THE ASSESSMENT OF CARDIAC RISK IN ELECTIVE AORTIC SURGERY

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TO TERRY-ANN

GLOSSARY

ASA	American Surgical Association
CABG	Coronary artery bypass graft surgery
CAD	Coronary artery disease
CASS	Cooperative Coronary Artery Surgery Study
CCF	Congestive cardiac failure
CO_2	Carbon dioxide
CRI	Cardiac risk index (Goldman)
CVP	Central venous pressure (cm H_20)
DT Scan	Dipyridamole/Thallium- 201 scan
ECG	Electrocardiograph
EF	Ejection fraction of ventricle
EST	Exercise stress test
FEV1	Forced expiratory volume in 1 second
FVC	Forced vital capacity
$HCO3^-$	Serum bicarbonate level (mmol/l)
ICU	Intensive care unit
JVP	Jugular venous pressure (cm)
K^+	Serum potassium level (mmol/l)
MI	Myocardial infarction
MOF	Multiple organ failure
Na^+	Serum sodium concentration (mmol/l)
O_2	Oxygen
Trash foot	Toe infarction due to microembolism
VPBs	Ventricular premature beats

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ABSTRACT

The high prevalence of coronary artery disease in patients undergoing elective abdominal aortic reconstruction accounts for the fact that the commonest cause of postoperative death or major morbidity is myocardial infarction or left ventricular failure . Accurate assessment of cardiac risk is essential in patient selection for surgery and in the allocation of limited medical resources and invasive monitoring techniques.

The factors which are clinically valid in predicting cardiac risk have yet to be defined in a large prospective study of patients undergoing aortic reconstruction. Scoring systems such as the Goldman cardiac risk index (CRI) developed in patients undergoing largely non vascular operations and the Cooperman formula developed in patients undergoing a wide range of vascular procedures require prospective evaluation in patients undergoing aortic surgery before their validity in this high risk group can be established.

Several non invasive or minimally invasive procedures are now available to assess ventricular performance or myocardial perfusion. To date the few studies that have investigated the predictive ability of radionuclide ventriculography or dipyridamole/thallium-201 scintigraphy in patients undergoing vascular surgery have been limited by small patient numbers and conflicting results.

In a prospective study representing a complete capture of all 220 patients undergoing elective abdominal aortic reconstruction in a single institution over a 3 year period, this study has demonstrated seven clinical factors to be valid in cardiac risk prediction using both univariate and multivariate analysis of a large number of possible risk factors. These factors are age greater than 70 years, angina, previous myocardial infarction, past or present evidence of congestive heart failure, an abnormal electrocardiogram, arrhythmia or previous stroke. No patient developed a major cardiac event postoperatively in the absence of at least one of these factors. The non-invasive studies evaluated were

not found to be clinically useful in the absence of these factors as the results were almost invariably normal in such patients.

Despite having a significant correlation with the risk of major cardiac events, the usefulness of the Goldman CRI was limited by the large number of patients in the lowest risk category that developed cardiac events. The Cooperman formula was found to be a remarkably accurate predictor of statistical cardiac risk.

The computation of left ventricular ejection fraction by equilibrium radionucliude angiocardiography significantly added to cardiac risk prediction and defined a subgroup of patients with poor left ventricular function in whom the operative risk was prohibitively high. The performance of dipyridamole-thallium scintigraphy as a predictive test was disappointing.

Patients who are at increased cardiac risk can be reliably identified using simple clinical criteria. Cardiac risk estimation can be further refined in those with clinical risk factors by simple non-invasive tests, particularly radionuclide ventriculography. The widely promoted policy of routine coronary angiography to detect coronary lesions prior to aortic surgery cannot be supported on the basis of this data and the clinical relevance of asymptomatic coronary lesions that may be detected by routine coronary angiography is questioned by this study. The potential for sudden death or acute myocardial infarction in patients with non-flow-limiting coronary stenoses will continue to be a source of error in any system of clinical risk prediction. None of the currently available non-invasive tests are able to detect such lesions or predict their natural history.

INTRODUCTION

1.1 CARDIAC DISEASE IN PATIENTS UNDERGOING AORTIC SURGERY

Coronary artery disease is usually the decisive factor that determines both early and late postoperative mortality following elective abdominal aortic surgery, accounting for approximately 40% of perioperative deaths [1,2,3]. Although improvements in recent years in anaesthetic techniques, sophisticated cardiac monitoring and intensive care units have made elective aortic reconstruction safer with current operative mortality rates of approximately 5% [4,5], the proportion of patients who succumb to cardiac complications has not changed in the past two decades. De Bakey in 1964 reported that 44% of postoperative deaths following elective abdominal aortic aneurysm repair were due to cardiac events [6]. In 1982 Hertzer attributed 39% of postoperative deaths to myocardial infarction following the same operation [7].

Routine coronary angiography prior to aortic surgery has demonstrated that 85% of patients have some degree of coronary artery disease with severe disease involving two or three vessels, or the left mainstem being demonstrated in 31% [8,9]

In order to further reduce the risk of elective abdominal aortic surgery, patients with significant coronary artery disease must be identified by careful analysis of clinical risk factors and screening tests. It may then be possible to reduce their risk by modifying the magnitude of the surgical procedure or improving their tolerance. The latter may include a change in pre-operative drug therapy, selection for more sophisticated peri-operative monitoring and support and under certain circumstances, pre-operative coronary artery bypass surgery.

1.2 CARDIAC CHANGES DURING AORTIC SURGERY

Aortic surgery increases the physiologic and metabolic demands on the heart not only during the period of anaesthesia and surgery but during the postoperative period accounting for the fact that most myocardial infarctions occur on the third postoperative day [10,11]. With a very limited capacity for anaerobic metabolism, the myocardium is dependent on a constant supply of oxygen via the coronary circulation for optimal contractile function. Coronary vasodilation is the normal physiological mechanism for increasing oxygen supply but in patients with coronary artery disease and a fixed stenosis this may be ineffective, resulting in myocardial ischaemia during periods of increased demand.

Coronary blood flow is greatest during early diastole when the pressure gradient across the coronary bed is greatest. Consequently oxygen delivery will be impaired by any factor which reduces the duration of diastole or reduces this gradient. Tachycardia reduces oxygen supply by reducing the period of diastole as well as the time for myocardial perfusion. Reductions in systemic diastolic pressure or a rise in left ventricular end diastolic pressure will decrease the perfusion gradient. A falling haematocrit due to blood loss or reduction in the inspired fraction of oxygen will further reduce oxygen delivery. All inhalation anaesthetic agents are myocardial depressants and many are arrhythmogenic. Crossclamping the aorta produces a sudden rise in left ventricular end diastolic pressure with a consequent reduction in coronary perfusion [10,12,13]. Release of the crossclamp is frequently associated with hypotension, particularly in the presence of relative hypovolaemia [10]. These various factors frequently conspire to increase oxygen demand at a time when delivery may be limited by a fixed coronary artery stenosis.

1.3 THE PREVALENCE AND DISTRIBUTION OF CORONARY ARTERY DISEASE IN PATIENTS UNDERGOING AORTIC RECONSTRUCTION

Studies in which all patients undergoing elective vascular surgery have undergone preoperative coronary angiography have provided considerable information on the prevalence and distribution of coronary artery disease within this patient group.

The information obtained from 1000 consecutive coronary angiograms performed in patients scheduled to undergo peripheral vascular surgery, and their subsequent course was reported from the Cleveland Clinic in 1984 [8]. Twenty six percent of the patients had an abdominal aortic aneurysm and patients scheduled for aortofemoral bypass made up a large proportion of the 38% with occlusive peripheral vascular disease. Patients who had previously undergone coronary angiography or coronary surgery were excluded as were patients requiring urgent vascular surgery. Coronary angiograms were classified as follows:

1. *Normal*

2. *Mild to moderate CAD*, with measurable disease of one or more coronary arteries but no lesion exceeding 70% stenosis.

3. *Advanced but compensated CAD*, with greater than 70% stenosis of one or more coronary arteries but no immediate indication for myocardial revascularisation because of adequate intercoronary collateral circulation or because the involved vessel supplied myocardium already replaced by scar.

4. *Severe, correctable CAD*, with greater than 70% stenosis of one or more coronary arteries serving unimpaired myocardium and representing immediate or foreseeable risk for myocardial infarction.

5. *Severe, inoperable CAD*, with greater than 70% stenosis of multiple coronary arteries representing inadequate targets for coronary artery bypass grafts because of diffuse distal disease or generalised ventricular impairment.

Of the 1000, 554 had clinical evidence of coronary artery disease (CAD) including an abnormal resting ECG in 500. Four hundred and forty six had no clinical evidence of CAD. All were studied using the trans-brachial route. The angiographic findings are listed in table 1.1:

Normal	8%
Mild/Moderate	32%
Advanced/Compensated	29%
Severe/Correctable	25%
Severe/Inoperable	6%

Table 1.1: Anatomical findings in 1000 coronary angiograms performed in patients scheduled for vascular surgery (Hertzer et al.[8]).

The severe/correctable group comprised 34% of the patients with clinical C.A.D. and 14% of those with no clinical evidence of C.A.D. Thus in the Cleveland Clinic experience, one third of patients with symptoms or signs of heart disease, or an abnormal resting ECG had a potentially life threatening coronary lesion. Far more important, perhaps is the group of asymptomatic patients who had no physical signs and a normal resting ECG. One in seven of these had a significant, and potentially correctable coronary lesion. Many patients undergoing aortic surgery lead a sedentary lifestyle either out of choice or habit, or because they are limited by claudication. Such patients may have severe coronary artery disease and yet be asymptomatic.

Tomatis et al. [14] in 100 consecutive coronary angiograms prior to elective peripheral vascular surgery found significant coronary disease in 47% of those with aorto-iliac occlusive disease and 75% of those with abdominal aortic aneurysm.

However, the demonstration of abnormal coronary anatomy does not necessarily translate into postoperative morbidity or mortality. A recent Australian study [15] employing routine coronary angiography in 100 consecutive patients scheduled to undergo abdominal aortic aneurysm surgery showed that whilst 94% of patients with clinical evidence of CAD and 67% of patients with no clinical CAD had at least one stenotic lesion >50%, cardiac events developed almost exclusively in the group with clinical CAD. Patients with more extensive lesions, particularly double and triple vessel and left mainstem lesions did have a higher cardiac event rate.

The clinical significance for operative risk of asymptomatic coronary stenoses detected in patients undergoing peripheral vascular operations remains to be established. This key question underlies the significance of the routine coronary angiography studies.

1.4 IDENTIFICATION OF THE PATIENT AT RISK

The accurate prediction of cardiac risk in aortic surgery is important in allocating medical resources and evaluating the risk-benefit ratio for operations, anaesthetic management and monitoring techniques.

Most patients undergoing surgery for abdominal aortic aneurysm are asymptomatic. Surgery is recommended to avoid fatal aneurysm rupture, and thus prolong life[16]. The approximate risk of rupture, depending on the size of the aneurysm can be inferred from several natural history studies[18,19,20]. This risk needs to be weighed against the projected operative risk which must be accurately assessed, particularly in patients with smaller aneurysms or severe coronary artery disease who may best be served by expectant treatment.

In the face of spiralling costs and nursing staff shortages, medical resources are becoming more limited, forcing surgeons and anaesthetists to be more circumspect in the allocation of intensive care facilities and the employment of expensive preoperative investigations and invasive perioperative monitoring. Furthermore these investigations and monitoring modalities may expose the patient to potential morbidity.

Accurate cardiac risk assessment will result in better patient selection for surgery and in the identification of patients at high risk who may have this risk modified by attention to pre-operative and peri-operative factors.

1.5 APPROACHES TO RISK PREDICTION

Several approaches are available for the prediction of cardiac risk and the detection of potentially dangerous coronary artery lesions.

1.5.i ROUTINE CORONARY ANGIOGRAPHY

The approach with the greatest accuracy would be to offer all patients cardiac catheterisation with coronary angiography[21]. It has, however not been uniformly successful in predicting which patients will die following surgery[1]. The potential for morbidity and mortality from the procedure[22] as well as its high cost make it an unrealistic approach to the problem. The fact that regardless of the demonstrated coronary lesion, it has been patients with clinical coronary artery disease that have usually developed cardiac complications[1,15] and the fact that several institutions that do not practice routine coronary angiography have reported mortality rates from myocardial infarction as low as 0.8% following aortic reconstruction in patients without a history of coronary artery disease[1,23] militate against the need for routine angiography.

1.5.ii CLINICAL SCORING

A careful history, physical examination, chest radiograph and resting ECG will be performed in all patients scheduled for aortic surgery and provide a wealth of information. Retrospective statistical analysis of risk factors involving large numbers of non-cardiac operations has enabled the development of various systems of scoring operative risk in an attempt to increase the accuracy of clinical assessment and define high and low risk groups.

