Preoperative evaluation of cardiac risk

Ventricular function is the most important predictor of cardiac risk for non-cardiac major surgery. There is now good evidence that patients with coronary artery disease without cardiac failure are at no higher risk for postoperative cardiac events than the general population.

Preoperative evaluation of cardiac risk should answer the question 'Can this patient safely undergo major non-cardiac surgery?' (Bodenheimer, 1996). All too often the preoperative evaluation attempts to answer quite a different question 'Does this patient have coronary artery disease?' At the authors' institutions, and probably many others, this approach results in the patient having a series of tests to evaluate the state of the coronary arteries. There is very little evidence that invasive procedures on the coronary vasculature improve the outcome of major non-cardiac surgery. One could then ask why these tests are performed?

Little or no importance is attached to evaluation of ventricular function; as this article will show, this is the aspect that must be addressed.

Evaluation of risk

Preoperative scoring systems

American Society of Anesthesiology classification

In 1963 the American Society of Anesthesiology published the *New classification of physical status* (American Society of Anesthesiology, 1963). This system is still used by many anaesthetists to assess overall risk for non-cardiac surgery and is certainly useful in performing group statistics.

Goldman Index

One of the best known risk evaluations is the Goldman Cardiac Risk Index (Goldman et al, 1977). It has been argued this study was not truly prospective (Tinker, 1981) and uses symptoms and signs rather than a clinical diagnosis (Howell and Sear, 2004). This may have led many to place less emphasis on cardiac failure, as it is not identified specifically as a risk factor. Cardiac failure is implied from the presence of jugular venous distension or a third heart sound, although these signs may well be absent in patients with cardiac failure. It nevertheless remains an important milestone in the development of risk assessment indices.

Detsky modification of Goldman Index

A modification of the Goldman Index was published by Detsky et al (1986). This modified the criteria for heart failure (HF) and added a measure of angina severity.

Evaluation of the indices

A common thread through these systems is the concept that ischaemic heart disease represents the major risk factor. As explained by Kertai et al (2004), plaque rupture accounts for only half of perioperative myocardial events and prediction of perioperative myocardial infarction based on location and severity of coronary lesions is unreliable.

Gilbert and colleagues (2000) found that none of the above indices were significantly better than any other and that they all performed poorly in prediction of postoperative cardiac events.

Lee Revised Cardiac Risk Index

Lee and colleagues (1999) proposed a system which used inherent surgical risk and clinical diagnoses to derive a Revised Cardiac Risk Index (RCRI). This removed one of the issues raised by Howell and Sear (2004) that the original Goldman Index was based on symptoms and signs. It is noteworthy that Goldman is one of the authors of the Lee paper.

Lee et al examined a total of 4315 patients; of these, 2893 patients were assigned to a cohort that was used to develop the RCRI. The validation cohort consisted of 1422 patients. Six independent predictors of postoperative cardiac events were identified:

1. High-risk type of surgery
2. History of ischaemic heart disease
3. History of congestive cardiac failure
4. History of cerebrovascular disease
5. Insulin dependent diabetes
6. Elevated preoperative serum creatinine level.

Each of these risk factors was allocated equal weight. The Lee index places a patient with three or four risk factors at only an 11% chance of a complication. This highlights the problem that this and other studies are based on

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group statistics and their relevance to an individual is less clear. The authors suggest that the risk classification may be useful in identifying patients in whom further investigation may be warranted.

American College of Cardiology/American Heart Association guidelines

The American College of Cardiology/American Heart Association (ACC/AHA) task force published a comprehensive set of guidelines to help the clinician in preoperative cardiac evaluation (Eagle et al, 1996). The reader is urged to obtain the latest update (Eagle et al, 2002), particularly because of the broad base and scope of the document.

