Cardiopulmonary Exercise Testing as a Screening Test for Perioperative Management of Major Surgery in the Elderly*

Paul Older, MBBS; Adrian Hall, MBBS; and Raymond Hader, MBBS†

Study objective: **To develop an integrated strategy for the identification and subsequent management of high-risk patients in order to reduce both morbidity and mortality.**
Design: **Prospective consecutive series in which all patients underwent cardiopulmonary exercise (CPX) testing.**
Setting: **CPX laboratory and level 3 ICU and high-dependency unit (HDU) of a metropolitan teaching hospital.**
Patients: **Five hundred forty-eight patients > 60 years of age (or younger with known cardiopulmonary disease) scheduled for major intra-abdominal surgery.**
Interventions: **The patients were assigned to one of three management strategies (ICU, HDU, or ward) based on the anaerobic threshold (AT) and ECG evidence of myocardial ischemia as determined by CPX testing that was performed as part of the presurgery evaluation, and by the expected oxygen demand stress of the surgical procedure.**
Results: **Overall mortality was 3.9%. Forty-three percent of deaths were attributed to poor cardiopulmonary function, as detected preoperatively. There were no deaths related to cardiopulmonary complications in any patient deemed fit for major abdominal surgery and ward management, as determined by CPX testing.**
Conclusions: **In elderly patients undergoing major intra-abdominal surgery, the AT, as determined by CPX testing, is an excellent predictor of mortality from cardiopulmonary causes in the postoperative period. Preoperative screening using CPX testing allowed the identification of high-risk patients and the appropriate selection of perioperative management.**
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Key words: anaerobic threshold; cardiovascular diseases; exercise test; postoperative complications; preoperative care; surgical procedures

Abbreviations: AT = anaerobic threshold; CPX = cardiopulmonary exercise; HDU = high-dependency unit; $\dot{V}E$ = minute ventilation; $Ve/\dot{V}O_2$ = ventilatory equivalent for oxygen; $\dot{V}O_2$ = oxygen consumption

Many strategies have been devised for perioperative risk assessment. Perhaps the earliest was that of the American Society of Anesthesiologists in 1963.[1] This method involves subjective evaluation of the patient but fails to take into account the surgery-specific risk. In 1977, Goldman et al[2] published an article, "Multifactorial Index of Cardiac Risk in Noncardiac Surgical Procedures." This work offered an improvement in that it added some objectivity to the assessment of the patient, and it took into account some measure of the surgery-specific risk. In essence, it identified elderly patients with preexisting cardiac disease who were undergoing major intracavity surgery as being at high risk of mortality. It also identified aortic surgery as a high-risk procedure. In 1987, the Confidential Enquiry into Perioperative Deaths[3] also identified elderly patients with preexisting cardiac or pulmonary disease scheduled for major surgery as a high-risk group. The same information came out of a study from Finland in 1994.[4]

These studies identified the patients at risk but were not designed to offer a strategy to assist in reducing mortality. There is a need for a strategy that both identifies high-risk patients and guides their management in order to reduce morbidity and mor-

*From the Western Hospital, Footscray, Victoria, Australia.
†Deceased.
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Correspondence to: Paul Older, MBBS, Director of Intensive Care Unit and Head of CPX Laboratory, Western Hospital, Footscray, Victoria, 3011, Australia; e-mail: paul.older@nwhcn.org.au

tality. Morbidity is an expensive consequence, in terms of ICU bed days and overall hospital stay, of the misdiagnosis of risk.

In 1993, we reported that cardiopulmonary exercise (CPX) testing during preoperative evaluation identified the elderly patients at greatest risk of postoperative death.[5] We found that 86 of 187 patients were identified as being at high risk primarily on the basis of a low anaerobic threshold (AT) or ECG abnormalities, which were determined during a CPX test. The patients were consequently admitted electively to the ICU. In 1996, we published a grading of perioperative risk based on CPX testing (Table 1) and a triage system based on the oxygen consumption ($\dot{V}O_2$) of the surgical stress response.[6]

This paper reports the results of a 3-year prospective study in which CPX testing was used as a screening test to grade surgical stress and to determine postoperative management.