The Goldman Cardiac Risk Index

Goldman et al.[24,25] prospectively studied 1001 patients over the age of 40 undergoing major non-cardiac operations. Only 16% of these procedures were vascular operations. Using multivariate discriminant analysis, nine independent significant correlates of life threatening and fatal cardiac complications were identified (see Table 1.2):

third heart sound/ jugular venous distension	11
myocardial infarction in the preceding six months	10
more than 5 premature ventricular contractions per minute recorded at any time	7
rhythm other than sinus or atrial premature beats	7
age greater than 70 years	5
intraperitoneal, intrathoracic or aortic operation	3
emergency operation	4
important aortic valvular stenosis	3
poor general medical condition	3

Table 1.2: The Goldman Factors

Scores were ascribed to each of these and patients separated into four classes of significantly different risk. Ten of the nineteen postoperative cardiac fatalities occurred in the eighteen patients in the class at highest risk. The implications of the clinical scoring in the 1001 patients studied in terms of cardiac complications or death appear in Table 1.3:

Class	Point Total	Life threatening Complication	Cardiac Death
I	0-5	0.7%	0.2%
II	6-12	5%	2%
III	13-25	11%	2%
IV	> = 26	22%	56%

Table 1.3: Correlations between Goldman score and the development of life threatening complications or cardiac death in 10001 operations [24].

Conspicuously absent from the list of significant risk factors are chronic stable angina, previous myocardial infarction before the six month period prior to surgery, ST or T wave changes on ECG, smoking, diabetes or hypertension.

Goldman et al. found subendocardial infarction to have the same prognostic importance as transmural infarction. Stable angina was associated with a three fold increase in incidence of cardiac complications but when controlled for associated factors it did not emerge as an independent predictor.

Detsky et al. [26] have modified the cardiac risk index to include myocardial infarction prior to six months and a classification of angina and have altered the calculation of risk by converting average risks for patients undergoing various procedures to average risks for patients with each index score. Although they have tested their system prospectively in 455 patients undergoing a wide variety of surgical procedures [27], there has been very limited clinical application of the system [28].

The application of the cardiac risk index to patients undergoing aortic surgery has had variable success. Whilst some workers have reported good predictive ability [29] or very poor predictive ability [30,31], most studies have been limited by small numbers [30,31] or retrospective data collection and analysis [29].

The Cooperman System

As noted above, one of the drawbacks of the Goldman study was the heterogeneous nature of the patient group with only 8% of the patients undergoing aortic surgery and a further 8%, peripheral vascular surgery. Cooperman et al. [32] analysed cardiac risk factors in 566 patients undergoing major vascular surgery and demonstrated five factors which showed significant individual associations with postoperative cardiac complications. These were:

Congestive heart failure

Prior myocardial infarction

Prior stroke

Arrhythmia

Abnormal resting ECG

A multivariate analysis of these factors as well as angina led to the development of an equation which predicts the probability of a postoperative cardiac complication and is expressed as a percentage risk. The equation, which is easily calculated on a programmable pocket calculator is:

$$P_{comp} = \text{antilog}_E\,(c_1x_1 + c_2x_2 + ... + c)$$

x_1 = angina (c_1 = 0.46)
X_2 = CCF (c_2 = 1.02)
X_3 = arrhyth (c_3 = 0.62)
X_4 = MI (c_4 = 0.64)
X_5 = CVA (C_5 = 1.15)
X_6 = ECG (C_6 = 1.25)

$$c = -3.81$$

This score has the advantage over the Goldman score of being expressed as a percentage risk which is easy to understand and communicate to patients, and easy to balance against the statistical risk of aneurysm rupture at various aneurysm sizes. Application of the system has been less widespread than the Goldman CRI but it may be more applicable to patients undergoing vascular operations [31,32]. To date only one study has prospectively evaluated the Cooperman system in patients undergoing vascular procedures and compared its predictive ability to the Goldman CRI. This small Australian study [31] comprised 100 patients, only 17 of whom underwent aortic reconstruction. The system requires further prospective application to a larger and more homogeneous group of patients in order to establish its credibility.

1.5.iii NON INVASIVE SCREENING TESTS

The advantage of risk factor analysis is that it is widely applicable without cost. The disadvantage is that it overlooks the patient with asymptomatic but haemodynamically significant coronary or other cardiac disease. It is likely that approximately 15% of asymptomatic patients undergoing aortic surgery fall into this category [8]. However, the clinical relevance of this asymptomatic group remains to be established.

Several non-invasive screening tests are currently being used to increase the accuracy of clinical risk prediction and to identify patients who may benefit from coronary angiography and coronary artery surgery. The largest experience has been with standard exercise testing. Left ventricular systolic function can now be measured easily and accurately by equilibrium radionuclide angiocardiography (ERNA) and Thallium-201 scintigraphy allows measurement of myocardial perfusion.

Exercise stress testing

Exercise testing is widely available but may be limited in its applicability to patients undergoing aortic surgery due to claudication, previous amputation, ischaemic ulceration or arthritis and the inability of many patients to attain diagnostic heart rates. Whilst several reports of the clinical application of stress testing in vascular surgical patients have been encouraging [33-39], others have drawn attention to serious limitations in their diagnostic use [24,25,40,41].

Radionuclide ventriculography

Equilibrium radionuclide angiography and multigated heart pool scans are widely used to estimate left ventricular ejection fraction and to detect ventricular dilatation and abnormalities of wall motion caused by ischaemia or infarction. The Cooperative Coronary Artery Surgery Study (CASS) showed that abnormalities of left ventricular function were more important than a previous history of myocardial infarction in predicting postoperative cardiac complications [42]. Ventriculography is well suited for testing peripheral vascular patients as it is relatively cheap, minimally invasive and requires no exercise. The ejection fraction appears to correlate well with haemodynamic information derived from pulmonary artery catheters in patients undergoing aortic surgery [43] and has been demonstrated to have important predictive value in patients undergoing aortic surgery in three clinical studies [44,45,46]. However Kazmers et al. [47] have recently reported finding no difference in perioperative cardiac complications between patients with ejection fractions greater than or less than 35% undergoing aortic aneurysm repair. These four studies have been limited by small patient numbers and results from larger clinical applications are needed to assess the role of isotope ventriculography.

Dipyridamole/Thallium-201 scintigraphy

The intravenous administration of dipyridamole causes coronary vasodilatation equivalent to that produced by exercise, but without a concomitant increase in myocardial oxygen consumption. The vasodilatation is attenuated in the presence of haemodynamically significant coronary artery stenoses. When Thallium-201 is injected as a marker for viable myocardium the resulting scan has been reported to have a sensitivity of 85-93% and a specificity of 64-80% for detecting coronary artery disease when compared to coronary angiography [48,49,50]. Scans are performed at 15 minutes and 3 hours in the anterior and 45^{o} and 75^{o} left anterior oblique positions. Normal myocardium takes up the thallium promptly and is visualized on the initial scan. Myocardium beyond a fixed stenosis will show uptake

only on the later scan (a phenomenon referred to as thallium redistribution) whilst infarcted myocardium will not take up thallium at all.

To date there have been few clinical reports of the use of dipyridamole/thallium imaging in patients undergoing aortic surgery [34,51,52,53].

AIMS OF THE STUDY

2.1 PROSPECTIVE DOCUMENTATION OF MORBIDITY & MORTALITY

Patients undergoing abdominal aortic surgery represent a fairly homogeneous high risk group. To date no South African study has prospectively studied morbidity and mortality, and in particular, cardiac events following elective aortic reconstruction. Retrospective reviews have inherent weaknesses and are likely to underestimate the true incidence of cardiac events. This study aimed to accurately study and document these events prospectively in a consecutive series over a three year period.

2.2 IDENTIFICATION OF RISK FACTORS

The study aimed to identify preoperative factors which correlate with the development postoperatively of major cardiac events or death and to assess their importance in estimating a patient's overall perioperative risk.

2.3 EVALUATION OF PREDICTIVE ABILITY OF SCORING SYSTEMS

The study aimed to test the ability of two established systems, the Goldman and Cooperman scores to predict cardiac events or death within a single homogeneous high risk group of patients undergoing major vascular surgery. Such an analysis demands prospective capture of data as inaccuracies in clinical examination and in clinical notes, often prepared by junior house staff will profoundly influence the scores in systems that attach heavy weights to the presence of an abnormal physical sign such as a third heart sound or an elevated jugular venous pressure. Validation of the scoring systems depends on application in new clinical settings and patient groups. Only two studies have prospectively applied the

Goldman CRI exclusively to patients undergoing vascular surgery and these have been limited by small numbers of patients undergoing aortic reconstruction [54,55]. The findings of these two studies differ significantly from the findings in three prospective studies that have applied the index to patients undergoing a wide variety of non cardiac procedures [56,57,58] and to retrospective studies that have applied it to vascular patients [29]. It has not yet been determined whether the recommendations proposed by Goldman and Cooperman are applicable to patients in Cape Town or South Africa. Patient populations are heterogeneous and recommendations from the literature cannot be blindly applied to another patient subset.

2.4 TESTING THE PREDICTIVE ABILITY OF SPECIAL INVESTIGATIONS

Beyond the simple investigations performed in all patients being considered for elective aortic surgery several more sophisticated and expensive investigations are available to clinicians and may add to the accuracy of clinical prediction of cardiac risk. This study aimed to assess the predictive ability of the following tests in the context of elective aortic surgery:

a) Exercise stress test (EST)

b) Equilibrium radionuclide angiocardiography (ERNA)

c) Dipyridamole/Thallium-201 scintigraphy (DT scan)

THE STUDY: PATIENTS AND METHODS

3.1 INCLUSIONS

All patients undergoing elective aortic reconstruction between April 1986 and February 1989 were eligible for inclusion in the study, regardless of the aetiology of the aortic disease, the indication for surgery or the age of the patient.

3.2 EXCLUSIONS

Adequate pre-operative evaluation was not possible in patients who underwent aortic reconstruction within 24 hours of admission to the hospital and such patients were excluded from the study. In this category were patients with clinical evidence of aneurysm rupture, acute abdominal pain with a tender aneurysm and patients with acute on chronic aortoiliac occlusions and an immediately threatened limb. Patients who underwent elective operations after adequate pre-operative assessment but were found at laparotomy to have a contained rupture of an abdominal aortic aneurysm were nevertheless included in the study.

3.3 INVESTIGATION PROTOCOL

A standard proforma was used for documentation and each sheet personally completed by the author. Data was subsequently entered into a data base designed by the author employing dBase III + (Ashton-Tate) on an IBM AT personal computer.

3.3.i CARDIAC EVALUATION

Patients entered into the study were evaluated by one of the participating cardiologists. In the patient's history particular attention was paid to symptoms of angina, dyspnoea, orthopnoea, paroxysmal nocturnal dyspnoea and the patient's effort tolerance. Previous myocardial infarctions were recorded as was any history of diabetes, hypertension or hyperlipidaemia. Current or previous tobacco use was recorded and the pack year history calculated. On clinical examination the following parameters were recorded: Systolic and diastolic blood pressure, pulse status, jugular venous pressure, peripheral oedema, the quality of the heart sounds and any evidence of a third or fourth sound and any clinical evidence of valvular heart disease.

A standard 12 lead resting ECG was obtained and classified as either normal if no abnormalities were detected; borderline if changes were confined to supraventricular extrasystoles, prolongation of PR interval, non diagnostic ST and T wave changes and ventricular hypertrophy purely on voltage criteria; and abnormal in the presence of pathological Q waves, atrial fibrillation or flutter, ventricular arrhythmia, convincing ST and T wave changes of ischaemia or more severe abnormalities of electrical conduction and axis change.

A standard PA and lateral chest radiograph was obtained noting any evidence of cardiac enlargement, pulmonary congestion, hyperinflation or active pulmonary pathology.

Left ventricular ejection fraction was routinely estimated by equilibrium radionuclide angiography and any evidence of ventricular dilatation or wall motion abnormality detected on the scan, noted.

Exercise stress tests, Dipyridamole/Thallium-201 scintigraphy and coronary angiography were employed selectively at the discretion of the participating cardiologists. Employment of

Dipyridamole/Thallium-201 scintigraphy depended on the availability of thallium. As a result many requests for Dipyridamole/Thallium-201 scans could not be complied with.

3.3.ii RESPIRATORY EVALUATION

Formal measurement of forced vital capacity (FVC) and the forced expiratory volume in one second (FEV1) ware performed in the pulmonary function laboratory in all patients and partial pressures of O_2 and CO_2 measured in an arterial blood specimen obtained whilst the patient was breathing room air.

3.3.iii RENAL EVALUATION

In addition to measurement of baseline serum urea and creatinine levels, a 24 hour urine specimen was obtained from which the 24 hour corrected creatinine clearance was estimated.

3.3.iv CEREBROVASCULAR EVALUATION

Patients with carotid bruits or clinical evidence of cerebrovascular disease (previous stroke, transient ischaemic attacks, amaurosis fugax) underwent screening using supraorbital directional doppler and spectral analysis. Patients with abnormal carotid dopplers were further evaluated using duplex doppler ultrasound. Carotid angiography was performed only in patients with symptomatic cerebrovascular disease being considered for carotid surgery.

3.4 INTRAOPERATIVE DOCUMENTATION

No attempt was made to standardise the aneaesthetic technique which varied depending on the anaesthetist and the clinical circumstances. A central venous catheter and a radial artery catheter were routinely employed and baseline measurements of central venous pressure and mean arterial pressure recorded on induction. A record was then kept of all further CVP and arterial pressure readings. Pulmonary artery catheters were used selectively at the discretion of the anaesthetist and were usually reserved for patients with poor ventricular performance. These catheters continued to be employed during the postoperative period, usually for a period of 48 hours. New ECG changes were recorded and the duration of the operation and volumes of transfused blood and crystalloid documented.