Functional capacity, i.e. cardiac failure

Importantly, in these guidelines there are several references to the relevance of both cardiac failure and coronary artery disease (CAD). Much emphasis is placed on functional capacity, which has been shown to be a reliable predictor for perioperative and long-term cardiac events. The importance of attempting to assess functional capacity as a surrogate of maximum oxygen uptake is highlighted and there is acknowledgment of the problem of detecting unsuspected cardiac failure.

London et al (2004) suggest the myocardial oxygen supply–demand balance as another mechanism for major cardiac complications. The actual mechanism is unclear; they postulate a variety of aetiological factors, including impaired ventricular function and reduced coronary perfusion pressure. They acknowledge that:

> **'limited physiologic data collection, most notably markers of the stress response or delineation of ventricular function have frustrated efforts to determine causal mechanisms'.**

Estimates of functional capacity are not objective

The guidelines discuss estimates of functional capacity in terms of METs. One 'MET' is the oxygen consumption of a 70 kg, 40-year-old male while at rest and is equal to 3.5 ml/min/kg. The task force suggests that a functional capacity below 4 METs is the important decision point in the determination of perioperative risk. They acknowledge that these are estimates and not an objective assessment, and suggest the use of treadmill exercise or arm ergometry for evaluation. The authors do not agree that estimates using 4 METs as a decision point or that treadmill exercise or arm ergometry are objective methods of evaluating functional capacity.

CPET is objective

The authors agree that functional capacity is of major importance, but it should be determined objectively. In reality all these 'tests' of ventricular function are surrogates of a cardiopulmonary exercise test (CPET). Cardiopulmonary exercise testing is the most reliable and objective test for evaluation of functional capacity. In 1988 the authors suggested that CPET could be used to evaluate surgical patients, and have developed and used this method since then (Older and Smith, 1988).

Surgery-specific risk

The ACC/AHA report places major emphasis on type of surgery. This is embraced in the term 'surgery-specific' risk and is regarded as high if the death rate or myocardial infarction rate exceeds 5%. High-risk surgery comprises aortic surgery, major peripheral vascular surgery and major procedures of the abdomen or thorax. This distinction is important as a patient may well be viewed as 'low risk' for endoscopic procedures or breast surgery but of increasing risk for head and neck or orthopaedic surgery and of major risk for abdominal aneurysm surgery.

The report acknowledges that pulmonary artery hypertension poses an increased risk for non-cardiac surgery but points out that there is no satisfactory trial to evaluate the problem. CPET is able to detect clinically significant pulmonary artery hypertension:

> **'...patients with coronary disease without heart failure have similar mortality...to the general population'.**

This important conclusion is reached in a study that examined outcome following major non-cardiac surgery of 47 801 patients over the age of 65 years (Hernandez et al, 2004). The study included both elective and emergency surgery. One cohort consisted of 1532 patients previously diagnosed with HF, another of 1757 patients previously diagnosed with CAD and 44 512 patients who had not been previously diagnosed with HF or CAD. The results showed a mortality rate in the HF cohort of 11.7% compared to 6.6% in the CAD cohort and 6.2% in the control group. These results showed 'patients with CAD without HF have similar mortality to a more general population'. At first sight this would appear to be in conflict with many other views. Actually that is not so.

Is heart failure or coronary artery disease more important?

How do we reconcile work showing that HF is the main issue with the current paradigm which stresses that CAD is the main issue? For many years the medical literature has emphasized that, directly or indirectly, myocardial ischaemia is the main perioperative risk (Fleisher, 1992; Aitkenhead, 1993; Bodenheimer, 1996; Mangano et al, 1996). This has resulted in anaesthetists and cardiologists concentrating on CAD rather than ventricular function. Tests for myocardial ischaemia are frequently performed but objective evaluation of ventricular function is hardly ever sought.

Thus, in a study of perioperative risk, a cohort of patients with CAD may be identified. If no objective measurement of ventricular function is made it follows that the cohort also has an unknown percentage of patients with unsuspected cardiac failure as well as CAD. Deaths in the 'coronary disease' group will almost certainly occur in patients with co-existing poor ventricular function, but because of the study design they will be attributed only to the CAD.