Materials and Methods

Patient Selection and CPX

The patients included in this study were those scheduled for major surgery who either were > 60 years of age, or were < 60 years of age but had previous diagnoses of myocardial ischemia or cardiac failure.

CPX testing was used as a screening test on all patients scheduled for major surgery in our hospital. Most of these patients were tested as outpatients up to 2 weeks before the scheduled surgery. This program received the full cooperation of both the anesthesiologists and surgeons, thus ensuring that all patients meeting the criteria were tested.

During the 3-year period of this study, a total of 702 surgical patients were tested; 82 of these patients were thoracic cases and were not included in this study. A total of 620 cases remained for analysis. Of these 620 patients, a total of 548 proceeded to surgery.

All CPX tests conformed to a strict protocol, with a doctor and full resuscitation equipment present. Invasive monitoring was not performed on any of these patients.

The metabolic cart used in this study (Medgraphics Cardi-O2; Medical Graphics Corp; St. Paul, MN) was calibrated before each test by a biomedical engineer and was validated by a gas exchange validator at intervals of 6 months.

Static respiratory function tests were performed and a resting 12-lead ECG (Mortara ELI-100XR; Mortara Instruments; Milwaukee, WI) was obtained for each patient. The patient was then seated on a bicycle ergometer (MGC Cardi-O2 Cycle Ergometer; Medical Graphics Corp); and with the mouthpiece inserted, baseline data were obtained for 1 min. The patient pedaled against 0 W for a period of 3 min; *ie*, the ergometer flywheel was assisted electrically to prevent the patient from feeling a resistance to pedaling. At 3 min, the work rate on the ergometer was progressively increased in a ramp pattern toward the maximum predicted for that patient. The aim was to produce a minimum of 6 min of exercise after ramping commenced. The algorithm used for this calculation was from Wasserman et al.[7]

The ECG and ST-segment change were monitored continuously in both analog and digital form. The test was stopped if the patient became distressed or if there was > 2 mm of ST depression in any lead; otherwise, the test was continued to the maximum tolerated work rate. The test protocol was not designed to determine the maximum aerobic capacity.

Measurements and Data Analysis

We configured the software of the metabolic cart (Breeze-3; Medical Graphics Corp) to display $\dot{V}O_2$, carbon dioxide output, heart rate, minute ventilation ($\dot{V}E$), and work rate (in W) throughout the test.

The data were subjected to multiple bivariate analyses. Calculation of the AT was by the V-slope method of Beaver et al.[8] Other data displayed included the relationship of $\dot{V}O_2$ to heart rate and the ventilatory equivalents for oxygen ($Ve/\dot{V}O_2$) and for carbon dioxide.[9]

The ECG software analyzed the ST segment by calculating the ST depression in millimeters, which is 60 ms from the J-point. One millimeter of new depression in one or more leads was considered significant. The trend of ST depression during the test was also analyzed. The relationships between ST segment change relative to $\dot{V}O_2$ and AT were determined.

Patient Triage

The age of the patient, a medical history indicative of cardiac failure (or New York Heart Association classification of cardiac failure), or a history of respiratory disease, myocardial infarction or myocardial ischemia were not used to triage the patient. Rather, triage was based on objective data provided by CPX testing and on the expected surgical stress. On the basis of our previous study,[5] the patients were admitted to the ICU, high dependency unit (HDU), or ward depending on the AT and the type of surgery.

ICU Admissions: Patients with an AT < 11 mL/min/kg were considered "high risk" and were admitted to the ICU preoperatively. This allowed us to obtain baseline hemodynamics and data on oxygen delivery and consumption via a pulmonary artery catheter and to optimize the fluid status and hemodynamics of these patients. In addition, all patients scheduled for aortic or esophageal surgery were admitted to the ICU preoperatively regardless of AT. These patients were considered at high risk by virtue of the type of surgery.[10] A total of 28% of the patients were admitted to the ICU preoperatively.

