Preoperative Evaluation of Cardiac Failure and Ischemia in Elderly Patients by Cardiopulmonary Exercise Testing*

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Major surgery in the elderly continues to have a high mortality rate. Preoperative myocardial ischemia is a known risk factor. Cardiac failure is also a risk factor, but is difficult to quantify objectively. One hundred eighty-seven elderly surgical patients were evaluated for cardiac failure by cardiopulmonary exercise testing (CPX). The overall mortality in these patients was 7.5 percent. If three deaths secondary to surgical causes are excluded, mortality was 5.9 percent. There were 55 patients in whom the anaerobic threshold (AT) was less than 11 ml/min/kg; of these, 10 died, a mortality rate of 18 percent. There were 132 patients with an AT of greater than 11 ml/min/kg and of these, 1 patient died, giving a mortality rate of 0.8 percent ($p<0.001$). A low AT associated with preoperative ischemia resulted in the death of 8 of 19 patients, a mortality rate of 42 percent. When the ischemia was associated with the higher AT, then 1 patient out of 25 died, a mortality rate of 4 percent ($p<0.01$). Both preoperative ischemia and preoperative cardiac failure are independent risk factors for perioperative mortality in the elderly.

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AT = anaerobic threshold; CPX = cardiopulmonary exercise testing; CVS = cardiovascular; OER = oxygen extraction ratio

Major abdominal surgery in the elderly is associated with a high mortality. Perioperative mortality rates vary in different studies, but rates of 9 percent or more have been reported for elective colorectal surgery.[1,2] Similar rates have been demonstrated for elective abdominal aortic aneurysm surgery.[3] The Confidential Enquiry into Perioperative Deaths[4] concluded that most perioperative deaths in the elderly were due not to surgical or anesthetic misadventure, but to preexisting cardiac or respiratory disease.

For editorial comment see page 663

The Confidential Enquiry into Perioperative Deaths and others[4,5] have highlighted the fact that cardiac failure is as likely a cause of perioperative mortality as myocardial infarction. Despite this, most published reviews of perioperative cardiac risk have focused mainly on myocardial ischemia and infarction.[6,7]

Detection of myocardial ischemia preoperatively is readily performed by such investigations as ECG treadmill tests, Holter monitoring,[8,9] or dipyridamole thallium scintigraphy, even though some doubts have been raised over the value of dipyridamole thallium scintigraphy as a preoperative screening test.[10]

Measurement of the extent of cardiac failure preoperatively is much more challenging. The New York Heart Association classification relies on subjective patient assessment. Estimates of resting or exercise ejection fraction correlate poorly with the extent of cardiac failure.[11,12] With the advent of cardiopulmonary exercise testing (CPX), it has been possible to objectively evaluate and classify cardiac failure on the basis of oxygen consumption at the anaerobic threshold (AT) and maximal aerobic capacity.[13]

Cardiopulmonary exercise testing is an objective evaluation of the response of the cardiovascular and respiratory systems to an increase in oxygen demand. We define major surgery as a procedure likely to cause a significant increase in oxygen demand, *eg*, abdominal aortic aneurysm resection, anterior resection of the rectum. This type of surgery may result in an oxygen consumption of 170 ml/min/m^2 (4.5 to 5 ml/min/kg), which could represent an increase of 50 percent or more over resting values as many elderly patients have a resting oxygen consumption of 110 ml/min/m^2 or less.[14]

We have studied preoperatively 187 surgical patients over the age of 60 years by CPX. With one noninvasive test, the extent of both myocardial ischemia and cardiac failure could be objectively evaluated. The extent of cardiac failure was classified according to the AT and postoperative mortality was compared with this classification.

Methods

Subjects

All patients over the age of 60 years scheduled for major abdominal surgery were subjected to a symptom-limited exercise test as part of the preoperative anesthetic assessment. A total of 191 patients were tested. Four tests were unsuccessful as either the patients could not cycle adequately or could not maintain the necessary cycling speed. The 187 patients presented herein all had major intra-abdominal surgery as defined above.

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Test Protocol

The exercise tests were performed with a MGC CAD/Net System 2001 and a computer-interfaced Mijnhardt KEM III cycle ergometer. This system is a "breath-by-breath" metabolic cart. The system was calibrated before each test by a biomedical engineer using a gravimetric gas standard for the gas analyzers. The pneumotachograph was calibrated using a 3-L syringe (Hans Rudolph).