3.5 POSTOPERATIVE PROTOCOL

All patients were initially nursed in an intensive care unit and the majority, electively ventilated. Continuous monitoring of ECG, CVP, arterial pressure, blood gasses and urine output was continued until discharge from the unit. In patients with pulmonary artery catheters, pulmonary artery and pulmonary capillary wedge pressures were recorded as were mixed venous oxygen tensions, cardiac output, systemic vascular resistance and ventricular stroke work index. 12 lead ECGs were repeated daily whilst in the ICU and on the 5th postoperative day. These ECGs were subsequently reviewed by one of the participating cardiologists. "Cardiac" enzymes were not measured in all patients but requested liberally wherever clinical suspicion of myocardial infarction existed. All patients were followed for at least 30 days or until discharge from hospital, whichever was the longer period.

3.6 END POINT DEFINITIONS

Three end points were clearly defined and various preoperative factors tested for their correlation with the subsequent development of each of these end points. These were:

Death

Major cardiac event

Myocardial infarction

These, and other important criteria were defined as follows:

a) **DEATH** Death due to any cause within 30 days of the aortic procedure or at any time later if the patient had not been discharged from hospital since the initial surgery.

b) **MYOCARDIAL INFARCTION** Diagnosis depended on the demonstration of at least one of the following:

Diagnostic ECG changes

>5% MB isoenzyme fraction of creatine phosphokinase

Autopsy evidence of recent myocardial infarction

c) **PULMONARY OEDEMA/ CARDIAC FAILURE** This was diagnosed on the basis of a combination of clinical and radiological criteria, usually supplemented by physiological data derived from the presence of a pulmonary artery catheter and a rapid response to diuretic and inotropic therapy. Patients developing transient pulmonary oedema thought to be on the basis of iatrogenic fluid overload were specifically excluded from this definition.

d) **MALIGNANT VENTRICULAR ARRHYTHMIA** This included at least one of: Ventricular tachycardia, ventricular fibrillation or greater than 5 ventricular extrasystoles per minute.

e) **MAJOR CARDIAC EVENT** Diagnosis depended on the demonstration of at least one of the following:

Myocardial infarction

Cardiac failure/Pulmonary oedema

Malignant ventricular arrhythmia

f) **CARDIAC DEATH** Deaths were attributed to a cardiac cause if it was thought to be either the sole cause of death or a major contributing factor. Thus a patient sustaining a postoperative myocardial infarction who ultimately died of septicaemia or pneumonia whilst still in the intensive care unit would nevertheless be considered a cardiac death.

e) **MINOR CARDIAC EVENT** These included:

Severe postoperative hypertension

Transient pulmonary oedema, possibly iatrogenic

Pulmonary embolus

Development of atrial fibrillation or flutter

Ischaemic changes on ECG but no infarction

3.7 RISK FACTOR ANALYSIS

3.7.i FACTORS STUDIED

Twenty five factors derived from the history, clinical examination and simple investigations performed routinely on all vascular surgical admissions were tested for their correlation with the development of each of the defined end points. These factors are tabulated in Table 3.1:

Age	Angina
Sex	Hypertension
Nature of aortic disease	Previous infarct
Diabetes	CCF/S3/Elevated JVP
Hyperlipidaemia	Arrhythmia
Smoking	Valvular heart disease
Previous stroke	Previous coronary surgery
Carotid bruit	Previous coronary PTA
Clinical COAD	Abnormal ECG
FEV1	Radiological cardiomegaly
PaO_2	
PCO_2	
Serum urea	
Serum creatinine	
Creatinine clearance	

Table 3.1: Possible risk factors studied for their correlation with postoperative events. COAD = chronic obstructive airways disease; FEV1 = forced expiratory volume in one second; PaO_2 = partial pressure of oxygen in arterial blood; PCO_2 = partial pressure of carbon dioxide in arterial blood.

A patient was considered to have hypertension if he was currently receiving antihypertensive therapy or had a blood pressure greater than 150/90 on admission. A patient was considered to have had a previous myocardial infarction if he gave a clear history of the event or had convincing ECG evidence. Patients were considered to be smokers if they had smoked within the preceding 12 months. Patients with abnormal ECGs were further studied with respect to electrocardiographic evidence of the following:

Previous infarction

Supraventricular arrhythmia

Ventricular arrhythmia

Ischaemic changes

Conduction disturbances

In addition, these clinical factors were used to score the patient's risk using two previously described systems:

3.7.ii THE GOLDMAN CARDIAC RISK INDEX

The factors involved in computing the Goldman score appear in TABLE 3.2:

FACTOR	SCORE
Third sound, elevated JVP	11
Myocardial infarct < 6 months ago	10
> 5 Ventricular extrasystoles/minute	7
Arrhythmia	7
Age > 70	5
Emergency surgery	4
Aortic surgery	3
Aortic valvular stenosis	3
Poor general condition *	3
Possible total	53

* Poor general condition:

PaO_2	< 8 Kpa
PCO_2	> 6 Kpa
K^+	< 3 mmmol/L
HCO_3	< 20 mmol/L
Urea	> 17 mmol/L
Bedridden patient	

Table 3.2: Computation of the Goldman Score

The minimum score for patients undergoing aortic surgery is thus 3. After computing the Goldman score patients were placed in one of four Goldman classes as depicted in Table 3.3:

CLASS	SCORE
I	3-5
II	6-12
III	13-25
IV	> = 26

Table 3.3: Allocation of patients to four Goldman classes by total score.

3.7.iii COOPERMAN SYSTEM

Six factors are used in computing the Cooperman score:

The score was calculated on an Apple IIe microcomputer using the formula:

	Factor	Score if Present	Score if Absent
A	Angina	1	0
B	CCF	1	0
C	Previous infarct	1	0
D	Previous stroke	1	0
E	Arrhythmia	1	0
F	Abnormal ECG	1	0

$$P_{(comp)} = \text{Antilog}_E\,(0.46A + 1.02B + 0.62C + 0.64D + 1.15E + 1.25F - 3.81)$$

The Cooperman score is expressed as a percentage probability of developing the predicted event.

3.8 STATISTICAL ANALYSIS

Univariate analysis of the correlation between various risk factors and the development of one of the end point events was performed using a 2X2 chi^2 test with employment of the Yates correction for small numbers where appropriate.

Log linear regression multivariate analysis [59] was performed on the same risk factors. Using the development of a major cardiac event as the dependent variable, all factors were entered in a stepwise manner using the Statistical Package for the Social Sciences.

The predictive ability of the Goldman and Cooperman scores was tested by chi-square goodness of fit and the G value [60] derived.

RESULTS

4.1 THE PATIENTS

The 220 consecutive patients entered into the study represented a complete capture of all patients undergoing elective abdominal aortic reconstruction during the three year period.

4.1.i Indications for surgery

The indications for surgery in the 220 patients are summarised in table 4.1:

Abdominal Aortic Aneurysm		**99**
Thoraco-abdominal	5	
Supra-renal/infradiaphragmatic	3	
Infra-renal	91	
Aorto-iliac Occlusion/Stenosis		**116**
Atherosclerotic stenosis	111	
Chronic saddle embolus	2	
Embolising aortic plaque	2	
Myxomatous degeneration	1	
Reno-vascular Hypertension		**2**
Orificial renal artery stenosis	2	
Miscellaneous		**3**
Aorto-duodenal fistula	1	
Septic Aortic graft	1	
Aortic: L Renal vein fistula	1	
		220

Table 4.1: Indications for surgery

4.1.ii Age, sex

The mean patient age was 60 with a range of 29 to 84 years. 44 patients were older than 70 and 2, older than 80. 172 were male and 45 female.

4.1.iii Prevalence of risk factors

The distribution of risk factors appears in Table 4.2.

4.2 SPECIAL CARDIAC INVESTIGATIONS

4.2.i NUMBERS OF STUDIES PERFORMED

These are summarised in table 4.3:

Investigation	No. Patients
Exercise stress test	35
ERNA scan	183
Dipyridamole/Thallium-201 scan	37

Table 4.3: Numbers of special cardiac investigations performed

RISK FACTOR		NUMBER OF PATIENTS
Angina		38
Previous myocardial infarction:		58
History	32	
ECG	53	
Either	58	
Both	27	
Previous infarct within 6 months of surgery		0
Arrhythmia:		27
Atrial	13	
Ventricular	14	
Congestive cardiac failure, past or present		9
Previous coronary artery bypass surgery		9
Previous coronary transluminal dilatation		4
Hypertension		90
Diabetes Mellitus		19
Previous stroke		15
Carotid bruit		8
Abnormal ECG		92
Previous infarct	53	
Ischaemia	19	
Ventricular hypertrophy	38	
Conduction disturbance	20	
Arrhythmia	27	
Abnormal pulmonary spirometry		66
Mean FEV1 (ml/min)	2770	
FEV1 < 1200ml/min	14	
FEV1/FVC < 50%	14	
FEV1/FVC < 40%	4	
Abnormal arterial blood gasses in room air		27
PaO_2 < 10 Kpa	23	
PaO_2 < 8 Kpa	2	
$PaCO_2$ > 6 Kpa	4	

Elevated serum urea concentration		**59**
Urea > 6 mmol/l	59	
Urea > 8 mmol/l	18	
Urea > 10 mmol/l	10	
Serum Creatinine greater than 120 mmol/l		**39**
Creat > 120 mmol/l	39	
Creat > 150 mmol/l	10	
Creat > 200 mmol/l	2	
Creatinine clearance: adequate specimen obtained		**156**
Clearance < 40 ml/min	15	
Clearance < 30 ml/min	5	
Carotid dopplers: numbers of patients studied		**17**
Normal or <49% stenosis	12	
50 - 79% stenosis	3	
> 80% stenosis	2	
Carotid angiography: number of patients studied		**4**
0 - 49% stenosis	1	
50 - 79% stenosis	1	
> 80% stenosis	2	

Table 4.2: Distribution of risk factors

4.2.ii PROTOCOL VIOLATIONS

37 patients did not undergo radionuclide ventriculography. This was usually due to scheduling difficulties, particularly in patients whose symptoms demanded rapid preoperative evaluation prior to elective surgery. Several requests for thallium scanning could not be complied with due to lack of availability of the isotope and the reluctance of surgeons to delay surgery on their patients in order to perform an investigation which at that time was of research interest only.

4.3 THE OPERATIONS

4.3.i TYPES OF OPERATIONS PERFORMED

These are summarised in Table 4.4:

AORTO-BIFEMORAL BYPASS GRAFT		**131**
Including:		
Simultaneous renal endarterectomy	6	
Simultaneous distal jump graft	19	
"Re-do" aortobifemoral bypass	6	
AORTO-BIILIAC BYPASS GRAFT		**57**
Including:		
Simultaneous renal endarterectomy	1	
AORTIC TUBE GRAFT		**21**
MISCELLANEOUS		**11**
Including:		
Crawford thoraco-abdominal repair	5	
Aorto-iliac endarterectomy	2	
Trans-aortic renal endarterectomy	1	
Aorto-renal Bypass	1	
Removal of septic aortic graft	1	
Aortic:renal vein fistula	1	

Table 4.4: Operations performed

4.3.ii INTRAOPERATIVE MORBIDITY AND MORTALITY

Intra-operative events are summarised in Table 4.5:

Intra-operative death	1
Major haemorrhage	12
Myocardial infarction	0
New ventricular arrhythmia	5
Major hypertension	12
Major hypotension	26
Pulmonary oedema	4

Table 4.5: Intraoperative events

The sole intra-operative death was recorded in a 29 year old patient with a thoraco-abdominal aortic aneurysm and associated aortic coarctation on the basis of Takayasu aortitis. Severe hypertension, left ventricular dilatation and hypertrophy and a pericardial effusion were present preoperatively and cardiac catheterisation revealed a left ventricular end diastolic pressure of 30 mm Hg. An attempted aortic reconstruction using a thoraco-abdominal exposure and involving reimplantation of the right renal artery and an auto-transplantation of the left kidney to the iliac fossa was complicated by massive haemorrhage from chest wall and mediastinal collaterals as well as profound left ventricular failure and pulmonary oedema.

In addition to this patient a further 11 patients required in excess of 15 units of blood replacement for major intra-operative haemorrhage, usually due to major venous injury.

Severe arterial hypertension requiring control with intravenous sodium nitroprusside was noted on 12 occasions and sustained hypotension with mean arterial pressures less than 50 mm Hg on 26 occasions.

4.4 POSTOPERATIVE PERIOD

4.4.i MORTALITY

		Cause of death	Contributing factors
AB	Day 13	Myocardial Infarct	"Trash foot",Amputation
FB	Day 4	Myocardial Infarct	None
PB	Day 32	Myocardial Infarct	Pneumonia, Septicaemia
SC	Day 2	Septicaemia, M.O.F.*	Mesenteric Ischaemia
AC	Day 5	Pulmonary Oedema/LVF	Burst Abdomen
SD	Day 52	Septicaemia, M.O.F.	Colon Necrosis
JD	Day 13	Myocardial Infarct	Arrhythmias
VF	Day 72	Septicaemia	Graft Sepsis
AH	Day 21	Septicaemia, M.O.F.	Graft Occlusion
HH	Day 5	Myocardial infarct	Uraemia
EH	Day 12	Pulmonary Oedema/LVF	Myocardial infarct,VSD
KK	Day 6	Pulmonary Oedema/LVF	Uraemia, Pneumonia
JR	Day 6	Septicaemia, M.O.F.	Mesenteric Ischaemia
WS	Day 21	Uraemia, M.O.F.	Paraplegia
RS	Day 33	Pulmonary Oedema/LVF	Graft Sepsis
CS	Day 4	Respiratory Failure	Bronchopneumonia
IT	Day 33	Myocard infarct/M.O.F.	Colon Necrosis, CCF

Table 4.6: Postoperative deaths: Causes of death and major contributing factors: MOF = multiple organ failure.

