The Role of Cardiopulmonary Exercise Testing for Preoperative Evaluation of the Elderly

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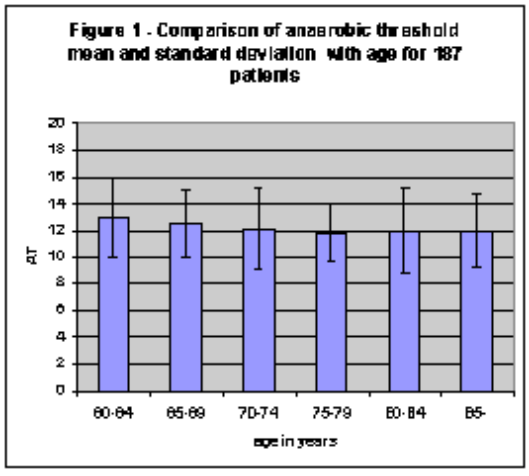
Introduction

Major abdominal surgery in elderly patients is associated with high mortality1. A paper in 1980 quoted a 9% mortality for colon resections2. A mortality of 18% for all patients over 80 years for abdominal surgery was reported at the 1994 Royal Australasian College of Surgeons Scientific Meeting (O'Rourke MGE, personal communication 1994). We reported an overall mortality of 7% following invasive hemodynamic measurements made at rest to assess risk3.

Comparison of mortality between studies of elderly surgical patients is very difficult. Review of the literature from 1984 to 1993 shows a variation of 1.4% to 11.3% 1-4 in reported mortality. Selection or exclusion criteria for surgery were not made clear in these reports. Low mortality can reflect either good surgery and perioperative care or good selection. The selection process could bias results: being too selective, using subjective criteria of cardiopulmonary function, could deny surgery to potential survivors, while failure to assess risk adequately may shorten the life of the patient.

The precise cause of postoperative death may be difficult to determine. Often death is ascribed to sepsis. Sepsis or Systemic Inflammatory Response Syndrome (SIRS)9 places increased demands on oxygen delivery that may not be met if the cardiac output is unable to increase sufficiently. We have found that these patients often have an oxygen consumption (VO2) of 220 mL/min/m2 or greater. These patients die from cardiac failure when oxygen delivery is insufficient to meet the oxygen requirement of the organs of the body. Thus, reduced cardiovascular reserve is the pivotal cause of death. Since age is associated with deteriorating cardiac function, the age of the patient to undergo surgery is of concern. The problem with using age to assess the risk of dying from surgery, however, is highlighted by a recent study comparing 116 patients over 80 years to 622 patients under 80 years having elective abdominal aortic aneurysms resected. The difference in mortality was not significantly different (3% and 2% respectively)10. The trend in any individual is for cardiac function to decrease with age. In fact, cardiac, pulmonary, renal, and immune systems all deteriorate with age and this compromises patients' ability to respond to the increased needs of surgery, trauma, or sepsis. Greenburg et al11 state that "if senescence alters the ability of the elderly person to respond to stress and trauma, complete preoperative assessment is required to minimize potential difficulties."



Wasserman has pointed out that we all age at different rates, thus chronological age is not the same as physiological age12. Our study showed that age is an unreliable indicator of cardiovascular function as

measured by anaerobic threshold (AT) (Figure 1).13 It is not appropriate to use age alone as a selection criteria for major surgery.

Cardiac Dysfunction as a Cause of Death

Dunlop et al showed that the severity of illness was a much better predictor of outcome than age in elderly patients14. Goldman et al showed in 1977 that cardiac failure and arrhythmias were potent causes of perioperative mortality and morbidity and had predictive value15. In 1980, an invasive study of 148 elderly surgical patients, preoperatively, showed a 23% incidence of serious cardiopulmonary abnormalities which placed them at high risk of postoperative mortality2. We reported that studies performed at rest would not reflect the patient's physiological state post-surgery, and that exercise studies might be a better technique for evaluating the ability of the cardiopulmonary system to respond to stress3.