HDU Admissions: The HDU provides for ECG, central venous

Table 1—*Code and Definitions for Grading of Perioperative Risk**

Degree of Cardiac Failure as $\dot{V}O_2$ at AT, mL/min/kg	Expected Postoperative $\dot{V}O_2$, mL/min/m^2	Organ System Dysfunction
A: > 14	1: < 120	P: $Ve/\dot{V}O_2 > 35$ p: $Ve/\dot{V}O_2 > 28$ and < 35
B: 11–13.9	2: > 120 and < 150	A: Supraventricular tachycardia a: Other arrhythmia
C: 8–10.9	3: > 150	I: Ischemia before AT i: Ischemia at/after AT
D: < 8		

*P or p denotes degree of pulmonary dysfunction; A or a denotes type of cardiac arrhythmia; I or i denotes onset of myocardial ischemia.

and arterial pressure monitoring, intensive physiotherapy, a staffing ratio of one nurse to two patients, and the continuous presence of experienced medical staff. Those patients with an AT > 11 mL/min/kg but with either myocardial ischemia (demonstrated during the CPX test) or a $V_E/\dot{V}O_2$ of > 35 were admitted to the HDU postoperatively. This represented 21% of patients tested by CPX.

Ward Admissions: All other patients were sent to the general ward after surgery. Thus, 51% of patients were managed on the ward, based on the results of CPX testing.

Cause of Surgical Mortality

Surgical mortality was defined as any death that occurred during the hospital admission for the surgical procedure. We divided surgical mortality into six groups according to cause:

1. *Early Cardiovascular Death:* Death directly attributable to cardiovascular causes (*eg*, acute myocardial infarction) or inadequate oxygen delivery attributable to impaired cardiac performance (*ie*, cardiac failure) within 10 days of surgery.
2. *Late Cardiovascular Death:* Death directly attributable to cardiovascular causes (*eg*, acute myocardial infarction) or inadequate oxygen delivery attributable to impaired cardiac performance (*ie*, cardiac failure) > 10 days after surgery. This grouping was necessary because some patients died some weeks after surgery (see Table 2) but had been supported in the ICU on ventilators and with inotropic drugs.
3. *Death Due to Progression of Disease:* Death in patients for whom only palliative surgery and/or palliative care was performed. This group includes patients with "not for resuscitation" orders given at the time of, or shortly after, surgery.
4. *Surgical Misadventure:* Death following a major surgical complication, *eg*, uncontrolled hemorrhage occurring intraoperatively or inadvertent damage to hollow viscus leading to peritoneal contamination.
5. *Anesthetic Death:* Death following anesthetic misadventure.
6. *Death From Miscellaneous Causes:* Death following events that are unrelated to CPX testing and not covered by above definitions, *eg*, an acute cerebrovascular event.

Results

AT and Age Distribution

The age distribution of the patients tested and the distribution of the AT for each age group are displayed in Figure 1. Eighty-eight percent of patients were ≥ 60 years old, with an average age of 69 years old. Consistent with our previous study,[5] there were no significant differences in the AT among the age groups. Patients < 60 years old who were tested by CPX had a documented history of myocardial ischemia or cardiac failure.

The overall distribution of AT is shown in Figure 2. The average AT for the group of 187 patients we described in the 1993 report[5] was 12.4 mL/min/kg. In the current study of 548 patients, the average AT was very similar, 12.6 mL/min/kg; 157 patients (28.6%) had an AT of < 11 mL/min/kg, the range of AT considered to place a patient at high risk.

Mortality by AT

Twenty-one of the 548 patients in the study died. The percent of deaths in each AT category is shown in Figure 3. Nine patients died of cardiovascular