As CAD and cardiac failure are not mutually exclusive, to gain complete understanding of the problem of perioperative cardiac mortality, risk must be stratified and outcome assessed according to both factors.

What represents an acceptable preoperative screening test?

The ideal screening test should provide an accurate assessment of myocardial function, detect myocardial ischaemia, be simply and easily performed in elderly patients, non-invasive, reproducible and cost effective.

Some commonly used screening tests are flawed

In 2000 the authors' group published an appraisal of various screening tests for detection of perioperative risk (Older et al, 2000). Certainly the routine treadmill test with electrocardiograph (ECG) falls far short of an ideal preoperative screening test as quantification of ventricular function is based on estimates. Many of the more commonly used screening tests have been flawed, e.g. echocardiography (Halm et al, 1996), dobutamine stress echocardiography (Hollenberg, 1999) or dipyridamole-thallium scintigraphy (Mangano et al, 1991). All such tests have limitations that make them unsuitable as screening tests and inaccurate as predictors of perioperative risk.

Cardiopulmonary exercise testing and outcome

In a prospective study (Older et al, 1999) 548 consecutive and unselected patients over 60 years of age scheduled for major surgery were evaluated by CPET. Approximately 24% of patients had ECG evidence of myocardial ischaemia. Overall there were nine deaths attributable to cardiovascular causes. All nine patients had cardiac failure defined as an anaerobic threshold (AT) of less than 11 ml/min/kg. Of this group, only two patients had ECG evidence of ischaemia. The authors showed that patients with myocardial ischaemia but with an AT greater than 11 ml/min/kg are not at risk. This is in agreement with the findings reported by Hernandez et al (2004).

Figure 1. An elderly patient cycling a bicycle ergometer. Note (a) the small and lightweight mouthpiece, (b) the oximeter probe attached to the forehead, (c) the electrocardiograph and (d) oximeter body.

What is a cardiopulmonary exercise test?

CPET simultaneously evaluates ventricular function, respiratory function and myocardial ischaemia. The authors' test method involves the patient cycling a bicycle ergometer (Lode Corvival, Medical Graphics Corp, St. Paul, MN) with respiratory gas analysis by a Metabolic Cart (Medgraphics Cardi-O2, Medical Graphics Corp, St. Paul, MN), and with cardiac monitoring by a 12-lead artefact-free ECG (Mortara ELI-100XR) (*Figure 1*). In physiological terms the metabolic cart measures oxygen consumption (VO_2) and carbon dioxide production (VCO_2) during continuously increasing exercise and simultaneously monitors a 12-lead ECG for detection of myocardial ischaemia and arrhythmias. The reader is referred to a previous description of this system (Older et al, 2000).

The physiological basis of CPET

The pattern of change in the arteriovenous oxygen content difference during exercise is similar in patients with heart failure to that of the normal population. Therefore a patient with HF has the same mechanisms of exercise limitation as a normal individual, i.e. the limitation in aerobic capacity is the result of an inability to increase cardiac output. Cardiac output is also a linear function of heart rate at higher levels of exercise because stroke index is maximally recruited early in exercise. In summary, limitation of oxygen consumption under exercise conditions is a function of stroke index and pulse rate.

The 'nine panel plot'