Major surgery is associated with high postoperative VO2 and cardiac output requirement3,16. We believe that postoperative mortality is high in elderly patients because cardiac reserve is reduced. As a result of cardiac failure, the increased postoperative oxygen demand cannot be met. The only options for raising V02 in postoperative patients are to increase oxygen extraction ratio (OER) and/or to increase oxygen delivery. While increases in OER to 35% are common in surgical cases, we find that an OER above 40% usually results in an increasing blood lactate. This will ultimately lead to a further increase in V02 secondary to Cori cycle conversion of lactate to glucose in the liver. The postoperative use of inotropic drugs to augment cardiac output is widely accepted and it has been shown that this approach reduces mortality17.

Use of Cardiopulmonary Exercise Testing to Evaluate Cardiac Function

Table 1 - Mortality data: AT above and below 11 ml/min/kg*

AT ml/min/kg	/Number	/CVS deaths	/Percentage mortality
<11	/55	/10	/18
>=11	/132	/1	/0.8
Totals	/187	/11	/ (p<0.001)

* AT = anaerobic threshold; CVS = cardiovascular

Cardiac failure is common denominator in many postoperative deaths. We use cardiopulmonary exercise testing (CPX) to quantify cardiac failure as well as identifying ischemia and arrhythmia. We measure AT using the technique described by Beaver et al18. and the classification system of Weber and Janicki to define the grade of the cardiac failure19.

Table 2 - Mortality data: AT above and below 11ml/min/kg associated with perioperative ischaemia*

AT ml/min/kg	/number/number with ischaemia/CVS deaths	/percentage mortality		
<11	/55	/19	/8	/42
>=11	/132	/25	/1	/4
Totals	/187	/44	/9	/ (p<0.01)

* AT = anaerobic threshold: CVS = cardiovascular

In our study13, we found that postoperative cardiovascular deaths were virtually confined to patients with an AT of less than 11 mL / min / kg (p = 0.001) (Table 1). We also found that an AT of less than 11 mL / min / kg associated with angina or ECG evidence of ischemia during exercise resulted in approximately 40% mortality following defined major surgery in patients over 60 years of age (Table 2). By comparison, myocardial ischernia (ST depression >1mm) with lesser degrees of cardiac failure (AT > 11 mL/min/kg) did not appear to be a major risk factor. Cardiac failure, defined as an AT < 11 mL/min/kg, appeared to be as good an indicator of mortality as evidence of ischemia alone. Elderly patients who exhibited neither cardiac

failure nor ischemia based on exercise testing criteria had a mortality of less than 1%, even for major surgery.

The "Surgical Anaerobic Threshold"

It is our hypothesis that if myocardial ischemia develops at or above the AT, it is less likely to develop in the postoperative period. This introduces the concept of a "surgical anaerobic threshold". This is similar to the exercise AT in that it is the point at which oxygen delivery is not adequate to support organ metabolism aerobically. This is the metabolic rate at which lactic acidosis develops.

We find that cardiac output, postoperatively, is less than peak cardiac output of preoperative CPX. If myocardial ischemia occurs at relatively high levels of exercise (high cardiac output), the patient is unlikely to reach that level of cardiac demand postoperatively, as compared to the patient who develops ischemia at a low metabolic rate.

The Relationship of Ischemia to Anaerobic Threshold

We studied 214 elderly elective surgical patients by CPX testing. The study concentrated on those patients who developed ischemia or arrhythmia during CPX testing, ischemia being defined as more than 1 mm horizontal depression on continuous 12 lead ECG monitoring (Mortara ELI-100XR, Mortara Instruments, Milwaukee WI). A cardiologist blinded to the CPX study reported every ECG. The relationship between ischemia, arrhythmia, AT, and postoperative cardiac events was examined.

Fifty-two out of the 214 patients (24.3%) had myocardial ischemia as defined by ECG criteria compared to 44 out of 187 patients (23.5%) in our initial study13 (Table 2). There appear to be two patterns of evolution of ST depression: one in which myocardial ischemia occurs very early in exercise, becoming positive within 2 minutes of commencement, and another where ischemia occurs late, i.e., around or above the AT. Ischemia may be the cause of the poor cardiac performance in some instances or the result of increased cardiac demand in others. On this basis, we examined the relationship between the time of onset of the ischemia and the AT. We found that in those patients in whom myocardial ischemia developed at reduced work rates, the AT was usually reduced. The average AT for the patients who developed ischemia at low work rates was 10.4 mL / min / kg (SD = 1.74: n = 21). In those patients who developed ischemia at higher work rates, the AT averaged 13.9 mL / min / kg (SD = 2.28: n = 31). These groups are significantly different for AT by Student's "t" test ($p = 0.05$). This supports our hypothesis that those patients in whom ischemia develops early in exercise are at higher risk than those in whom it develops late. Thus, patients with early ischemia and low AT are more likely to reach their "surgical AT" postoperatively, and manifest ischemia and cardiac failure. We have found an extremely high mortality rate associated with the combination of low AT and myocardial ischemia13.