Table 2—*Deaths From All Causes in the 548 Patients Studied***

Patient No.	Age, yr	Surgery	AT	$V_E/\dot{V}O_2$	Code	Triage	Days to Death	Group	Cause of Mortality
Cardiovascular deaths									
1	73	Colorectal	10.1	52	C3P	ICU	8	1	Early CVS
2	71	Colorectal	10.9	38	C3P	ICU	2	1	Early CVS
3	81	Colorectal	14.3	36	A3IP	HDU	1	1	Early CVS
4	84	Colorectal	10.8	31	C3p	ICU	4	1	Early CVS
5	83	Palliative	7.5	42	D3P	ICU	4	1	Early CVS
6	72	Colorectal	—	31	3pi	HDU	17	2	Late CVS
7	79	AAA	12	43	B3P	ICU	32	2	Late CVS
8	59	Ax. bifem.	8.3	39	C3PI	ICU	10	2	Late CVS
9	72	Colorectal	8.3	49	C3P	ICU	17	2	Late CVS
Deaths from other causes									
10	73	Colorectal	11	35	B3p	HDU	7	3	Disease
11	82	Colorectal	10	44	C3Pa	ICU	34	3	Disease
12	80	Gastrectomy	10	38	C3P	ICU	8	3	Disease
13	78	Palliative	9.7	32	C3Ip	ICU	20	3	Disease
14	66	Palliative	14.6	25	A3	Ward	2	3	Disease
15	78	Colorectal	13	31	B3p	Ward	40	3/4	Disease/surgical
16	77	AAA	10	47	C3P	ICU	3	4	Surgical
17	83	Colorectal	9.6	31	C3pi	ICU	0	4	Surgical
18	79	AAA	10	26	C3i	ICU	73	4/2	Surgical/late CVS
19	83	AAA	13.2	31	B3p	ICU	30	4/2	Surgical/late CVS
20	73	AAA	10	32	C3p	ICU	12	6	Miscellaneous
21	67	Colorectal	12.1	49	B3PI	HDU	22	6	Miscellaneous

*AAA = abdominal aortic aneurysm; Ax. bifem. = axillary bifemoral bypass; CVS = cardiovascular system disease. Refer to Table 1 for definitions of codes. Triage indicates recommendation for perioperative management. See text for definitions of Group and Cause of Mortality.