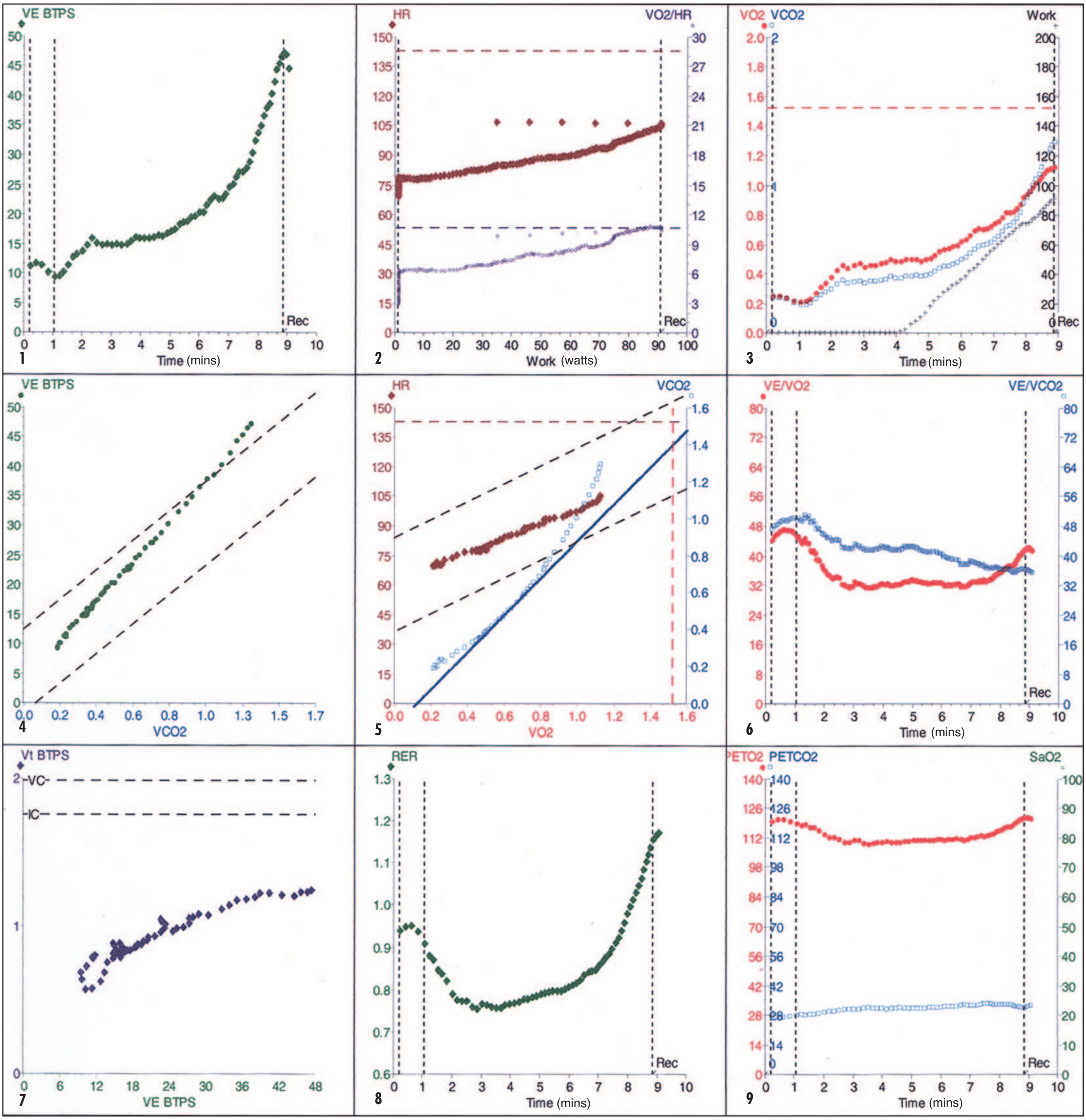
CPET is normally reported from a montage of nine graphs containing 15 plots (*Figure 2*). The graphs are numbered 1–9 from left to right and top to bottom. Each plot represents a discrete area of cardiopulmonary performance and they are arranged for assessment of cardiovascular, ventilatory, ventilation–perfusion and metabolic responses. The addition of ECG analysis provides data on ischaemia and arrhythmia. No other test provides such comprehensive information.

Anaerobic threshold

The most important single variables relative to cardiac function are the AT (*Figure 2(5)*), and the peak VO_2 (*Figure 2(3)*).