Following written informed consent the tests were performed to a strict protocol with one of us (P.O., R.S., P.C.) and full resuscitation equipment present. Static respiratory function tests were performed to establish forced vital capacity, FEV_1, FEF25-75, and inspiratory capacity. A 12-lead ECG was obtained at rest. Throughout the test the patient was monitored on leads V_4, V_5, and V_6. Full 12-lead ECGs were taken every minute or less. The patient was seated on the cycle ergometer and connected to the metabolic cart via a mouthpiece. When the patient was settled and comfortable, baseline data were established for a period of 1 min with the patient at rest. The patient then commenced cycling at 50 to 60 rpm for 3 min with no load (unloaded cycling). This approximates to 20 W of work. At the end of this period, the load on the ergometer was continuously increased via the computer until cessation of the test. Thus, the test uses a "ramp protocol" as opposed to an "incremental or stepwise protocol." The rate of increase of work load was determined in relation to the maximum predicted work rate for that patient. The algorithm used was suggested by Wasserman et al.[15] The aim was to achieve a minimum of 6 min of cycling after the period of unloaded cycling. The test was stopped if the patient became distressed, developed ST depression of >2 mm, or developed an excessive tachycardia. All tests were stopped at predicted maximum work rates. This study made no attempt to define maximum aerobic capacity.

We developed the computer program (of the MGM 2001) to perform graphic analysis of the data using the method of Beaver et al[16] of identifying the AT.

Patients were grouped first according to age. A χ^2 analysis was used to determine the significance of differences in AT between age groups. Patients were then grouped according to AT. A χ^2 analysis was used to determine the significance of the difference in mortality between the different AT groups. Finally the patients were grouped with reference to both AT and preoperative myocardial ischemia and again, χ^2 analysis was used for statistical evaluation.

Results

The data for the 187 patients tested and operated on are as follows. Eighty-five patients were female and 102 were male. The average age was 70 years (SD = 7) with a distribution as shown in Figure 1. A total of 44 patients had evidence of preoperative ischemia defined as a documented history of a previous infarct, angina, or a positive ischemic CPX.

There were no significant differences in AT between the age groups (Fig 2).

The average oxygen consumption for all patients at AT was 12.4 ml/min/kg (SD = 2.7) with a distribution as shown in Figure 3. There were a total of 14 deaths in these 187 patients. This is an overall in-hospital mortality of 7.5 percent. Three of the deaths were unrelated to cardiovascular (CVS) causes. If these three deaths are excluded, 5.9 percent of this patient population died of CVS-related causes. Figure 3 also shows CVS mortality data using the cardiac failure classification as suggested by Weber and Janicki.[13] The

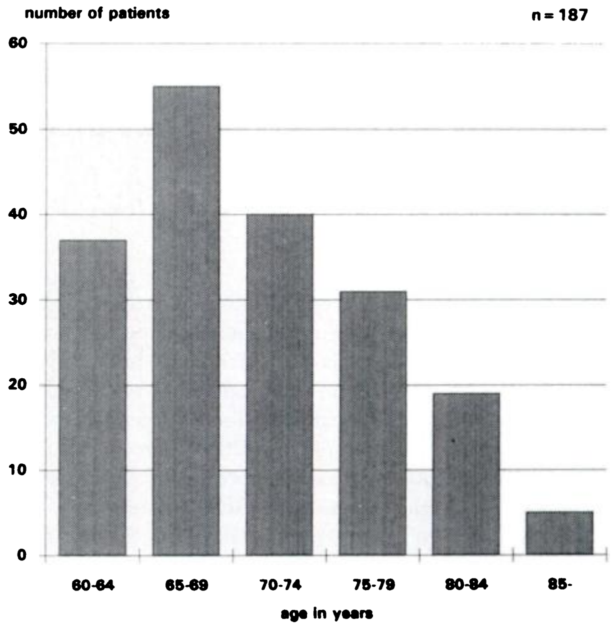

FIGURE 1. Age distribution histogram for 187 elderly surgical patients.

difference in mortality rate for the group with an AT of 8 to 10.9 ml/min/kg (8 deaths in 51 patients) and the group with an AT of 11 to 13.9 ml/min/kg (1 death in 86 patients) is highly significant ($p<0.001$). There is no significant difference between the group with an AT of 11 to 13.9 ml/min/kg and the group with an AT exceeding 14 ml/min/kg (no deaths).