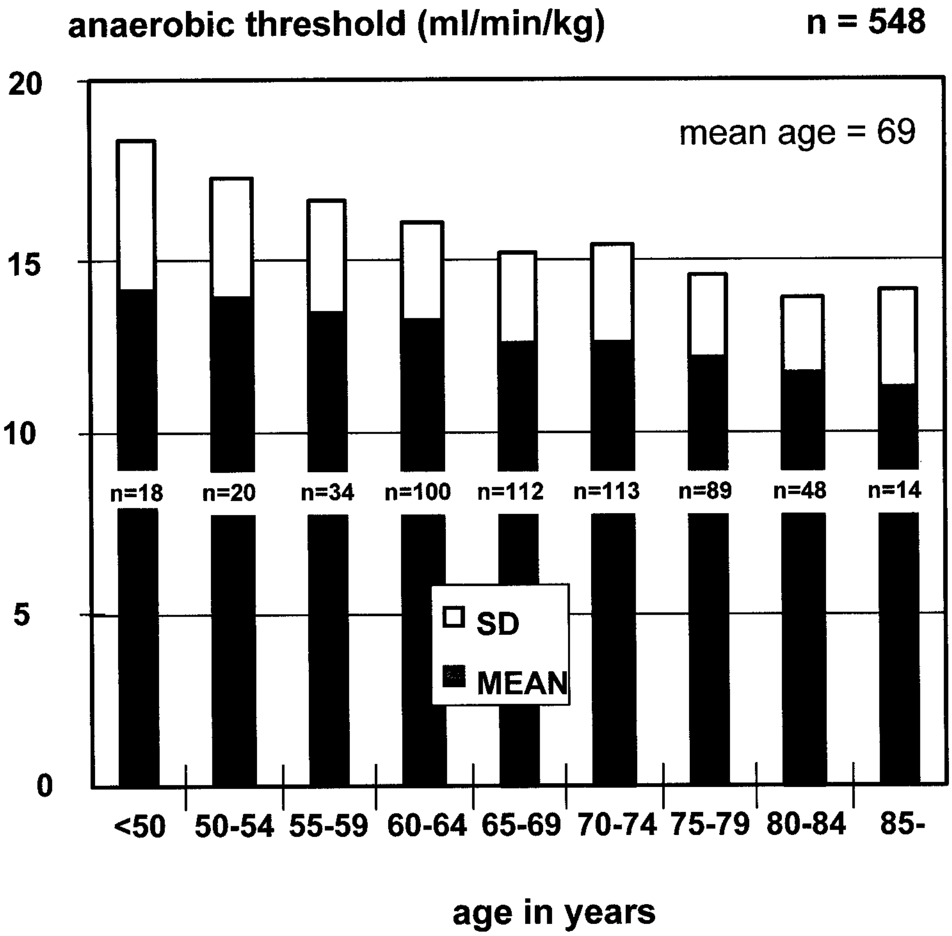

FIGURE 1. Distribution of AT according to age group for 548 surgical patients undergoing preoperative CPX testing.

causes; of these, seven had an AT of < 11 mL/min/kg. Five patients died of surgical complications, three of whom had an AT of < 11 mL/min/kg. Three of the five patients who died from the progression of their preoperative disease had an AT of < 11 mL/min/kg. The remaining two patients had cerebrovascular events (Table 2).

Mortality by Triage Site

The overall and cardiovascular mortality according to triage site are shown in Figure 4. Nineteen of the 21 patients who died were triaged to the ICU or HDU; 14 of these 19 patients had an AT of < 11 mL/kg/min, demonstrating that the CPX assessment identified the patients at greatest risk (Table 2). In terms of cardiovascular mortality, the fact that almost 3.4% of the patients who were admitted to the ICU/HDU died, whereas none of the patients who were admitted to the ward died, attests to our success in identifying the high-risk patients. Only 2 of the 279 patients who were triaged to the ward died, and these deaths were due to the progression of their neoplastic disease. They were not admitted to ICU.

Figure 5 summarizes the triage system and the results. A total of 548 patients who underwent surgery had CPX testing. Of these, 153 patients had an AT of < 11 mL/min/kg, and all 153 were admitted to the ICU. Seven of these patients (4.6%) died cardiovascular deaths. One hundred fifteen patients had an AT of > 11 mL/min/kg, but also had either a $Ve/\dot{V}o_2$ of > 35 or ECG evidence of myocardial ischemia on CPX testing. These patients were treated in the HDU. The deaths of 2 of the 115 patients (1.7%) were cardiovascular related. The 280 patients who had an AT of > 11 mL/min/kg with no evidence of myocardial ischemia and a $Ve/\dot{V}o_2$ of < 35 were all triaged to the ward, and there was no cardiovascular mortality in this group.

Discussion

Preoperative screening tests for cardiac and pulmonary dysfunction are not routinely performed in most hospitals. CPX testing is an inexpensive and totally noninvasive technique used for the objective evaluation of cardiac and pulmonary function. For

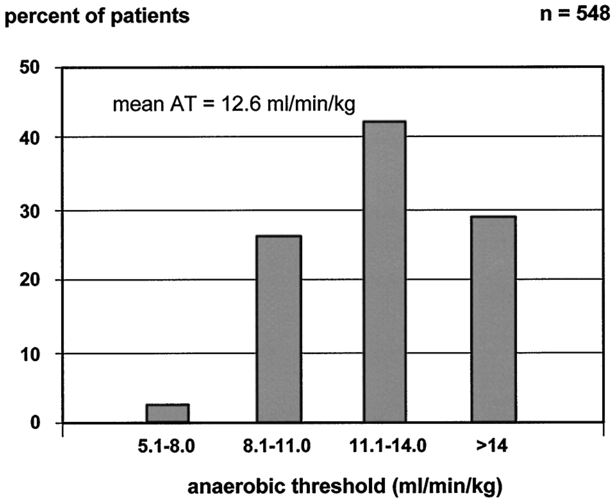

FIGURE 2. AT distribution for 548 surgical patients who underwent preoperative CPX testing.