The authors prefer the use of the AT as it is easy to detect and is independent of patient motivation. The AT is the point at which anaerobic metabolism is necessary to supplement the existing aerobic metabolism, i.e. oxygen supply to the exercising muscles is not adequate. This will result in release of lactic acid into the circulation and a metabolic acidosis will ensue, resulting in an increase in CO_2 elimination relative to O_2 uptake to correct the acidosis. This point is easily identified on a simultaneous plot of VO_2 and VCO_2 – *Figure 3* shows this method for determination of the AT. These are actual test data of a 69 kg male patient aged 77 years and scheduled for major abdominal surgery. The VO_2 at the AT in this instance is approximately 0.82 litres/min. This is normally expressed as ml/min and indexed to body mass, in this instance the AT is therefore 11.9 ml/min/kg.

Figure 2. The 'nine panel plot'. It displays a total of 15 plots, i.e. there are often several plots on one graph. While other plots may be made, these 15 cover the majority of information obtained from a cardiopulmonary exercise test. BTPS = body temperature pressure saturated; HR = heart rate; PETCO$_2$ =end tidal carbon dioxide partial pressure; PETO$_2$ = end tidal oxygen partial pressure; Rec = recovery; RER = respiratory exchange rate; SaO$_2$ = saturation %; VCO$_2$ = carbon dioxide output (litre/min); VE = minute volume (litre/min); VO$_2$ = oxygen uptake (litre/min); Vt = tidal volume.



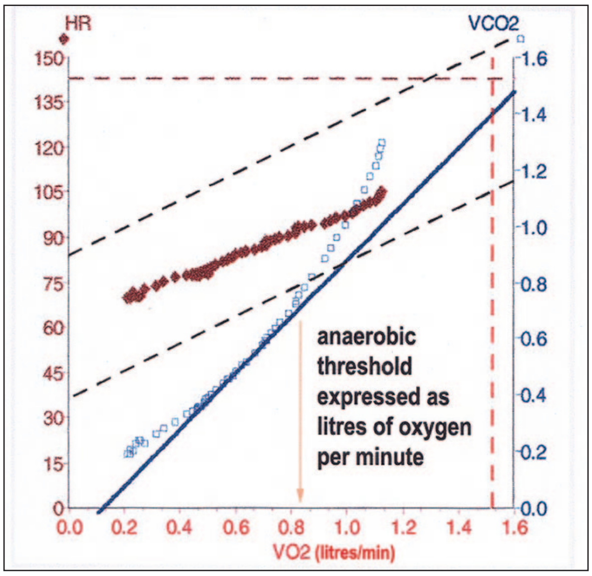


Figure 3. Determination of the anaerobic threshold by the point where the rate of increase in carbon dioxide output (VCO_2) (litre/min) exceeds that of oxygen uptake (VO_2) (litre/min). HR = heart rate.

Risk assessment from CPET

From *Table 1* this AT corresponds to mild cardiac failure, class B and low risk. As this patient was scheduled for major surgery then the overall classification is 'B3'. As explained above this patient would be classified as 'low risk' for cardiopulmonary complications, even if he demonstrated myocardial ischaemia. Had the AT been below 11 ml/min/kg, the patient would be classified 'C3', i.e. high risk. If myocardial ischaemia was also present then the classification would be 'C3I' and would represent highest risk.

Figure 4 illustrates the ventilatory equivalents for oxygen and carbon dioxide. They are dimensionless numbers that relate to the efficiency of ventilation and to the degree of ventilation–perfusion mismatch. Restrictive or obstructive pulmonary disease results in characteristic patterns; however, in this instance the ventilatory equivalents are normal for a man of this age. *Figure 2(7)* shows the relationship of tidal volume to inspiratory capacity, and *Figure 2(4)* shows the slope of the plot of the ventilatory equivalent for carbon dioxide (Ve/VCO_2) which is a marker of respiratory efficiency.

This CPET shows that there is mild impairment of cardiac and respiratory function but not sufficient to place the patient at risk from the postoperative response to the surgical procedure.