Conveying the Preoperative Data to Our Colleagues

The whole thrust of our work since 1985 has been to identify patients at risk following major surgery. The logical extension of this work is to evolve a preoperative system which allows anaesthetists and surgeons to easily appreciate operative risk. This would also provide our patients with better information on which to base their consent for treatment.

Ideally the system selected should be based not only on cardiovascular function, but also on the function of other organs which are critically important during the operative and postoperative periods; for example, preexisting pulmonary disease and renal disease are relevant.

The important concept is that perioperative cardiac mortality is an issue of oxygen demand versus oxygen supply. Minor surgery has a much lower oxygen demand than major surgery and therefore a lesser demand on cardiac reserve. A patient having an operation for excision of a bunion is not at the same risk as if he were subjected to an abdominoperineal resection of a rectal tumor. Therefore, we need to know both the cardiovascular status of the patient and the "oxygen demand stress" of the procedure. It follows that any risk

assessment must include the planned surgery in the evaluation. We therefore suggest a classification system quite different from the 30-year-old American Society of Anesthesiologists (ASA) Classification[20].

Proposed Grading of Preoperative Risk

Proposed grading of operative risk based on cardiopulmonary reserve, magnitude of surgery, and functional status of heart, lungs and kidneys
Degree of cardiac failure
A - E
postoperative VO2 (ml/min/M2)
1 - 3
Organ system dysfunction
P,p,A,a,I,i,R,r
Weber and Janicki Grade
A,B,C,D (ref 19)
E = emergency
or unknown
1 = VO2 < 120
P = Ve/VO2 > 35
A = SVT
I = early ischemia
R = CrCl*<30 ml/min

p = 28<VeVO2<35
a = other arrhythmia
i = late ischemia
r = CrCl>30 ml/min

2 = 120<VO2<150
3 = VO2 > 150

Our classification uses an alphanumeric system. The first digit describes the extent of cardiac failure based on CPX data; the letters A, B, C or D indicate the Weber and Janicki grade[19]. The letter E is used to indicate an emergency procedure and implies that the Weber and Janicki classification is not known.

The second digit, a number 1-3, indicates the likely extent of the surgical stress response in terms of VO2 The number 1 indicates a minor procedure, 2 an intermediate procedure, and 3 a major procedure. This is based on the average oxygen consumption of 170 mL / min / M2 observed following major surgery[3,21]. Resting oxygen consumption of the elderly is approximately 110 mL / min / M2 [3].

Following the first two alphanumerics, a letter or series of letters indicate organ system dysfunction; for example, if the patient has myocardial ischemia, the letter I follows the first two alphanumerics. As we have pointed out, the ischemia may have major or minor significance. Therefore, we suggest the use of an uppercase I to suggest high significance of the ischemia, or a lowercase i if ischemia is of less significance. Cardiac arrhythmias are treated in the same manner with A or a.

Other organ system dysfunction may influence outcome or postoperative problems. An uppercase P implies major pulmonary dysfunction; for example, the presence of severe restrictive or obstructive disease associated with marked elevation in the ventilatory equivalent for oxygen (VE/VO2) at AT (>35). A lowercase p denotes less significant pulmonary disease.

Uppercase R signifies creatinine clearance less than 30 mL / min, or lowercase r indicates a lesser degree of renal impairment.

The classification is presented as an alphanumeric series (Table 3). Thus A1p, indicates a patient with excellent cardiovascular function (A) and insignificant pulmonary disease (p) scheduled for a minor

procedure (1). Alternatively, B3IR describes a patient with mild cardiac failure (B), significant ischemia (I), and severe renal disease (R) scheduled for a major procedure (3).

Nonoperative Mortality

In our studies, there has always been a group of patients whose operation was cancelled or postponed. In our latest analysis, 10 patients from a group of 118 were not operated on because they were felt to be at high risk for mortality. Six of these are still alive 6 months to 23 months after original presentation. Of the patients who died, three died of cardiovascular disease and one from the original disease. In contrast, of the 108 who had the operation, 3.7% died over the same period.