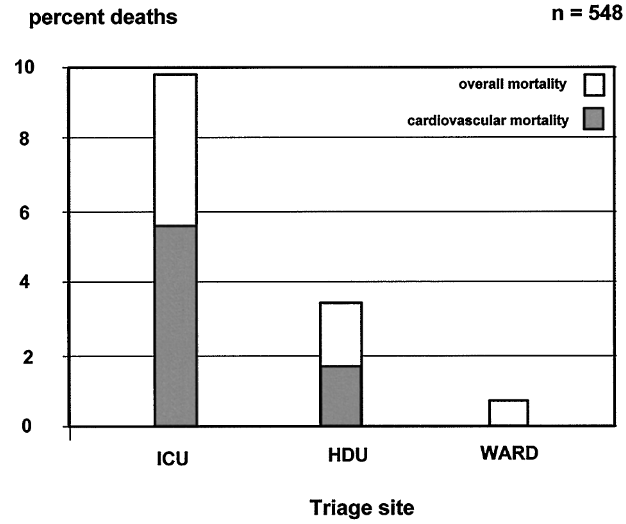

FIGURE 4. Overall and cardiovascular mortality according to triage site for 548 patients.

this reason, all elderly patients scheduled for major surgery, as well as younger patients with known cardiovascular disease, are routinely screened with CPX at our hospital.

The parameter in which we have the most interest is the AT. This is the point during exercise at which anaerobic metabolism is needed to supplement aerobic metabolism. The AT is detectable by gas exchange techniques as the point at which the rate of increase of carbon dioxide output exceeds the rate of increase in $\mathrm{V}o_2$; this is the basis of detection of AT by the V-slope method as described by Beaver et al.[8] The AT is an accurate objective assessment of cardiac function and has been used to classify cardiac failure.[11] The advantage of using the AT over maximum aerobic capacity is that the AT is independent of the motivation of the patient, and it occurs well before maximum aerobic capacity. Thus, the AT is readily obtained even in elderly patients because this measurement does not require high physical stress.

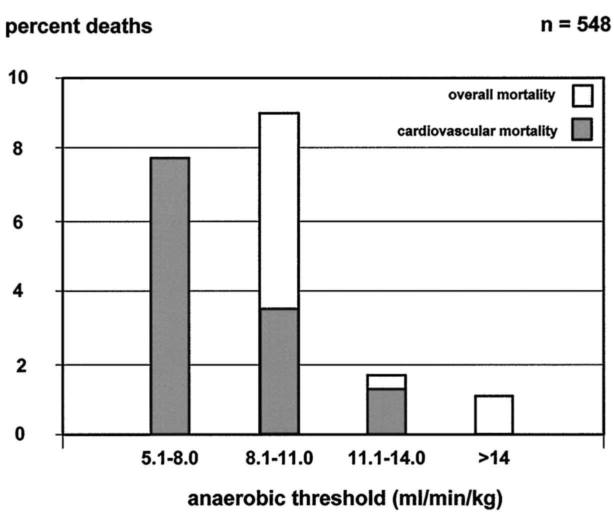

FIGURE 3. Overall and cardiovascular mortality according to AT for 548 patients.

CPX testing closely mimics the postoperative situation, as it requires an increased cardiac output to satisfy the increased oxygen demand. Patients identified as having poor oxygen delivery on the bicycle ergometer would be expected to have a poor ability to increase cardiac output following surgery. Whereas increasing age produces a decrease in aerobic capacity, the reduction in AT is more dependent on disease and fitness than age. Our results show that the variation of AT vs age is such that one SD encompasses all age groups (Fig 1). If age is used as the criterion for fitness for surgery, it may deny fit elderly people life-saving operations, as well as possibly expose younger patients with occult cardiopulmonary disease to increased risk.[12]

The CPX test takes 1 h to perform, it is noninvasive, it requires minimal preparation, and it may be performed on an outpatient basis. ECG and respiratory function tests are an integral part of the CPX test. The test is extremely safe, and of the $> 2{,}000$ patients we have tested in 8 years, only 3 patients have required treatment for myocardial ischemia. Symptomatic angina is very uncommon.

Perioperative management is based on the result of the CPX test. In a previous study, we showed that cardiovascular mortality was restricted to patients with an AT of < 11 mL/min/kg.[5] For this reason, we use the AT as the major discriminator for management.