In addition to the single intra-operative death, 17 patients died within 30 days of the aortic procedure or without leaving hospital for a perioperative mortality of 8.2%. The causes of death and the major contributing causes are tabulated in table 4.6:

Eleven of the eighteen perioperative deaths (5%) were primarily cardiac in origin. Seven acute myocardial infarctions (4.1%) were recorded in this group resulting in rapid demise in five and contributing to eventual death in left ventricular failure and pulmonary oedema in a further two. In addition, a further three patients with poor left ventricular function pre-operatively died in intractable pulmonary oedema, either on the operating table or in the postoperative period. A total of eight new ventricular arrhythmias were recorded in these eleven patients.

4.4.ii CARDIAC MORBIDITY

Twenty-four patients suffered at least one major cardiac event. These are detailed in Table 4.7:

	No. Patients
MAJOR CARDIAC EVENTS	**24 (11%)**
Acute Myocardial Infarction	9 (4.1%)
Died	7
Survived	2
Pulmonary Oedema/ LVF	15 (7%)
Died	7
Survived	8
Malignant Ventricular Arrhythmia	15 (7%)
Died	10
Survived	5

Table 4.8: Major Cardiac events recorded.

In addition to these 40 minor cardiac events were recorded in 31 patients (see Table 4.9):

MINOR CARDIAC EVENTS	40 (18%)
Severe hypertension	16
Severe hypotension	8
New Arrhythmia	5
Iatrogenic Pulmonary oedema	3
Stroke	1
Pulmonary embolus	2

Table 4.9: Minor cardiac events

4.4.iii NON CARDIAC MORBIDITY

Sixty eight patients (30%) suffered at least one postoperative complication. These are enumerated in Table 4.10:

The low event rate of pulmonary embolism (2 patients, none fatal) and postoperative stroke (1 patient, not fatal) should be noted. The presumed high incidence of stroke has prompted several centers to routinely screen patients for carotid disease prior to aortic reconstruction and to offer carotid surgery to those asymptomatic patients who have significant stenoses. Others routinely use pharmacological prophylaxis or even vena caval interruption in order to prevent fatal postoperative pulmonary embolism in this group.

TECHNICAL	No.Patients	No.Died
Splenic injury: splenectomy	2	
Early graft occlusion	5	2
Major embolus	3	
"Trash foot", peripheral emboli	7	2
Major amputation	3	2
Haematoma/Seroma	4	
Reoperation for haemorrhage	6	1
Burst abdomen	5	1
SEPTIC		
Wound sepsis	2	
Graft sepsis	4	2
GASTRO-INTESTINAL		
GI Haemorrhage	2	1
Small bowel obstruction	3	
Prolonged ileus	3	
Acute gastric dilatation	1	
Colon necrosis	2	2
Small bowel necrosis	2	2
Faecal fistula	2	
Pancreatitis	1	
Jaundice/liver failure	4	3
RESPIRATORY		
Major atelectasis	8	
Major pneumonia	12	5
Iatrogenic pneumothorax	1	
Pulmonary embolus	2	
Prolonged ventilation >10 days	5	
Accidental extubation	2	
RENAL		
Renal failure	8	6
Dialysis required	4	3
Renal artery occlusion	2	
Massive Haematuria	1	
NEUROLOGICAL		
Stroke	1	
Paraplegia	1	1
Convulsions	1	

Table 4.10: Non cardiac morbidity

ANALYSIS: CLINICAL SCORING

5.1 RESULTS OF RISK PREDICTION ANALYSIS

5.1.i UNIVARIATE ANALYSIS OF RISK FACTORS

The significance of various pre-operative risk factors as predictors of postoperative death, a major cardiac event or myocardial infarction was tested using cross-tabulation and chi-square analysis. The p values obtained appear in table 5.1.

Patients who had previously suffered a stroke were more likely to die postoperatively ($p=.0468$), as were patients with an abnormal ECG ($p=.0146$) or clinical evidence of cardiac failure ($p=.0465$). Significant electrocardiographic parameters were evidence of previous infarction ($p=.0435$) and a conduction disturbance ($p=.0287$).

The following factors correlated significantly with the development of a major cardiac event:

Age > 70 years	$p=.0484$
Angina	$p=.0022$
Previous myocardial infarction	$p=.0021$
Arrhythmia	$p=.0018$
Abnormal ECG	$p=.0001$

RISK FACTOR	DEATH	MAJOR CARDIAC EVENT	MYOCARD INFARCT
AGE > 70	.7149	**.0484**	.1391
CATEGORY	.3331	.0946	.3107
ANGINA	.2044	**.0022**	.3946
PREVIOUS MI	.0848	**.0021**	.2503
PREVIOUS CABG	1.000	.O974	1.000
HYPERTENSION	1.000	1.000	1.000
DIABETES	.5188	.6593	1.000
PREV. STROKE	**.0468**	.1098	**.0109**
CAROTID BRUIT	.3330	1.000	1.000
ARRHYTHMIA	.3451	**.0018**	.2678
S3/JVP/CCF	**.0465**	.0976	.8208
ABNORMAL ECG	**.0146**	**.0001**	**.0011**
ECG MI	**.0435**	**.0170**	**.0006**
ECG ISCHAEMIA	.1389	.0617	**.0010**
ECG VH	.2044	1.000	.9608
ECG COND	**.0287**	.0812	**.0465**
PaO_2 < 10 Kpa	.2091	1.000	1.000
PCO_2 > 6 Kpa	.8104	1.000	1.000
FEV1 < 1200 ml/sec	1.000	.2254	.3430
UREA > 10 mmol/l	.6451	1.000	1.000
CREAT > 200 mmol/l	1.000	.5208	1.000
CR.CL < 40ml/min	.7389	.1939	.1076

Table 5.1 : p values derived from cross tabulations of risk factors and postoperative events using the chi-square test.

Key : CATEGORY = Abdominal aortic aneurysm or aorto-iliac occlusive disease. MI = myocardial infarction; CABG = coronary artery bypass graft; ECG MI = electrocardiographic evidence of previous infarction; ECG ISCH = electrocardiographic stigmata of myocardial ischaemia; ECG VH = voltage criteria for left ventricular criteria satisfied; ECG COND = conduction disturbance on ECG; FEV1 = forced expiratory volume in 1 second; CR.CL = corrected creatinine clearance.

Of the various electrocardiographic parameters only evidence of previous infarction (p=.0011) and an arrhythmia (p=.0018) predicted the subsequent development of a major cardiac event.

Only two factors correlated significantly with postoperative myocardial infarction: A previous stroke (p=.0109) and an abnormal ECG (p=.0011), particularly evidence of previous infarction (p=.0006), ischaemia (p=.0010) or a conduction disturbance (p=.0465).

Thus the factors that correlated significantly with one of the major end points in the study were:

1. Age > 70 years
2. Angina
3. Previous myocardial infarction
4. Previous stroke
5. Arrhythmia
6. Clinical cardiac failure
7. Abnormal ECG

It should be noted that, apart from age which was a significant factor in the Goldman study [24], the factors are identical with those found to be significant by Cooperman et al [32].

No patient developed a major cardiac event in the absence of at least one of the above 7 risk factors (see Table 5.2)

	MAJOR CARDIAC EVENT	NO MAJOR CARDIAC EVENT
NO RISK FACTORS	0	100
RISK FACTORS	24	96
		($p < 0.001$)

TABLE 5.2: Cross-tabulation of significant risk factors and major cardiac events.

RISK FACTOR	EVENT RATE
Age > 70	20.5 %
Angina	26.3 %
Previous MI	28.1 %
Previous Stroke	26.7 %
Arrhythmia	37.5 %
CCF	33.3 %
Abnormal ECG	21.7 %

TABLE 5.3: Event rates associated with each significant risk factor.

The event rates associated with the 7 significant risk factors are tabulated in table 5.3. Each carries a risk of subsequent development of a major cardiac event of at least 20%.

5.2 ANALYSIS OF THE PREDICTIVE ABILITY OF THE GOLDMAN CRI

The distribution of patients between the 4 Goldman categories and the numbers of significant postoperative events occurring in each group is tabulated in Table 5.4. The Goldman category

correlated significantly with death ($p<0.02$) and a major cardiac event ($p<0.001$) but not with postoperative myocardial infarction ($p=0.144$).

However, 5% of the patients in the lowest risk category developed a major cardiac event. One third of all such events recorded in the study occurred in patients in this low risk category. Of those 153 patients with no Goldman factors other than the fact that they underwent an aortic procedure (ie: score = 3), 7 (4.6%) developed a major cardiac event. One third of the patients in class III developed a major cardiac event. The number of patients in class IV was too small for statistical analysis.

GOLDMAN CATEGORY	SCORE RANGE	NUMBER PATIENTS	DIED	MAJOR CARDIAC	MYOCARDIAL INFARCT
I	3-5	16	**19** (5.6%)	**8** (5%)	**4** (2.5%)
II	6-12	42	**5** (12%)	**11** (26%)	**3** (7%)
III	13-25	15	**4** (26.7%)	**5** (33%)	**2** (13.3)
IV	>=26	2	**0**	**0**	**0**

TABLE 5.4: Distribution of patients among the 4 Goldman classes and the incidences of significant postoperative events.

5.3 ANALYSIS OF THE PREDICTIVE ABILITY OF THE COOPERMAN FORMULA

The distribution of patients between five Cooperman categories is tabulated in table 5.5. Within each group it is possible to determine the mean probability of one of the patients within that group developing a major cardiac event. The number of events that the equation would predict in each group appears in the table and can be compared with the number of events that actually occurred. There is a highly significant correlation between the two when tested by chi^2 goodness of fit ($G^2= 1.84$; df = 4). The hypothesis that the two distributions of events predicted and events recorded are significantly different was rejected with a p value of 0.755.

Within the lowest risk category 2.5% of the patients developed a major cardiac event. However, of the 113 patients with none of the Cooperman factors, only 1, non-fatal cardiac event was recorded, an event rate of 0.88%.

RANGE OF COOPERMAN SCORES	NUMBER PATIENTS	MEAN PROBABILITY	PRED EVENTS	EVENTS OCCURRING
0 - 5	122	2.334	2.85	3
5 - 10	28	7.580	2.12	2
10 - 15	29	13.565	3.93	6
15 - 25	21	23.171	4.87	3
> 25	20	53.070	10.61	10

TABLE 5.5: Distribution of patients in 5 Cooperman groups. The number of predicted events in each group and the number of events actually occurring following 220 aortic reconstructions. Statistical analysis by Chi-square goodness of fit. G2 = 1.84; df = 4. There is no significant difference in the distributions.

5.4 MULTIVARIATE ANALYSIS OF THE RISK FACTORS

Log linear regression multivariate analysis [59] was applied to the risk factors.

5.4.i METHOD

The logarithm of major cardiac event was selected as the dependent variable and other variables entered in a stepwise manner using the Statistical Package for the Social Sciences. Five variables were selected according to their contribution to variance and their tolerance, accounting for 18% of the variance. These are listed in Table 5.6:

ANGINA

ARRHYTHMIA ON PHYSICAL EXAMINATION

ARRHYTHMIA ON ECG

CCF

ERNA VENTRICULAR WALL MOTION ABNORMALITY

No interaction terms or second order terms were entered. These variable were used to derive a linear discriminant analysis.

Subsequently the Goldman and Cooperman scores were added to the variables and the discriminant analysis repeated.

5.4.ii RESULTS

The discriminant function obtained using the above factors had a positive predictive value of 33.33%, a negative predictive value of 95.34%, a sensitivity of 66.66% and a specificity of 83.67%.

OBSERVATION	Classified by Discriminant Function		
	EVENT PREDICTED	NO EVENT PREDICTED	TOTAL
EVENT OCCURRED	16	8	24
NO EVENT OCCURRED	32	164	196
TOTAL	48	172	220

Positive predictive value	33.33334 %
Negative predictive value	95.34883 %
Sensitivity	66.66667 %
Specificity	83.67347 %
Prevalence	10.90909 %
Accuracy	81.81818 %

Addition of the Goldman and Cooperman scores as possible significant factors in the analysis resulted in four variables being selected. These accounted for 25.6% of the variance and appear in Table 5.7.

COOPERMAN SCORE

GOLDMAN SCORE

ECG ARRHYTHMIA

ERNA VENTRICULAR WALL MOTION ABNORMALITY

The discriminant function obtained had a positive predictive value of 32.35%, a negative predictive value of 93.01%, a sensitivity of 45.83% and a specificity of 88.26%.

OBSERVATION	Classified by discriminant function		
	EVENT PREDICTED	NOEVENT	TOTAL
EVENT OCCURRED	11	13	24
NO EVENT OCCURRED	23	173	196
TOTAL	34	186	220

Positive predictive value	32.35294 %
Negative predictive value	93.01075 %
Sensitivity	45.83334 %
Specificity	88.26531 %
Prevalence	10.90909 %
Accuracy	83.63636 %

5.5 DISCUSSION: THE ROLE OF CLINICAL SCORING

Goldman et al's 1977 study [24] represents the first multivariate approach to cardiac risk prediction. Prior to this most studies had concentrated on the relationship between individual variables, such as previous myocardial infarction and the risk of perioperative events.