Table 1 shows the data broken down into two groups with the AT above or below 11 ml/min/kg. There is a highly significant difference in mortality between these two groups ($p<0.001$).

Of the 55 patients with an AT of less than 11 ml/

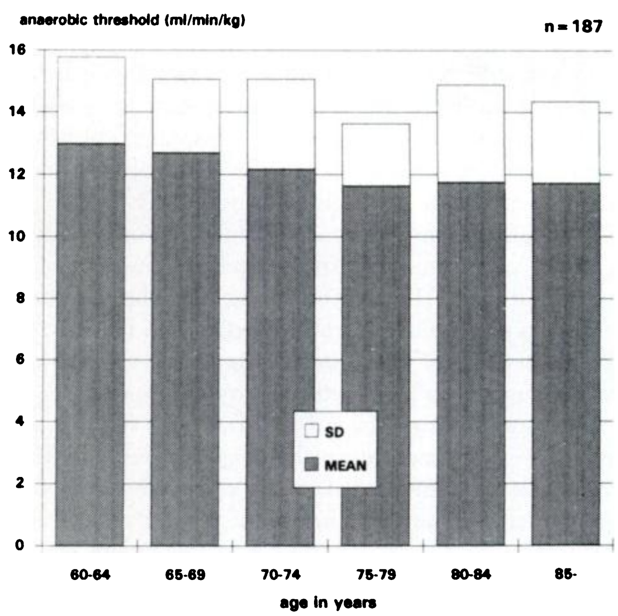

FIGURE 2. Comparison of anaerobic threshold (mean and standard deviation) with age for 187 elderly surgical patients.

Table 1—*Mortality Data: AT Above and Below 11 ml/min/kg**

AT, ml/min/kg	No.	CVS Deaths	Percentage Mortality
<11	55	10	18
≥11	132	1	0.8
Totals	187	11	($p<0.001$)

*AT = anaerobic threshold; CVS = cardiovascular.

min/kg, there were 19 who demonstrated preoperative ischemia as defined above (Table 2). This group had a CVS mortality rate of 42 percent. In those patients in whom the AT was greater than 11 ml/min/kg, there were 25 patients with preoperative ischemia. This group had a mortality of 4 percent. There is a significant difference between these two groups ($p<0.01$).

Discussion

To our knowledge, this is the first time that CPX has been used prospectively to evaluate the cardiopulmonary function of surgical patients. In a previous study of preoperative hemodynamic status of 100 surgical patients using pulmonary artery catheters, we found more than 10 percent of the patients had severe cardiac dysfunction.[14] We concluded that static haemodynamic studies were not adequate to detect all patients who might develop problems when "stressed" by surgery. In our view, static evaluation of cardiac failure would not be expected to identify all patients who are unable to meet the increased oxygen demand of major surgery.[12]

Weber and Janicki[14] classified cardiac failure into five groups on the basis of CPX. Our results in Figure 3 are plotted using those groups. There were no patients with an AT of less than 5 ml/min/kg and only four patients with an AT of less than 8 ml/min/kg, but the other groups all had substantial numbers. Figure 3 shows that approximately 30 percent of an elderly surgical population is likely to have an AT of 11 ml/min/kg or less and from Figure 2 it is clear that age is not a valid predictor of AT.

Clearly the AT is a powerful discriminator of mortality for patients undergoing major surgery. The discriminatory power of CPX is related not only to detection of myocardial ischemia, but also to detection of poor ventricular function. Poor ventricular function

Table 2—*Mortality Data: AT Above and Below 11 ml/min/kg Associated With Preoperative Ischemia**

AT, ml/min/kg	No.	No. With Ischemia	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.

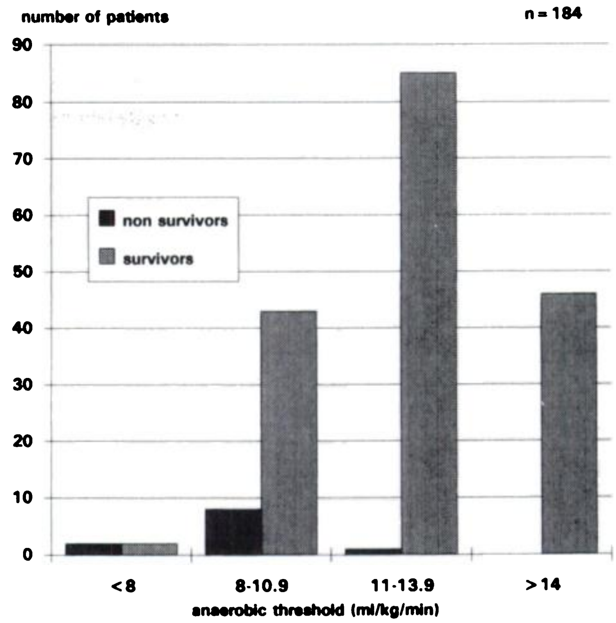

FIGURE 3. Comparison of cardiovascular mortality with anaerobic threshold.