Almost all studies of preoperative evaluation are

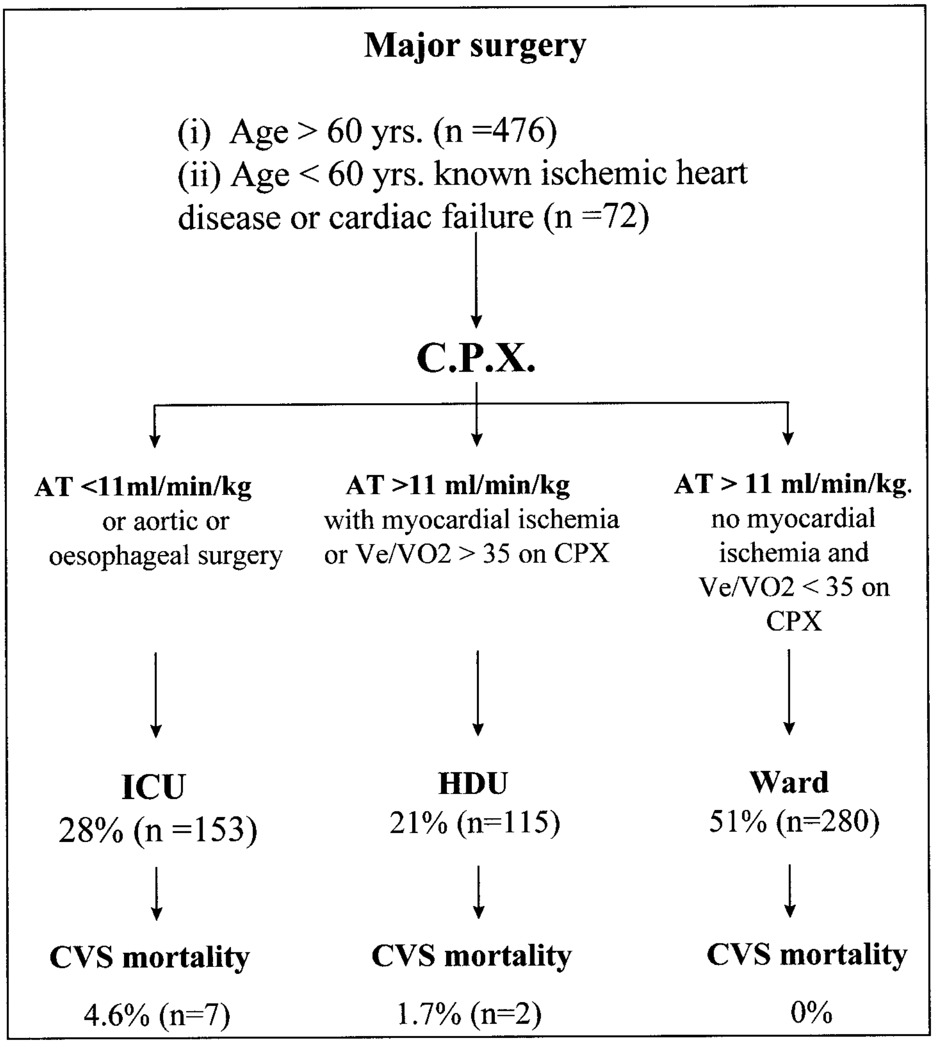

FIGURE 5. Flow chart showing postoperative triage site and outcome following major surgery. CVS = cardiovascular system.

more concerned with myocardial ischemia than cardiac failure.[13] Goldman et al[2] identified the importance of cardiac failure as a preoperative risk factor. Our studies suggest that cardiac failure is responsible for more deaths than myocardial ischemia. In this study, of the 11 deaths associated with cardiac causes, only four patients had detectable ischemia (Table 2). Death from cardiac failure is not acute nor dramatic, but it is associated with a slow decline in organ function. It presents as oliguria, hypotension, and tachypnea, often occurring several days postoperatively.