Although the data for the Goldman index was gathered prospectively, the index itself was derived retrospectively. Any index needs prospective local testing before it can be used confidently in a particular hospital [25]. The Goldman index has performed well in three prospective studies applying the index to patients undergoing a wide range of non-cardiac operations [56,57,58]. However, few of these patients underwent major vascular surgery. Waters et al. [61] in a similar study found the index to be no better than the American Surgical Association (A.S.A.) physical status in predicting cardiac risk. This study also found that abdominal aortic surgery was related to the incidence of cardiac complications and cardiac death. In contrast, the Goldman index assigns no greater risk to aortic surgery than to any other intraperitoneal operation.

Jeffrey et al. [54] evaluated the Goldman index prospectively in 99 patients undergoing elective abdominal aortic surgery and found that the risk of major cardiac events was significantly underestimated in Class I and that there were no significant differences between Class 2 and Class 3. They consequently concluded that the Goldman system was not applicable to patients undergoing aortic surgery.

The Goldman and Cooperman systems were compared in 100 patients undergoing elective and emergency vascular surgery procedures by Domaingue et al 75. Only 13 of the patients underwent elective aortic procedures. As in the study of Jeffrey et al [54] the Goldman system significantly underestimated cardiac events. The Cooperman system proved more accurate in risk prediction. No patient in the low risk category with none of the Cooperman factors developed a major cardiac event.

The current study has demonstrated the ability of both the Goldman and the Cooperman systems to predict major cardiac events in a large number of patients undergoing elective aortic operations. However the usefulness of the Goldman system is limited by the high event rate in Class 1 and even in patients lacking any of the Goldman factors. The Cooperman formula was remarkably accurate in predicting major cardiac events.

No patient developed a major cardiac event in the absence of one of the Cooperman factors. Thus it is possible to define a low risk group on the basis of these criteria and patients within this group can undergo aortic surgery at negligible cardiac risk. This finding challenges the clinical implications of the routine coronary angiography studies and the clinical relevance of occult coronary artery disease. The present study has demonstrated that patients without clinical evidence of heart disease can proceed to aortic surgery without the need for further expensive or invasive investigation and this confirms earlier findings in smaller studies [23,54].

The Goldman system has been criticised on the basis of overpenalising age, and neglecting the significance of previous myocardial infarction and chronic stable angina [62].

This study confirmed the importance of an age greater than 70 as a single predictor. Both previous myocardial infarction and chronic stable angina correlated significantly with the development of major cardiac events although only angina was an independent predictor on multivariate analysis. Previous studies have demonstrated the importance of a prior myocardial infarction as a risk factor for re-infarction following general surgical operations [63,64]. Knapp et al [63] found a risk of re-infarction of 6% in patients with previous infarction compared to a risk of 0.7% in those with no previous infarction in 8557 general surgical operations. Similar figures were reported from the Mayo clinic in 32 877 patients [64]. However patients with prior myocardial infarction are a heterogeneous group and it is particularly those with an extensively damaged myocardium that are at increased risk. Further investigations will be required to identify such patients and radionuclide ventriculography shows considerable promise in this regard.

A cardiac risk index is merely a model or starting point for consideration of cardiac risk and cannot be taken in isolation from other factors in the patient's history and physical examination. It does allow the clinician, who may be faced with an enormous number of clinical variables to focus on the key factors that will determine cardiac risk and to identify the patient who requires carefully selected investigations to further refine the estimation of that risk.

ANALYSIS: THE EXERCISE STRESS TEST

6.1 RESULTS OF EST IN THIS STUDY

In this study effort stress tests were not protocolled as part of the investigative work-up of the patients but were performed at the discretion of the participating cardiologists. Clear indications for EST were not defined. Consequently only 35 patients underwent stress tests.

6.1.i PATIENTS

Fourteen patients had clinical evidence of cardiac disease. Twenty one patients had no such evidence (see Table 6.1)

No clinical evidence of cardiac disease		21
Clinical cardiac disease		14
	Angina	5
	Previous MI	9
	Arrhythmia	3
	CCF	0
	Abnormal ECG	12

Table 6.1: Characteristics of 35 patients under-going exercise stress tests.

One patient had undergone coronary surgery 10 years prior to the test. A further patient had undergone percutaneous transluminal coronary artery dilatation (PTCA) 8 months prior to the study. No other patient had undergone a stress test or coronary angiogram previously.

6.1.ii METHODS

All tests were performed according to the Bruce protocol [65,66]. Each patient had continuous 12 lead ECG monitoring throughout the exercise period. Testing was terminated when the patient achieved 90% of predicted maximal heart rate or was forced to stop because of claudication, chest pain, shortness of breath, ventricular arrhythmia or hypotension. The test was considered positive if the patient showed new or additional ST segment depression of at least 1mm.

6.1.iii RESULTS

None of the 35 patients died in the postoperative period and only 1 major cardiac event was recorded: an episode of ventricular tachycardia that rapidly responded to an infusion of lignocaine. This event rate is too low to draw any meaningful conclusions regarding the predictive ability of an effort stress test in the sample studied.

Six positive tests were recorded. Two of these patients had clinical evidence of cardiac disease; both proceeded directly to aortic surgery without further evaluation and their perioperative course was uneventful. Of the 4 patients with no clinical evidence of cardiac disease, one underwent coronary angiography. This showed diffuse, severe and inoperable coronary artery disease (Hertzer class 5). The patient underwent repair of a symptomatic aneurysm without complication. The remaining 3 patients underwent aortic surgery without further investigation and without postoperative cardiac events.

Twenty nine patients had a negative test, 12 of whom had clinical heart disease and 17 of whom did not. One cardiac event was recorded in a patient with clinical CAD. No other patients developed cardiac events postoperatively.

Patients with at least one of either the Cooperman or Goldman factors were no more likely to have a positive EST than patients without these factors.

6.2 DISCUSSION: ROLE OF EST

Exercise testing is easily performed and interpreted and it has been suggested that the myocardial response to exercise may be similar to the stresses imposed by surgery, anaesthesia and recovery following aortic operations [62]. Despite this its current role in evaluating cardiac risk prior to major vascular surgery remains controversial [33].

It has been widely assumed that EST will be of little value in vascular surgical patients because of their limited ability to exercise [62]. However, three early studies examining the role of EST in vascular patients [35,38,39] indicated that 20 - 49% developed significant changes at low levels of exercise. When studied with coronary angiography the majority of these patients can be shown to have significant coronary artery disease.

Arous et al.[36] performed exercise tests in 808 patients scheduled to undergo vascular reconstruction. 135 patients had an ischaemic response to exercise testing. These were divided into four groups: Group 1 consisted of 56 patients undergoing vascular surgery as originally planned, ignoring the implications of the positive EST. Group 2 consisted of 23 patients in whom an alternative smaller surgical procedure was chosen in the light of the EST result. The 10 patients in group 3 underwent coronary artery bypass surgery prior to the vascular operation. The intended vascular operation was cancelled in 46 patients (group 4) because of the EST result. Myocardial infarction developed in 15 (27%) of the patients in group 1 and was fatal in 11. 17% of the patients undergoing a smaller procedure in group 2 suffered myocardial infarction postoperatively. No infarctions were recorded in the 10 patients having undergone aorto-coronary bypass. 22% of those whose operation was cancelled died of myocardial infarction during the 5 year follow up period. 37 of the patients with a positive EST were asymptomatic and had a normal resting ECG and the myocardial infarction rate in patients in this group who proceeded directly to vascular surgery was 24%. None of the patients who underwent aorto-coronary bypass in response to the test result suffered a myocardial infarct during the 5 years of

follow up. The authors strongly advocated screening of vascular patients with EST and performing coronary angiography in all patients with a positive test. If suitable coronary lesions and well preserved ventricular function were identified, the authors recommended prophylactic aorto-coronary bypass to reduce operative risk and increase long term survival.

In a recent study of 100 patients undergoing EST prior to major vascular surgery [37], inability to achieve more than 85% of predicted maximum heart rate, rather than the degree of ST depression was the significant factor which predicted cardiac events. Recently Nicolaides [67] has suggested that a bicycle exercise test enables a greater proportion of vascular patients to achieve target heart rates.

The most notable feature of the current study has been the very low cardiac event rate in patients lacking clinical evidence of heart disease. Furthermore only four asymptomatic patients with a normal resting ECG had a positive EST. Although one of these was shown to have severe coronary artery disease on angiography, no cardiac events were recorded in this group. This study has not confirmed the large proportion of asymptomatic patients who will have a positive EST if tested and who are at increased risk perioperatively, that has been demonstrated in North American studies. Performing EST in all asymptomatic patients in this study could not have reduced the event rate.

The Coronary Artery Surgery Study (CASS) demonstrated considerable lack of specificity in the results of EST. When compared to coronary angiography in patients with undiagnosed chest pain EST added little to clinical impression and a negative test was frequently falsely negative [68]. This sentiment is echoed by Goldman et al. [24,25,69]. Some workers have raised serious doubts about the predictive value of ST depression [70,71] and it is likely that this depends on the pretest risk of coronary artery disease in the population being studied [41]. In a population with a high prevalence of coronary artery disease such as patients undergoing aortic surgery, positive tests are likely to merely confirm the high likelihood of disease whereas negative tests will frequently be falsely negative.

At least one third of vascular patients will be unable to achieve a diagnostically useful test because of claudication, amputation, ulceration, arthritis or the influence of beta blockers or digitalis. In these patients a screening test that does not involve exercise must be sought. It is in this group that dipyridamole/thallium scintigraphy shows the most promise.

Despite the above shortcomings, exercise stress testing, particularly when combined with careful risk factor analysis remains a widely applicable cost effective screening test of proven efficacy in vascular patients. However the current study has indicated that such screening is probably only required in patients with some clinical evidence of cardiac disease, either on history, physical examination or resting ECG.

ANALYSIS: THE ERNA SCAN

7.1 RESULTS OF ERNA IN THIS STUDY

One hundred and eighty three patients were studied using equilibrium radionuclide angiocardiography (ERNA). The left ventricular ejection fraction and the presence or absence of dilation of either the left or right ventricle, or wall motion abnormalities involving either the right or left ventricle were noted.

7.1.i PATIENTS

There were no significant differences in the patient characteristics and distribution of risk factors between the 183 patients undergoing radionuclide ventriculography and the 220 patients in the universal group. Using the Cooperman factors as criteria, 97 of the patients (53%) had clinical evidence of cardiac disease and 86 (47%) did not (see Table 7.1).

Clinical evidence of cardiac disease	**97**(53%)
Angina	37
Previous infarct	54
Abnormal ECG	83
CCF/JVP/S3	7
Arrhythmia	16
No clinical evidence of cardiac disease	**86**(47%)

Table 7.1: Characteristics of 183 patients undergoing Equilibrium radionuclide angiocardiography (ERNA).

7.1.ii METHOD

ERNA was performed with electrocardiographically synchronised images of 99mTc labelled red blood cells using a small field of view scintillation camera interfaced with a dedicated computer. Anterior, left anterior oblique and left lateral images were obtained and displayed in cine mode for the detection of ventricular dilation or regional wall motion abnormalities. Global resting ejection fraction was calculated in the LAO view using a time/activity curve. Ejection fractions greater than 50% were regarded as normal.

7.1.iii RESULTS

The ERNA failed technically in two patients, both of whom had chaotic atrial rhythms rendering computation of the ejection fraction by the computer impossible. It was, however possible to assess ventricular size and contractility in these two patients.

The mean ejection fraction (EF) was 61% with a range of 29% to 92%. There was no significant difference between the mean EF in the 86 patients with abdominal aortic aneurysm (60%) and the 96 patients with aorto-iliac occlusive disease (59%).

Patients with clinical cardiac disease were more likely to have an EF less than 45% ($p<0.001$)

	N	EF>45%	EF<=45%
Clinical CAD	95	72	23
No Clinical CAD	86	85	1
			$p < 0.001$

Table 7.2: Patients with clinical evidence of CAD were more likely to have an abnormal ejection fraction.

Ventricular dilatation was noted in 49 patients and abnormalities in regional wall motion in 51.

Sixteen of the patients died during the postoperative period for an operative mortality within this group of 8.7%. 9 of the 16 deaths were cardiac in origin. In addition, 21 patients suffered at least one major cardiac event for an event rate of 11.5%. These are tabulated in Table 7.3:

Operative mortality		16(8.7%)
Cardiac	9	
Non cardiac	7	
Major cardiac events		21(11.5%)
Myocardial infarct	9	
Pulmonary oedema/CCF	15	
Ventricular arrhythmia	12	

Table 7.3: Postoperative events in 183 patients studied with ERNA prior to aortic surgery

7.2 ABILITY OF ERNA TO PREDICT CARDIAC EVENTS

The correlation between ejection fraction and the incidence of major cardiac events and cardiac death at various levels of EF was tested using a chi^2 test and a significant correlation found at each level (Table 7.4). Sixty two percent of the patients with an EF less than 35% suffered a major cardiac event. However, variations in EF above 50% (ie: within the normal range) had no bearing on the incidence of cardiac events (Fig 1). Furthermore, a normal EF did not guarantee freedom from cardiac events with 10 such events being recorded. 5 of the 9 cardiac deaths occurred in patients with an ejection fraction greater than 50%. Figure 2 plots the distribution of patients with and without cardiac events in various ejection fraction ranges.

There was no correlation between ejection fraction and the development of postoperative myocardial infarction but a consistent correlation with postoperative cardiac failure/ pulmonary oedema was demonstrated. An ejection fraction less than 35% correlated with postoperative death ($p<0.05$).