may result from myocardial ischemia, but in the majority of cases in this study, no such correlation could be detected. In this study of 187 patients, there were 44 identified preoperatively with ischemia. Twenty-five of these had an AT of >11 ml/min/kg. The only death in this group was not attributable to myocardial infarction. Thus, it would appear that in the absence of cardiac failure, ischemia is not a potent cause of perioperative mortality even for major surgery. Conversely, from Table 2 it is apparent that poor ventricular function and myocardial ischemia constitute the highest risk combination. The study of Shoemaker et al[17] showed an improved survival from major surgery by use of inotropes postoperatively. The need for inotropes suggests that improvement of ventricular function is necessary to meet the increased oxygen demand of major surgery. This reinforces the concept that poor ventricular function is a major issue in postoperative mortality.

The extrapolation from exercise stress to surgical stress requires explanation. The main difference in oxygen supply and demand in surgical stress and exercise stress lies in the global oxygen extraction ratio (OER). Elderly patients that we have subjected to CPX with central venous and arterial access show an OER of approximately 50 percent at work rates near their AT. Weber and Janicki[18] showed a rise in mixed venous lactate level to occur at an OER exceeding 60 percent. Patients following major surgery rarely exceed an OER of 35 to 40 percent; more commonly, the OER is around 30 percent.

Comparing postsurgical stress with CPX, the lower OER following surgery will require a higher cardiac output for any given oxygen consumption. It follows that cardiac output following surgery will have to be approximately 65 to 70 percent greater than it was for the same oxygen consumption on CPX. The average oxygen consumption following major surgery is 4.5 to 5 ml/min/kg (170 ml/m^2)[14] and it is not uncommon to see levels of 6 to 7 ml/min/kg (240 ml/min/m^2). Therefore, if patients are unable to achieve an AT of 8.5 to 11.5 ml/min/kg (290 to 390 ml/m^2) on CPX, they may be unable to meet the increased oxygen demand and consequential increased cardiac output of major surgery.

The association of cardiac failure (an AT <11 ml/min/kg) and preoperative ischemia resulted in a very high mortality (42 percent). Two causes are possible: either the ischemia prevented the increase in cardiac output necessary after major surgery or the increase in cardiac output caused ongoing ischemia. This study was not designed to evaluate this problem. It is of note that patients with preoperative ischemia but good ventricular function had a very low mortality (4 percent). It must be emphasized that all these patients had undergone major abdominal surgery.

In all, 86 patients were admitted to the ICU, the majority electively. Many patients tested were admitted to the ICU for reasons other than a poor AT on CPX. Other reasons identified during the preanesthetic workup included severe respiratory disease or previous myocardial infarction, high doses of negative inotrope medication such as β-blockers or calcium channel blockers. An ischemic exercise test was always an indication to admit the patient to the ICU, regardless of the AT. The average duration of stay in the ICU was less than 5 days, including the day of admission.

Cardiopulmonary exercise testing is noninvasive, inexpensive, may be performed on all patients with minimal preparation, and can supply answers in less than 1 h. We suggest that it be done as soon as surgery is contemplated. This allows the anesthetist and surgeon to take into account the objective cardiopulmonary status of the patient and the fact that an ICU bed may be needed before surgery. In our own hospital, early knowledge of surgical risk has allowed the surgeon to more easily assess treatment options.

Conclusions

Although preoperative myocardial ischemia is an accepted mortality risk factor in major surgery in the elderly, cardiac failure is equally a risk factor. Patients with an AT <11 ml/min/kg and myocardial ischemia represent approximately double the risk of either factor independently. The AT is not predictable from the age of the patient.

Based on this study, we now suggest that all patients scheduled for major intra-abdominal surgery with an AT of <11 ml/min/kg should be admitted to ICU preoperatively. Finally, CPX in the elderly is easily and reliably performed and age is not a barrier to such tests.

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