonntag et al., 1979), and may increase the coronary vascular reserve (Merin, 1980; Verrier et al., 1980). Bland and Lowenstein (1976) showed that 1-MAC halothane anaesthesia reduced the severity of myocardial ischaemia caused by coronary ligation in dogs. Enflurane and isoflurane also cause dose-dependent myocardial depression and they appear to produce more arteriolar dilatation and fewer arrhythmias than does halothane (Delaney et al., 1980).

The narcotic analgesics are used most often for anaesthetizing patients with poor left ventricular function, since they are relatively free of myocardial depressant properties. Morphine continues to be used widely in doses ranging from 0.5 to 3 mg kg\(^{-1}\) body weight. Recently, attention has been focused upon the substitution of large doses of fentanyl for morphine in narcotic anaesthetic techniques. Fentanyl appears to be desirable because it evokes little if any histamine release and therefore is less likely than morphine to produce hypotension during induction of anaesthesia. Doses ranging from 50 to 150\(\mu\)g kg\(^{-1}\) have been shown to produce cardiovascular stability and attenuation of sympathetic responses to noxious stimulation (Lunn et al., 1979). Preliminary work with sufentanil and other fentanyl analogues suggests that they may be superior to fentanyl in this regard (de Lange, Stanley and Boscoe, 1980). Nitrous oxide, which has relatively benign haemodynamic effects in patients with good ventricular function, may not be tolerated by the sickest patients because of its myocardial depressant properties. However, it is often helpful when used intermittently during the most stressful periods of an operative procedure. The potent volatile anaesthetics usually are not used in this group of patients because of their myocardial depressant effects.

The preceding discussion has focused on the anaesthetic management of patients with either
good or poor left ventricular function. However, there is a spectrum of left ventricular function apparent during surgery. Patients starting with good left ventricular function may demonstrate signs of myocardial dysfunction during periods of stress or ischaemia. Conversely, patients with impaired left ventricular function may show improvement with decreased oxygen consumption under anaesthesia. Therefore, the majority of patients should be considered to be in a dynamic state, with ventricular function varying throughout the course of anaesthesia and surgery. For this reason, the choice of anaesthetic and cardioactive drugs should be made and constantly reassessed for each individual patient, based upon information derived from continuous monitoring. We have found that the induction of anaesthesia with a narcotic and tranquillizer combination is useful even in patients with good left ventricular function (Waller, Kaplan and Jones, 1979). Using this basal anaesthetic, low concentrations of the potent inhalation anaesthetic agents can be added as needed to achieve adequate depth of anaesthesia. Thereafter, should the patient's ventricular function deteriorate, the volatile agent can be eliminated quickly.

PHARMACOLOGICAL INTERVENTION

Despite the most skillful manipulation of anaesthesia, ischaemia still may result during surgery. Recognition of this fact has led to the use of a variety of drugs to treat ischaemia and to prevent it. Vasodilators and beta-adrenergic receptor blocking drugs are the primary agents used for this purpose (table III). Vasodilators are used to treat episodes of hypertension, increased left ventricular filling pressure or coronary artery spasms. I.v. nitroglycerin (Kaplan, Dunbar and Jones, 1976) and sodium nitroprusside (Lappas, Lowenstein and Waller, 1976) are the drugs most commonly used. Other vasodilators, such as phenothiazines, ganglionic blocking drugs, and alpha-adrenergic receptor antagonists are sometimes used. These drugs produce varying degrees of arteriolar and venous dilatation with variable effects on preload, afterload and overall haemodynamics. Nitroglycerin is our drug of choice during operation for patients with CAD in the following situations: hypertension; increased pulmonary capillary wedge pressure or the appearance of large A and V waves in the wedge pressure tracing; e.g. changes of ischaemia; coronary artery spasm; recent or evolving myocardial infarction.

In selected situations, nitroglycerin and phenylephrine may be used in combination. Borer, Redwood and Levitt (1975) have shown that this combination may reduce myocardial ischaemia more than nitroglycerin alone. The rationale is that nitroglycerin decreases the preload of the heart while the vasopressor maintains diastolic perfusion pressure during the administration of the vasodilator. We have found this drug combination to be especially useful in patients with either severe left main coronary artery disease or unstable angina.

Patients with poor left ventricular function may require inotropic support during the course of an anaesthetic. Calcium chloride and ephedrine are useful when administered in bolus forms, since they are relatively short-acting and produce moderate increases in myocardial contractility (Hug and Kaplan, 1979). More intense and prolonged inotropic support may be provided by the infusion of sympathomimetic drugs such as dobutamine, dopamine or, in the most extreme situations, adrenaline, noradrenaline or isoprenaline. Many investigators have shown that vasodilators such as nitroprusside may be added to the inotropic drugs to maximize their effects on cardiac output and ventricular function.

<table>
<thead>
<tr>
<th>Table III. Therapeutic interventions for ischaemia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Associated with:</td>
</tr>
</tbody>
</table>
| Increased arterial pressure | a. Deepen anaesthesia  
   b. Vasodilator  
   c. Beta-blocker |
| Increased heart rate | a. Deepen anaesthesia  
   b. Beta-blocker |
| Increased PCWP or CVP | a. Vasodilator  
   b. Restrict fluids  
   c. Diuretic  
   d. Inotropic agent |
| Decreased arterial pressure | a. Lighten anaesthesia  
   b. Restrict fluids  
   c. Inotropic agent or vasopressor |
| Arrhythmias | a. Lignocaine  
   b. Beta-blocker  
   c. Calcium-blocker |
| Coronary artery spasm | a. Vasodilator  
   b. Calcium-blocker |
SUMMARY
Safe anaesthetic management techniques for patients with coronary artery disease have been devised. Thorough familiarity with the underlying pathophysiological principles, and the techniques for circulatory monitoring and anaesthetic management is required if optimal anaesthetic care is to be assured.

REFERENCES

BRITISH JOURNAL OF ANAESTHESIA


SUMMARY
Safe anaesthetic management techniques for patients with coronary artery disease have been devised. Thorough familiarity with the underlying pathophysiological principles, and the techniques for circulatory monitoring and anaesthetic management is required if optimal anaesthetic care is to be assured.

REFERENCES