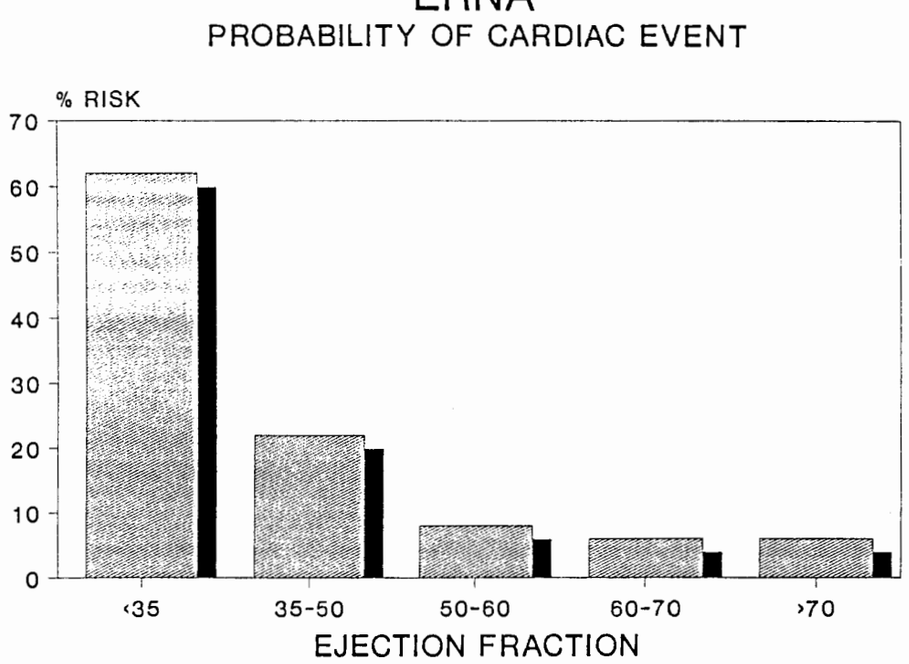


Fig 7.1: EF versus risk of Cardiac Event

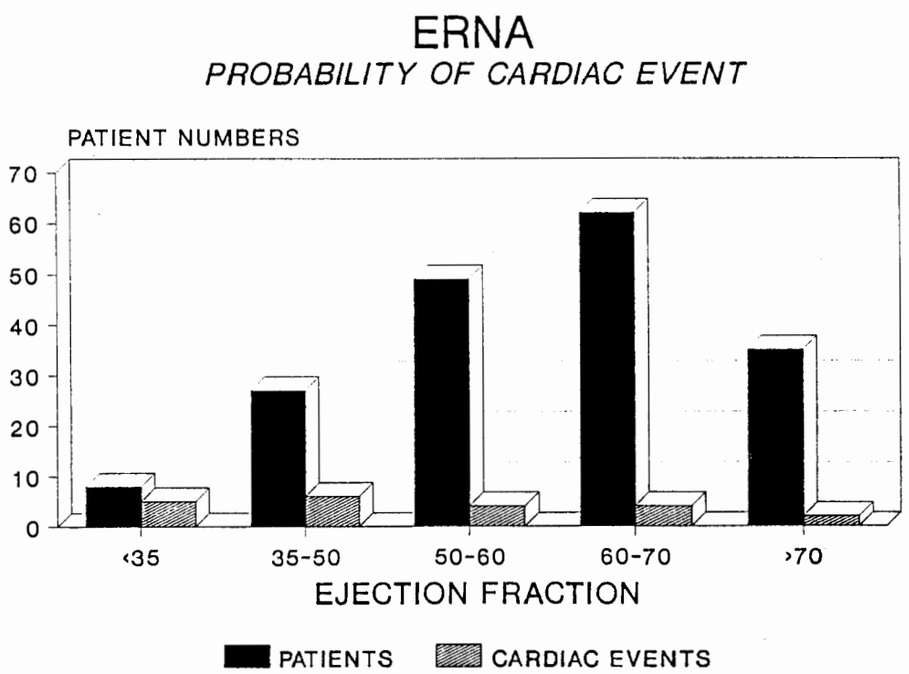


FIGURE 7.2: Distribution of EF

EF RANGE	N	MAJOR CARDIAC EVENT		DEATH		MYOCARD INFARCT		CCF	
		YES	NO	YES	NO	YES	NO	YES	NO
> 50%	143	10	133	1	132	6	137	6	137
< =50%	38	11	27	5	33	3	35	9	29
P			**<0.001**		<0.231		<0.304		**<0.001**
> 45%	157	13	144	12	145	8	149	8	149
< =45%	24	8	16	4	20	1	23	7	17
P			**<0.001**		<0.143		<0.378		**<0.001**
> 40%	164	15	149	13	151	8	156	10	154
< =40%	17	6	11	3	14	1	16	5	12
P			**<O.O1**		<0.181		<0.342		**<0.01**
> 35%	173	16	157	13	160	8	165	11	162
< =35%	8	5	3	3	5	1	7	4	4
P			**<0.001**		**<0.05**		<0.432		**<0.001**

Table 7.4:Correlation between left ventricular ejection fraction (EF) and major postoperative events: death,myocardial infarction, cardiac failure (CCF).

	N	MAJOR CARDIAC EVENT		DEATH		MYOCARD INFARCT		CCF	
		YES	NO	YES	NO	YES	NO	YES	NO
LVD	46	13	33	6	40	5	39	8	31
No LVD	137	8	129	10	127	4	133	6	131
P		**<0.001**		<0.186		**<0.05**		**<0.01**	
LVWA	39	12	27	7	32	5	34	8	31
No LVWA	144	9	135	9	135	4	140	7	137
P		**<0.001**		**<0.05**		**<0.05**		**<0.01**	

Table 7.5: Correlation between left ventricular dilatation or regional wall motion abnormalities and the development of major cardiac events or death.

* *LVD = Left ventricular dilatation*

** *LVWA = Left ventricular wall motion abnormality*

The presence of left ventricular dilatation ($p<0.001$) and abnormalities in left ventricular wall motion ($p<0.001$) both correlated well with the subsequent development of a major cardiac event (see Table 7.5) but no such correlation was observed for right ventricular dilatation or wall motion abnormality. Furthermore left ventricular dilatation correlated well with both myocardial infarction ($p<0.05$) and cardiac failure ($p<0.01$). Patients with left ventricular wall motion abnormalities were not only more likely to develop myocardial infarction ($p<0.05$) and cardiac failure ($p<0.01$), but were more likely to die ($p<0.05$).

The subgroup of patients with no clinical evidence of cardiac disease (ie: no Cooperman factors) are analysed in Table 7.6. Their mean EF of 64% is not significantly different from the mean EF of 57% among the patients with clinical cardiac disease. However no patient had an EF less than 40% in this group and only 3 patients had an EF in the abnormal range. Although 13 dilated ventricles and 6 abnormalities in regional wall motion were noted in these patients only one, non fatal cardiac event was recorded.

PATIENTS WITH NO CLINICAL CARDIAC DISEASE
N = 86

Mean EF	64%
EF < 40%	0
Dilated Ventricle	13
Wall motion abnormal	6
Cardiac events	1
Cardiac deaths	0

Table 7.6: Outcome of ERNA scans in 86 patients with no clinical evidence of cardiac disease.

7.3 DISCUSSION: THE ROLE OF RADIONUCLIDE VENTRICULOGRAPHY

The use of radionuclide ventriculography to assess cardiac function in patients with peripheral vascular disease was first described in 1979 by Jones et al. [72]. In their small study of 22 patients, only 7 of whom had abdominal aortic aneurysms there was a suggestion of increased operative risk in patients with low ejection fractions, the single operative death occurring in the patient with the lowest EF. Subsequently Fiser et al. [43] correlated nuclear ejection fraction with cardiac index measured using a pulmonary artery catheter in 20 patients undergoing elective abdominal aortic surgery. In the latter study the only two deaths were in patients with ejection fractions less than 30% and an initial cardiac index less than 2 liters/m^2.

Mosley et al. [44] performed radionuclide ventriculography in 41 patients undergoing aortic surgery and found that patients with an EF less than 30% were more likely to die of cardiac failure postoperatively with 3 of 4 such patients dying in contrast to only 1 death in the remaining 37 patients with an EF greater than 30%.

The ability of a reduced ejection fraction to predict postoperative myocardial infarction rather than merely cardiac death was explored by Pasternak et al. [45] in 50 patients undergoing aortic surgery.

Three groups were identified: The 25 patients with an EF from 56%-85% suffered no myocardial infarcts; the 20 patients with an EF between 36% and 55% had a 20% incidence of myocardial infarction but no cardiac deaths; and of the 5 patients with an EF in the 27% to 35% range, 4 developed postoperative myocardial infarction of whom 1 died. Such a correlation between EF and postoperative myocardial infarction has not been shown by any other study.

EF RANGE	N	MYOCARDIAL INFARCTION	DEATH
56 - 85%	25	0	0
36 - 55%	20	20%	0
27 - 35%	5	80%	20%

Table 7.7: Correlation between left ventricular ejection fraction (EF) and postoperative myocardial infarction in 50 patients undergoing aortic aneurysm repair (Pasternack et al. 1984 [45]).

Recently Fletcher et al. [46] reported that the only 3 deaths among 72 patients undergoing elective aortic surgery occurred in the group of 10 patients with an EF less than 35% and that patients with an EF less than 45% were more likely to develop postoperative cardiac failure, but not myocardial infarction. Only patients with a past or current history of cardiac disease were found to have an EF less than 45%.

In sharp contrast to these studies, Kazmers et al. [47], studying 60 patients undergoing abdominal aortic aneurysm repair found no difference in the incidence of myocardial infarction, cardiac failure or postoperative death in patients with an EF greater than or less than 35%. However, when followed beyond 30 days, patients with EF<35% had a significantly reduced long term survival.

The current study is greater than twice the size of any previously reported evaluation of radionuclide ventriculography in patients undergoing vascular surgery. On the basis of the findings of the study, the following conclusions are suggested:

Conclusions:

1. Patients with ejection fractions in the abnormal range (ie: less than 50%) are more likely to develop a major cardiac event. However it is the ability of the EF to predict the development of postoperative cardiac failure rather than myocardial infarction which is the basis for the positive correlation. It is hardly surprising that non-invasive measures of left ventricular function are so potent in predicting prognosis in patients submitted to aortic surgery. Left ventricular function is a powerful predictor of prognosis in patients with coronary artery disease and may well be the most powerful predictor in patients who have suffered a previous myocardial infarction [73]. In contrast to the findings of Pasternack et al.[45] no correlation between EF and postoperative myocardial infarction has been demonstrated at any level of EF in this study.

2. Patients with ejection fractions less than 35% run a particularly high risk of developing a major cardiac event (62% in this study) and are statistically more likely to die. This finding is in agreement with several earlier studies [44,45,46] although in sharp contrast to the findings of Kazmers et al. [46] in a much smaller study. This reason, and the fact that patients with ejection fractions less than 35% have been shown to have very poor long term survival prospects [74] should contra-indicate surgery except for the most compelling of indications in this group.

3. The Coronary Artery Surgery Study (CASS) [42] indicated that a previous history of myocardial infarction (regardless of when it occurred) did not have a significant association with operative mortality or cardiac morbidity following non-cardiac surgery and this is consistent with the findings of Goldman et al. [24] who found prior myocardial infarction to be significant only if it predated the surgery by less than six months. In contrast, impaired left ventricular function was the most important prognostic indicator in the CASS. It is likely that it is the degree of myocardial damage and ventricular impairment produced by the myocardial infarction that is important rather than the history of an infarction, many of which do not result in serious ventricular injury. The routine use of ERNA prior to

aortic surgery in patients with a history or ECG evidence of previous infarction will identify those patients whose myocardial infarctions have placed them at increased risk.

4. This study has shown that patients without clinical evidence of heart disease almost invariably have normal ejection fractions and this is consistent with previous reports [46] including a recent study that demonstrated a 95% reliability of a normal ECG predicting normal left ventricular ejection fraction [75]. This, and the fact that the cardiac event rate in this group is extremely low indicate that ERNA can be reserved for patients with clinical evidence of heart disease only. This would eliminate the need for ERNA in approximately 50% of our patients undergoing aortic surgery.

5. An ejection fraction in the normal range provides no reassurance that the patient is at lower risk of postoperative myocardial infarction and some other screening test that assesses coronary perfusion rather than ventricular performance will be required to answer this. Variations in the actual ejection fraction among patients with EF in the normal range are without clinical relevance.

6. Patients with low ejection fractions are at greatly increased risk of postoperative cardiac failure and probably should be selected for routine use of a pulmonary artery catheter and careful postperative monitoring in an intensive care area with monitor-guided fluid therapy and enhancement of ventricular performance [76,77].

7. The demonstration that poor left ventricular function is the most important determinant of early [78,79,80] and late [81] survival after coronary artery bypass surgery, particularly in patients older than 65 [82] indicates that the finding of a low EF should negatively influence a decision to offer a patient coronary artery surgery prior to abdominal aortic surgery. The anticipated high operative mortality of coronary artery surgery in patients with poor left ventricular performance is likely to negate any potential benefit of prophylactic myocardial revascularisation prior to aortic surgery.

8. This study has demonstrated the importance of left ventricular dilatation or abnormalities in left ventricular wall motion in predicting both postoperative cardiac failure and myocardial infarction, and in the case of wall motion abnormality, postoperative death. Previous reports on radionuclide ventriculography have not drawn attention to this feature.