What is the Significance of Supraventricular Arrhythmia During Cardiopulmonary Exercise Testing?

In our series of 214 patients, there were five patients who developed a supraventricular tachycardia (SVT) during exercise testing. Three of these patients developed significant ST depression during SVT. The ST depression did not exist in the absence of the SVT. We classified these as a rate-dependent ischemia. The same patients developed supraventricular arrhythmias in the ICU despite preoperative digitalization.

Are the Newer Endoscopic Procedures Less "Stressful"?

Quantification of the oxygen demand stress of surgical procedures has increasing relevance as laparoscopic surgery becomes more prevalent. If the laparoscopic procedure results in a lower postoperative oxygen demand than conventional surgery, then the procedure could be offered to patients with a lower cardiac reserve.

Making the Best Use of Intensive Care Unit/High Dependency Unit Resources

Our indication for admission to the intensive care unit (ICU) or the high dependency unit (HDU) for elderly patients scheduled for major surgery remains unaltered since 1989. Patients with an AT of less than 11 mL / min / kg (C3 or worse) are electively admitted to the ICU preoperatively where they are invasively monitored by pulmonary artery catheters. Filling pressures are optimized with appropriate fluid therapy, renal function is estimated via creatinine clearance, and all preoperative surgical and anaesthetic orders are implemented. This policy has the additional benefit of identifying those patients with extremely high values for pulmonary vascular resistance, a known mortality risk factor22. It also reduces anaesthetic time in that all "lines" are in place and X-rays are performed prior to anaesthesia. Patients who have an AT?? , 11 mL / min / kg, but exhibit either myocardial ischemia or significant arrhythmia are admitted to HDU postoperatively for cardiovascular system (CVS) monitoring (A3 or B3 with I or A). We also admit patients to HDU postoperatively if they have significantly disturbed pulmonary function or a VE/VO2 at AT of >35 during CPX testing. All patients scheduled for major vascular surgery (resection of abdominal aortic aneurysm, distal vascular grafting) are routinely admitted to the ICU regardless of the results of CPX testing. Finally, the very few patients (<4% in our series) who could not successfully perform CPX are invasively monitored preoperatively in the ICU.

We have examined the ICU bed utilization in our hospital over the period of a decade, from 1983 to 1993. Before CPX was available, approximately 450 ICU bed-days were occupied for each 100 elderly patients undergoing major abdominal surgery. Patients who deteriorated on the ward were admitted to the ICU as emergencies, and they had a stay of 10 days or more associated with a high mortality rate.

Since we started to evaluate patients by CPX testing, approximately 40% of patients were managed postoperatively on the wards, 50% were admitted to the ICU preoperatively, and 10% were electively admitted to the HDU postoperatively. Of the last 450 elderly patients evaluated by CPX testing, no patient identified as at low risk was admitted to ICU from the wards as an emergency. The average duration of stay was 4.8 days for patients electively admitted to the ICU.

Only 220 bed-days were occupied for each 100 patients who went to surgery, and this includes the day of preoperative admission. Mortality rate has been reduced to less than 5% from >12%.

Summary

Mortality remains high in elderly patients undergoing major abdominal surgery. While chronological age is a poor guide to physiological status, senescence is associated with a deterioration in cardiopulmonary, renal, and immune function. The importance of both cardiac failure and ischemia in the operative patient has long been recognized. We believe that the reduction in cardiopulmonary reserve is the pivotal factor in mortality following major surgery. Postoperatively, there is a large increase in oxygen demand which requires an increase in cardiac output. We used CPX testing to relate the cardiopulmonary reserve to postoperative mortality. The degree of cardiac failure assessed by CPX testing is an important predictor of mortality. Early onset exercise-induced cardiac ischemia is associated with a low AT and this is also an important predictor of mortality.

We found that the patient's ability to transport oxygen during exercise can reasonably predict operative risk when the oxygen demand stress of surgery is taken into account. Outcome is influenced by ventricular function, ischemia, arrhythmia, and impaired pulmonary and renal function. We propose a system for grading operative risk which includes evidence of these abnormalities within the framework of cardiopulmonary function based on CPX testing.

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References