Each plot of data from the CPET has specific diagnostic value and readers are referred to the excellent book of Wasserman et al (1999) for a detailed description of the conduct and interpretation of CPET.

Conclusions

Most preoperative scoring systems fall short of the requirement of a complete cardiac risk evaluation for major surgery. Many commonly used screening tests for cardiac disease, while having an important place in cardiology, are not of value as screening tests for major non-cardiac surgery. The ACC/AHA guidelines are comprehensive and important but use poor descriptors of cardiac function. A significant body of work suggests that cardiac function rather than myocardial ischaemia is the

Figure 4. Relationship of the minute volume (VE; litre/min) to the oxygen uptake (VO_2 red; litre/min) and carbon dioxide output (VCO_2 blue; litre/min). These are the ventilatory equivalents. AT = anaerobic threshold; VE/VO_2 = ventilatory equivalent for oxygen; VE/VCO_2 = ventilatory equivalent for carbon dioxide.

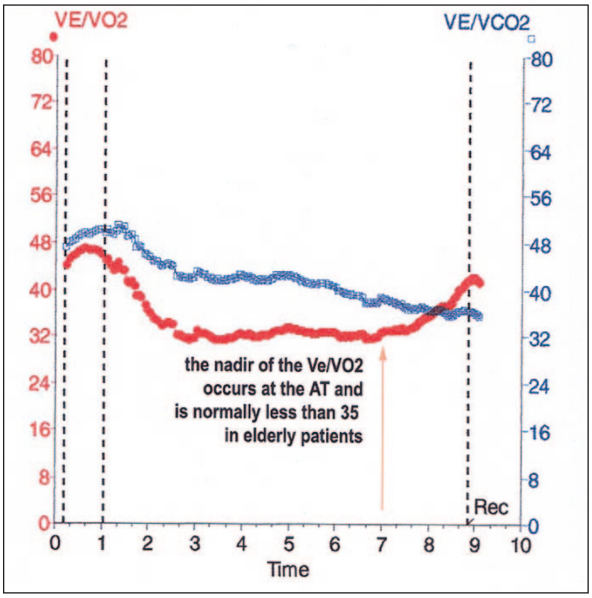


Table 1. Grading operative risk based on CPET functional status, myocardial ischaemia and surgery-specific risk

Degree of cardiac failure expressed at AT as VO_2 (ml/min/kg)	Onset of myocardial ischaemia	Expected postoperative VO_2 (ml/min/m^2) as measure of surgical magnitude
A >14 (no specific risk)	I = ischaemia with AT <11	1 $VO_2 < 120$ (low-risk surgery)
B 11–13.9 (low risk)	i = ischaemia with AT >11	2 $120 < VO_2 < 150$ (intermediate-risk surgery)
C 8–10.9 (high risk)		3 $VO_2 > 150$ (high-risk surgery)
D <8 (very high risk)		

AT = anaerobic threshold; CPET = cardiopulmonary exercise testing; VO_2 = oxygen uptake.

main determinant of outcome. The authors suggest that the best test for a complete cardiac risk evaluation is a CPET. This test evaluates cardiac and respiratory function and detects myocardial ischaemia in a single non-invasive, cost-effective test and accurately identifies patients at high cardiac risk. BJHM

Conflict of interest: none.

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KEY POINTS

- Which questions should we be asking to determine perioperative risk?
- Many of the indices of risk assessment are inadequate; they do not assess ventricular function in an objective fashion.
- Postoperative risk is related to ventricular function rather than myocardial ischaemia.
- Myocardial ischaemia as a sole finding is not a major risk factor.
- Many tests of proven value in cardiology are flawed as screening tests for perioperative risk.
- Cardiopulmonary exercise testing is a proven method of determining perioperative risk.
- Cardiopulmonary exercise testing evaluates cardiac function, respiratory function and the presence and extent of myocardial ischaemia.