9. ERNA is a minimally invasive, relatively inexpensive test that can be recommended for all patients with clinical evidence of heart disease who are being considered for elective aortic surgery. It is not able to identify patients who have asymptomatic, but haemodynamically significant coronary artery lesions which place them at increased risk of postoperative myocardial infarction, and which may be surgically correctable.

ANALYSIS: DIPYRIDAMOLE/THALLIUM-201 SCINTIGRAPHY

8.1 RESULTS OF DT SCAN IN THIS STUDY

Thirty seven patients had a dipyridamole/thallium-201 scan in this study. Indications for these scans were not defined and were requested at the discretion of the participating cardiologists. The numbers of scans performed were limited by a lack of availability of thallium and scheduling difficulties. Most surgeons were unwilling to delay surgery in their patients in order to perform an investigation which was considered to be of research interest only.

8.1.i PATIENTS

Twenty three patients had clinical evidence of heart disease, having at least one of the Cooperman factors. 14 patients had no Cooperman factors (Table 8.1):

Clinical evidence of CAD		23
	Angina	8
	Previous MI	16
	CCF	2
	Arrhythmia	4
	Abnormal ECG	20
No clinical evidence of CAD		14

Table 8.1: Characteristics of 37 patients undergoing Dipyridamole/Thallium-201 scans prior to aortic surgery

Four patients had an EST in addition to the thallium study. No patient had previously had a coronary angiogram.

8.1.ii METHODS

All patients were assessed by one of the participating consultant cardiologists. The imaging technique was a modification of that described by Albro et al. [83]. With the patient supine, a baseline 12 lead electrocardiogram (ECG) and blood pressure were recorded and these were repeated at 2 minute intervals during the first 15 minutes of the study. Dipyridamole (Boehringer Ingelhein Ltd. USA, Ridgefield, Conn) was infused at a rate of 0.14 mg/Kg/minute for 4 minutes. This was followed 3 minutes later by 2.0 to 2.5 mCi of intravenous thallium 201 (du Pont-NEN Products, Billerica, Mass.) Myocardial images in the anterior, 45^0 and 70^0 left anterior oblique positions were collected at 5 minutes and again at 150-180 minutes.

All studies were interpreted jointly by an experienced cardiologist and nuclear medicine consultant. A perfusion defect which did not fill on the delayed scan was considered to indicate an area of infarction. A defect which showed delayed perfusion only was termed thallium redistribution and taken to indicate an area of ischaemia. The results of the study were made available to the surgeon, anaesthetist or cardiologist.

8.1.iii RESULTS

No complications from the dipyridamole/thallium scans were recorded. Thirteen patients were considered to have a positive scan on the basis of thallium redistribution. Only one of these patients had no clinical evidence of CAD (Table 8.2). He proceeded directly to vascular surgery without further investigation and without postoperative complication. 3 of the remaining 12 patients with positive scans underwent coronary angiography. One of these patients was shown to have no evidence of coronary artery disease whatsoever. Severe, operable disease was noted in one patient who subsequently underwent carotid endarterectomy followed by aorto-coronary bypass without complication followed 6

weeks later by aorto-bifemoral bypass, once again without complication. The third coronary angiogram showed diffuse inoperable triple vessel disease. This patient underwent aortofemoral bypass without incident. Nine patients with positive scans underwent aortic reconstruction without further investigation. 2 fatal cardiac events and one non-cardiac fatality were recorded in this group.

Twenty four patients had a negative scan. Of these 11 had clinical evidence of heart disease. All proceeded directly to aortic reconstruction with 3 patients developing major cardiac events, 2 of which were fatal myocardial infarctions. 1 of 13 patients with no clinical CAD and a negative scan underwent coronary angiography as part of a cardiac catheterisation study prior to repair of a thoraco-abdominal aortic aneurysm caused by Takayasu aortitis. This study was entirely normal. All 13 patients underwent aortic reconstruction without incident.

	+ve DT Scan	-ve DT Scan
Clinical CAD	12	11
No clinical CAD	1	13

TABLE 8.2: Proportions of patients with positive or negative dipyridamole-thallium scans having clinical evidence of coronary artery disease.

	Major Cardiac Event Or +ve C.A.	No Major Cardiac Event No +ve C.A.
+ve DT Scan	4	9
-ve DT Scan	3	21

Table 8.3: Numbers of patients subsequently shown to have significant coronary disease on coronary angiography (CA) or developing a major cardiac event following aortic surgery

8.2 DISCUSSION: ROLE OF DT SCAN

In this small patient group, three important false negatives were recorded among 24 negative scans, all three developing major cardiac events, two of which were fatal myocardial infarctions (Table 8.3). 1 of 11 patients with a positive scan was subsequently demonstrated to have normal coronary arteries on angiography. The major cardiac event rate in the 13 patients with a positive scan was 30%. However the event rate in patients with a negative scan was still high at 12.5%.

The "false positive" and "false negative" rates in this study are considerably worse than those that have been reported in the literature to date and in this regard, the results of dipyridamole-thallium scintigraphy have been disappointing.

Boucher et al [34] first reported the use of dipyridamole-thallium imaging prior to major vascular surgery in 1985. Only patients with suspected stable coronary artery disease on the basis of angina, prior myocardial infarction or an abnormal resting ECG were included in their study. Of 54 patients studied, 24 had thallium redistribution. 6 of these underwent coronary angiography and all were shown to have severe multivessel coronary disease. 16 proceeded directly to vascular surgery without further investigation. 8 (50%) developed a major cardiac event. No cardiac events were recorded in the 32 patients with negative scans who subsequently came to vascular surgery (Table 8.4).

N = 54	DT Scan +ve	DT Scan -ve
Cardiac event	8	0
No cardiac event	8	32
+ 6 patients undergoing coronary angiography:		all +ve.

TABLE 8.4: Outcome of 54 Dipyridamole - thallium scans followed by elective vascular surgery or coronary angiography. (Boucher et al. 1985)

A previous myocardial infarction was associated with an adverse clinical outcome after surgery only if the scan demonstrated redistribution and no cardiac events were recorded in 12 patients with persistent defects only.

Similar results were reported by Leppo et al.[52] in 100 patients scheduled to undergo major vascular surgery (Table 8.5). The predictive probability of a cardiac event in patients not having redistribution was 2+-2% (1 of 47) whereas with redistribution it was 33+-7% (14 of 42). Coronary angiography performed in 11 patients showed multivessel coronary disease in all patients studied. Non-linear stepwise logistic regression analysis demonstrated thallium redistribution to be the best predictor among all the clinical, exercise and scintigraphic variables studied.

N = 100	DT Scan +ve	DT Scan -ve
Cardiac event	14	1
No Cardiac event	28	46
+ 11 patients undergoing coronary angiography		: all +ve

TABLE 8.5: Outcome of 100 dipyridamole-thallium scans followed by vascular surgery or coronary angiography. (Leppo et al. 1987)

A further report from the same institution [51] examining 91 patients undergoing abdominal aortic surgery once again found thallium redistribution to have the best statistical correlation with postoperative myocardial infarction. The odds of a patient with an abnormal DT scan having a postoperative myocardial infarct were 12 times greater than for those with a normal scan (Table 8.6).

	DT Scan +ve	DT Scan -ve
Cardiac event	8	0
No cardiac event	23	60

TABLE 8.6: Outcome of 91 dipyridamole-thallium scans followed by abdominal aortic surgery. (Cutler et al. 1987)

Fletcher et al. [53] reported that 2 of 3 patients with positive DT scans among 17 being studied, subsequently developed a postoperative myocardial infarct following major vascular surgery. The remaining patient suffered an infarct one year later. Following this, a consecutive group of 50 patients were studied using dipyridamole-thallium imaging with 6 of 7 positive scans further evaluated by coronary angiography. Four were shown to have either a left mainstem lesion or severe triple vessel disease. Three were considered to be operable and underwent coronary artery surgery prior to peripheral vascular surgery. The remaining patient was felt to have inoperable coronary disease but nevertheless underwent an uneventful carotid endarterectomy. No major cardiac events were recorded in this group of 50 patients. The authors stated that not only was dipyridamole-thallium scintigraphy the ideal screening test for coronary artery disease prior to vascular surgery, but that an aggressive policy of coronary angiography for positive scans and coronary artery surgery for patients with left mainstem and triple vessel disease would significantly alter the incidence of postoperative cardiac events.

In the present study only one patient had a positive scan in the absence of clinical evidence of coronary artery disease. In spite of this being investigated no further his subsequent aortic reconstruction was uneventful. The very low cardiac event rate in patients without evidence of cardiac disease in this study, and the fact that those with positive scans almost invariably do have clinical evidence of cardiac disease suggests that dipyridamole-thallium imaging can be reserved for patients with at least one of the Cooperman factors.

This has recently been confirmed in a further study from Boucher's group in Worcester, Massachusetts [84] evaluating a further 50 patients undergoing peripheral vascular surgery by preoperative dipyridamole- thallium imaging and extending the indications to include patients with no clinical evidence of coronary disease. Six of the 23 patients with no clinical heart disease had positive scans but no cardiac events were recorded in any of the 23 patients leading the authors to recommend the investigation only in patients with clinical evidence of coronary artery disease.

Whilst the excellent results being reported in the literature suggest that dipyridamole-thallium imaging may well fulfil its promise as the ideal screening test for coronary artery disease prior to aortic surgery, this has not be bourne out by the results of this small study.

ANALYSIS: PREOPERATIVE CORONARY ARTERY BYPASS SURGERY

9.1 THE ROLE OF PROPHYLACTIC CORONARY BYPASS SURGERY PRIOR TO ELECTIVE ABDOMINAL AORTIC SURGERY

Advocates of prophylactic coronary bypass surgery in patients with significant coronary disease state that this will reduce 30 day mortality following elective aortic surgery [8,85,86,87,88,89,90,91,92,93] and increase long term survival [94,95,96,97] when compared to patients who have not undergone coronary surgery.

There seems little doubt that patients who have survived a successful coronary artery bypass operation can subsequently be operated on at low risk. The operative mortalities of more than three thousand such procedures appear in Table 9.1.

AUTHOR	Ref	PATIENTS	MORTALITY
McCollum (1977)	80	60	0
Crawford (1978)	81	358	1.1%
Edwards (1978)	83	74	0
Hertzer (1984)	8	1066	2%
Reul (1986)	84	1093	0.2%
CASS (1986)	89	743	0.9%
Mahar (1987)	82	99	0

TABLE 9.1: Operative mortalities recorded after major surgical procedures in patients having undergone prior coronary artery bypass surgery

The impact of prior coronary bypass surgery on subsequent perioperative mortality following non-cardiac surgery has been convincingly demonstrated in the Coronary Artery Surgery Study (CASS) [92]. 1400 patients underwent major non-cardiac surgery. The mortality of 0.9% among those who had undergone prior coronary surgery contrasted with the 2.4% among those with significant coronary disease who had not.

However it is possible that coronary artery surgery represented a survival test, eliminating those patients who would otherwise have developed a cardiac complication following the non-cardiac operation [62]. Prophylactic coronary artery bypass entails a combined mortality rate of coronary angiography, coronary surgery and aortic surgery and this is the important figure. Unfortunately since most of the studies to date have been retrospective, this figure is difficult to obtain. Of 226 patients undergoing a prophylactic aorto-coronary bypass in Hertzer's prospective study [8] the operative mortality for the coronary surgery was 5.3%. Those who subsequently underwent vascular reconstruction did so for a mortality of 2%. The combined mortality for those who who underwent both procedures was 3.9% but many patients did not come to vascular reconstruction as they died during cardiac surgery or died from aneurysm rupture during the period between the procedures.

The factors contributing to increased operative risk in coronary artery bypass surgery have been fairly well defined and are frequently present in patients scheduled to undergo abdominal aortic surgery. The major factors are Age, female sex, poor ventricular function, reoperations, insulin dependent diabetes and extensive coronary disease [78,82,98]. Mortality rates as high as 18% have been recorded in patients over 70 years [91,98]. Furthermore, peripheral vascular disease has been identified as a predictor of a poor early and late outcome following coronary bypass surgery [99,100].

A proportion of patients under consideration for aortic surgery justify coronary artery surgery because of severe symptomatic coronary disease. Surgery in these patients is not prophylactic. Even the proponents of prophylactic coronary bypass would offer asymptomatic patients coronary surgery only if severe correctable disease was demonstrated. This would usually be a significant left mainstem stenosis or severe triple vessel disease [91]. Left main lesions were found in only 4% of Hertzer's 1000 angiograms [8]. Although triple vessel disease was recorded in 18%, many of these were inoperable. Ultimately coronary surgery was performed in less than 10% of patients who lacked prior evidence of vascular disease. A policy at the Mayo Clinic of selective myocardial revascularisation on the basis of clinical symptoms only [1,97] yielded an overall mortality following aortic reconstruction among 422

patients of 1.7% with a 0.8% mortality from myocardial infarction. Ruby et al [101] have reported an operative mortality of 1.3% among 227 patients undergoing abdominal aortic aneurysm repair where coronary surgery was reserved for the 10 patients with unstable coronary artery disease only. Such figures do not support a policy of routine prophylactic coronary surgery.

The present study has demonstrated a very low cardiac risk in patients lacking clinical evidence of cardiac disease. Only one major cardiac event was recorded among 101 such patients and this was not fatal. It is inconceivable that aggressive screening, coronary angiography or prophylactic coronary surgery could have improved the outcome in this group.

Coronary angiography was performed in 13 patients in this study. The results and outcome following aortic surgery are summarised in table 9.2.