We distinguished two patterns of ST depression occurring during CPX studies.[6] The first pattern is the group of patients who developed ischemia at high work rates, at or above the AT. The second group had already developed ischemia prior to reaching the AT, the ECG often becoming positive for ischemia within 2 min of the onset of exercise. The latter tended to have a lower AT. We hypothesize that there is a surgical or postoperative metabolic rate analogous to an AT, which, if exceeded in the postoperative period, would result in the development of myocardial ischemia or circulatory failure. The AT determined during exercise provides insight into the reserve in the oxygen transport function of the patient.

We have previously shown that the combination of ECG evidence of myocardial ischemia and an AT indicative of moderate cardiac failure (*ie*, < 11 mL/min/kg) was associated with high mortality and had the worst possible outcome.[5]

We have shown before that approximately 24% of all elderly surgical patients tested have myocardial ischemia based on ECG criteria, whether they have angina or not.[5,6] Many elderly patients have a low AT without demonstrable ischemia. Aging results in reduced left ventricular compliance, making patients in this age group candidates for heart failure based on diastolic dysfunction.[14] The presence of a low AT, even in the absence of ischemia, is associated with a high-mortality risk.[5]

It is important to note that a history of myocardial ischemia or previous myocardial infarct did not serve as a criterion for admission to ICU/HDU. The criteria for admission were the result of the CPX study and the extent of proposed surgery (described as "surgery-specific risk" by the American Heart Association[10]). On this basis, the patients scheduled for repair of abdominal aortic aneurysm or esophageal surgery were admitted to the ICU regardless of the CPX result.

It is of prime importance to determine operative risk as a function of both preexisting cardiopulmonary disease and the surgery-specific risk.[10] The focus of this study is that a preoperative screening test results in high-risk patients being identified and treated in a different manner than low-risk patients are being treated.

In a previous study of 100 elderly patients scheduled for major surgery, the patients were admitted to the ICU for invasive hemodynamic monitoring preoperatively.[15] It was clear from this study that a large number of patients did not need such management, as no interventions were made in the postoperative period on the basis of information from the hemodynamic study. By admitting to the ICU only the patients who had significant cardiac failure as defined by CPX, we were able to reduce the use of the ICU resource and to restrict the use of the pulmonary artery catheter to those patients who were most likely to benefit from it. We find that the majority of patients admitted to the ICU with an AT of < 11 mL/min/kg require considerable support in the immediate postoperative period.

Overall mortality was 21 of 548 patients (3.9%). Of these 21 deaths, 11 deaths (52%) occurred in patients with poor cardiopulmonary function detected preoperatively. Two of these deaths followed massive blood loss associated with abdominal aortic aneurysm repair and occurred > 30 days after surgery. Of the other 10 patients who died, 6 patients died from progression of their disease and had "do not resuscitate" orders, two deaths were related to surgical complications, and two deaths were from unrelated causes (Table 2).

The deaths due to cardiopulmonary causes were virtually confined to patients who had an AT of < 11 mL/min/kg and/or had significant myocardial ischemia on CPX. Even in the group of deaths that were not related to cardiopulmonary disease, all but one patient had an AT of < 11 mL/min/kg and/or significant myocardial ischemia (Table 2). Of the five patients with an AT of > 11 mL/min/kg who died, two patients had early myocardial ischemia ("I"), one patient had severe pulmonary disease ("P") with a $Ve/\dot{V}o_2$ of 43 (Table 1), one patient died following surgical complications, and one patient was given only palliative care for advanced cancer. Of the 279 patients (51%) deemed fit for general ward management, there were 2 deaths, both associated with progression of underlying disease and not from cardiopulmonary complications (Fig 4).

The average duration of stay for those admitted to the ICU, including the day of admission preoperatively, was 4.5 days. Those admitted to the HDU had an average stay of 1.8 days.

In summary, the results of CPX have a very high predictive value for patients at risk of death from cardiopulmonary causes in the postoperative period. It is even more reliable at detecting those not at risk, in that there were no deaths related to cardiopulmonary complications in any patient we identified through CPX testing as fit for major surgery with ward management (Fig 4).

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