ANGIOGRAPHY	No	PERIOPERATIVE COURSE
Normal	3	1 non fatal event No MI s
Mild/Moderate	4	No cardiac events
Severe/Operable	4	CABG 3: 2 developed CCF PTCA 1: Uncomplicated
Severe/Inoperable	2	No cardiac events

TABLE 9.2: Results and outcome in 13 patients undergoing coronary angiography. CABG = coronary artery bypass graft. PTCA = percutaneous coronary angioplasty.

Correction of the coronary lesion was undertaken in all patients with severe operable disease, three undergoing standard coronary artery surgery and 1 undergoing percutaneous coronary angioplasty. All of these patients had clinical evidence of cardiac disease. Two of the CABG patients, both with high Cooperman scores (22.77% and 71.89%) developed pulmonary oedema postoperatively. The third patient's postoperative course was uncomplicated. No myocardial infarcts were recorded in these

patients. Both patients with severe inoperable coronary disease subsequently underwent aortic reconstruction without complication. During the period of the study a further two patients underwent coronary surgery on the basis of a positive coronary angiogram but did not come to aortic surgery. The first patient died of mesenteric infarction following her cardiac procedure. The second patient with an abdominal aortic aneurysm died suddenly at home 10 days after her cardiac procedure. Consent for autopsy was refused.

In addition to the four patients undergoing coronary bypass surgery prior to their aortic procedure, nine had previously undergone coronary bypass surgery (6) or PTCA (3). One patient in this group with a high Cooperman score (27.7) died in pulmonary oedema postoperatively. No myocardial infarctions were recorded in this group.

The numbers of patients undergoing coronary angiography or coronary surgery in this study is very small. Selection criteria were uncontrolled and consequently no definite conclusions can be drawn from this subset.

The role of prophylactic coronary surgery in increasing long term survival after elective aortic surgery remains controversial. A high late mortality from cardiac disease has been documented in patients surviving elective aortic surgery [78,94]. Hertzer recorded a five year mortality of 30% and an eleven year mortality of 52% among 343 patients undergoing aortic aneurysm resection. Myocardial infarction accounted for 40% of late deaths [94].

In contrast to this, a fatal cardiac event rate of only 4.3% was recorded among 70 patients undergoing abdominal aortic resection preceded by coronary bypass surgery at the same institution and followed for 3-7 years [95]. Recent reports from the Mayo clinic [97,102] have indicated that patients less than 70 who underwent aortic aneurysm resection without prior coronary bypass surgery had a disappointingly poor long term survival despite a very acceptable perioperative mortality rate. Further studies have

claimed improved long term survival after peripheral vascular surgery in patients who had undergone prior myocardial revascularisation when compared to historical controls who had not [89,90] but there remain no randomised studies on this question. However, mortality from coronary artery disease has been falling in the United States, quite independently of coronary surgery [62] and this questions the validity of comparison with historical controls.

Randomised studies of patients undergoing coronary surgery have been able to demonstrate increased longevity consistently in only two subgroups: patients with left mainstem disease and patients with triple vessel disease and impaired left ventricular function [103,104,105,106,107 ,108,109]. However, among Hertzer's 1000 coronary angiograms performed in patients scheduled for major vascular surgery only 4% demonstrated a left main stem stenosis greater than 50% and although 18% of patients had triple vessel disease many of these were inoperable [8]. There appears to be a proportion of patients who stand to benefit in increased longevity should they undergo coronary artery surgery prior to aortic surgery but this proportion may be as small as 10%.

Patients with clinical evidence of coronary disease can have their risk further refined by careful risk factor analysis. Screening of such patients with exercise stress testing or dipyridamole/thallium scintigraphy will define a group at high risk. Coronary angiography should probably be offered to those patients if they would be reasonable candidates for coronary artery surgery. In practice this will exclude most patients over 70 years and those with severely impaired left ventricular function. Of the remainder, those who are shown to have a left mainstem stenosis > 50% or operable triple vessel disease will probably benefit from prophylactic coronary surgery. This is likely to reduce their overall operative risk and may well increase their prospects for long term survival.

CONCLUDING DISCUSSION

10.1 THE CONCLUSIONS REACHED BY THIS STUDY

Patients scheduled to undergo aortic reconstruction who are at increased cardiac risk can be identified using simple clinical criteria. The most important appear to be a history or ECG evidence of previous myocardial infarction, angina, arrhythmia, an abnormal electrocardiogram, congestive heart failure and a previous stroke. Postoperative major cardiac events were virtually confined to patients with at least one of these risk factors in this study, and in several others [23,29,46,110]. In the absence of these factors patients can undergo aortic surgery at extremely low cardiac risk and do not justify further cardiac evaluation. Exercise stress testing, dipyridamole-thallium scintigraphy, radionuclide angiocardiography and coronary angiography are not required in these patients. Certain patients within this group may be selected for postoperative management in a "high care" environment rather than the surgical intensive care unit depending on the particular hospital's resources and the demand for intensive care beds.

Although studies reporting the results of routine coronary angiography prior to aortic surgery have indicated a high prevalence of coronary artery lesions in patients without clinical evidence of cardiac disease this study questions the clinical importance of these lesions in the light of the fact that such patients are able to undergo aortic reconstruction, without prior myocardial revascularisation, at extremely low risk. Such atherosclerotic lesions are not necessarily flow limiting and when demonstrated angiographically in asymptomatic patients their relevance is questionable.

The clinical assessment of cardiac risk can be further refined using the Goldman or Cooperman formulas. Apart from focussing the clinician's attention on the key risk factors involved, the figures derived allow comparison with the projected risks of aneurysm rupture in the particular patient and

facilitate clinical decision making and patient counselling. This study has shown the Cooperman system to be particularly accurate when applied to patients undergoing abdominal aortic reconstruction.

Several non-invasive or minimally invasive tests are available to further assess coronary artery disease in patients with risk factors. Standard exercise stress testing remains applicable to many patients scheduled for aortic surgery [33,35,36,37,38,39] and should be the first choice. Where patients cannot participate in the test or where no diagnostic information can be derived because of drug influence or failure to achieve diagnostic heart rates dipyridamole-thallium scintigraphy appears to offer the most promise. Although the small experience with the test in this study has not been able to validate its role, the results currently being reported in the literature remain impressive [34,50,51,52,53]. The high cost of the test will continue to limit its role as a screening test in many institutions.

Radionuclide angiocardiography will provide information that will assist the clinician in determining the appropriateness of coronary artery surgery (and thus angiography) and invasive perioperative monitoring with a pulmonary artery catheter. It will refine further the evaluation of cardiac risk and define a subgroup of patients with ejection fractions less than 35% who are not only at greatly increased operative risk but whose prospects for long term survival are limited. Elective aortic surgery should not be offered to such patients unless the indications are particularly compelling. Patients without cardiac risk factors can be certain to have good ejection fractions. The use of radionuclide ventriculography in such patients involves unnecessary expense.

It is naive to assume that any test can accurately predict all patients at risk of sudden death or acute myocardial infarction. All available tests can only detect flow limiting stenoses. It is however clear that non-flow-reducing stenoses may progress rapidly and unpredictably by the process of plaque rupture and/or superadded thrombosis [112,113]. None of the currently available tests are able to detect such lesions or predict which ones may progress. Similarly, there is no guarantee that minor stenoses demonstrated by invasive coronary angiography will not progress abruptly. The mechanism of

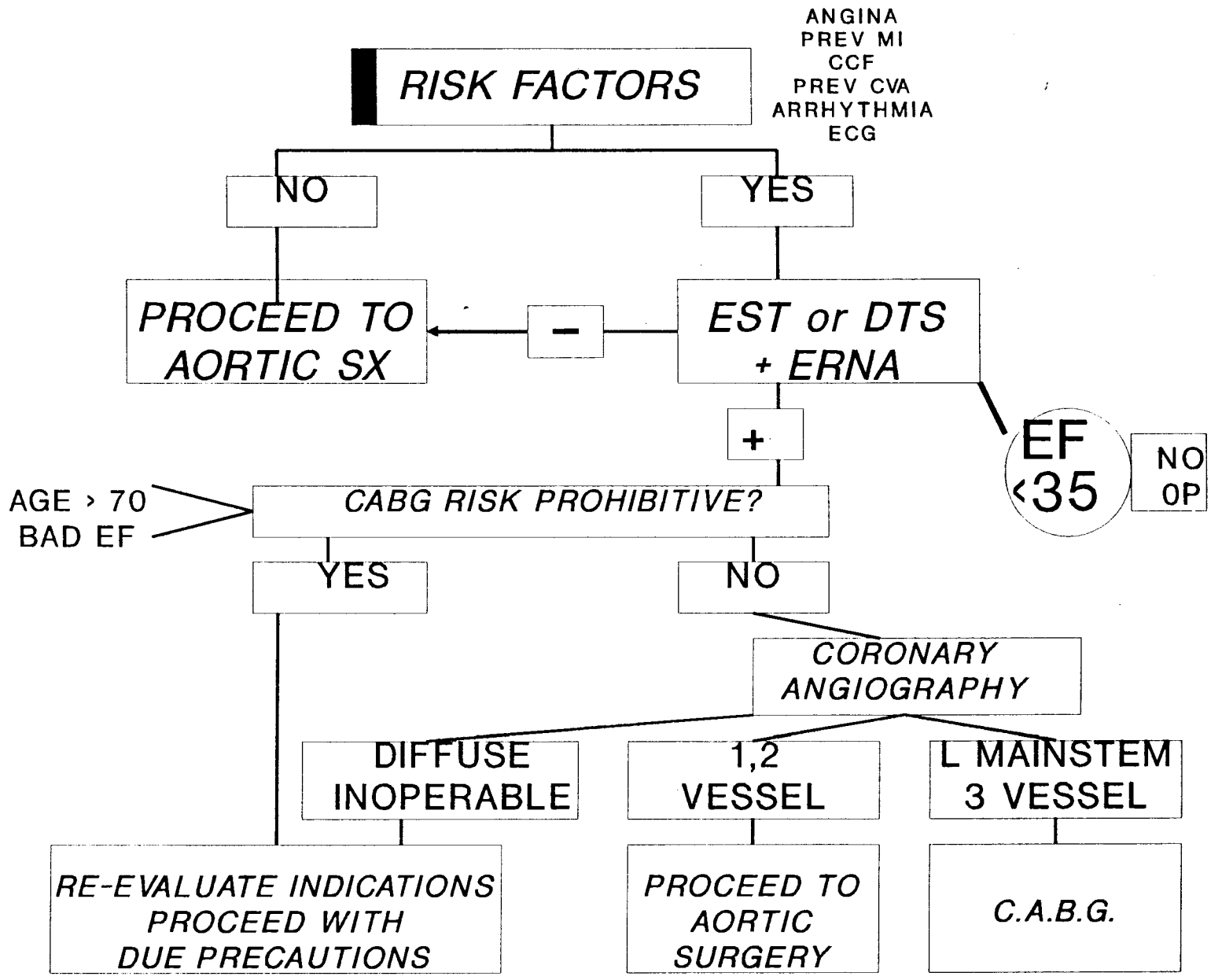
progression is unclear but acute haemodynamic alterations, such as may occur during aortic surgery may be important. While somewhat speculative, such considerations seem to be gaining credence recently with emerging evidence to suggest that they may be important and have profound influences on all attempts at screening [113].

Patients with severe or unstable coronary artery disease and patients with positive exercise stress tests or redistribution on dipyridamole-thallium scintigraphy should be further evaluated by coronary angiography if they are perceived to be reasonable potential candidates for coronary artery bypass surgery. In practice this will exclude most patients over 70 years and patients with very poor ejection fractions, particularly if they have no angina.

Patients who are demonstrated to have single or two vessel disease will usually be recommended to proceed with the scheduled aortic procedure without myocardial revascularisation, particularly if they are asymptomatic. The subgroup of patients with a significant left main stem lesion or triple vessel disease should probably undergo myocardial revascularisation prior to aortic reconstruction not only to reduce perioperative mortality, but to possibly increase eventual longevity.

The indications for aortic surgery will require re-evaluation in patients shown to have severe but inoperable triple vessel disease. If the indications are compelling such patients should probably proceed with aortic surgery as operative mortality rates in such patients have been acceptably low [8].

A management algorithm is presented in Figure 10.1. Based on the above conclusions, it has been found to be clinically appropriate when applied to vascular surgical patients in Cape Town.


RISK FACTORS
ANGINA
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NO
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PROCEED TO AORTIC SX
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EF <35
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AGE > 70
BAD EF
CABG RISK PROHIBITIVE?
YES
NO
CORONARY ANGIOGRAPHY
DIFFUSE INOPERABLE
1,2 VESSEL
L MAINSTEM 3 VESSEL
RE-EVALUATE INDICATIONS PROCEED WITH DUE PRECAUTIONS
PROCEED TO AORTIC SURGERY
C.A.B.G.

10.2 FUTURE DIRECTIONS

Current interest is focussed on the ability of cardiac risk factors and cardiac risk indices to predict long term survival following reconstructive vascular surgery [111]. It remains to be established whether identifying and correcting significant coronary artery lesions prior to elective aortic reconstruction will result in improved long term survival but at least one study has indicated a disappointingly low 5 year survival rate among patients who underwent successful aortic reconstruction without prior myocardial revascularisation [97].

The 220 patients in this study comprise a cohort that will continue to be followed in order to determine the ability of the identified risk factors to predict long term survival after aortic reconstruction.

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