cosides, but as well to some drugs whose active metabolites are excreted by the kidney, such as acetylprocainamide[14] and normeperidine.[15]

Review of the data on age-related changes in renal function leads to a final message concerning older patients who come under our care. There are substantial differences in renal function between older patients (and by implication, with regard to a variety of other functions). Chronologic age is a notoriously poor indicator of biologic age, and each patient must be regarded as an individual system when age-related changes in drug disposition are considered. No formula solutions can be considered applicable to all elderly, because the problems of each person are unique.

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Cardiac risk assessment and reduction in the elderly

Cardiovascular complications are a significant and potentially avoidable source of perioperative morbidity and mortality in the elderly.[1] Ideally, preoperative risk assessment will identify a high-risk subgroup of patients in which a variety of strategies aimed at risk reduction can be employed. Table I lists several indices of the risk of major perioperative cardiovascular complications. Some indices are obtainable from a history, physical examination, and routine laboratory investigations, whereas others are relatively expensive or invasive. Table II reports findings regarding the sensitivity, specificity, and overall predictive value of the indices listed in Table I, as well as details of experimental design and statistical analysis. In general, conclusions from large prospective studies employing a multivariate statistical approach should be given most credence. Most readily available indices lack either the sensitivity or specificity necessary to precisely identify a subgroup of patients at high risk. Other more powerful indices are too expensive for widespread application as screening tools. Available data do not allow description of a cost-effective technique by which currently available indices of risk can be sequentially applied to comprehensively screen a large geriatric surgical population. Furthermore, none of the available strategies for risk reduction have been prospectively demonstrated to alter perioperative cardiac morbidity or mortality in patients at risk. Much further research will be necessary before

TABLE I Indices of risk

ASA physical status
Cardiac risk index
Exercise ECG
Thallium 201 myocardial imaging
Radionuclide ventriculography
Coronary angiography

clinicians can confidently approach the dual problems of risk assessment and reduction in the elderly.

Indices of risk

The ASA physical status is the risk index that is most familiar to anaesthetists.[2] The ASA status is highly sensitive and most high-risk patients are ASA status III or IV. However, the index is rather nonspecific and many low-risk patients are included in these same categories.[3] This nonspecificity limits the usefulness of the ASA score as a screening tool. Nonetheless, the ASA score has not been demonstrated in a large prospective study to be inferior to any other risk index.

In 1977 Goldman *et al.* described the Cardiac Risk Index.[3] This landmark study represented the first credible attempt to define which of the many variables available from the preoperative history, physical examination, and routine laboratory investigations were associated with major perioperative cardiac complications. The authors derived the CRI retrospectively from data obtained preoperatively from 1001 patients aged 40 or over who underwent surgery in 1975–76. Multifactorial analysis revealed nine variables which independently correlated with risk (Table III). These variables were assigned a point value in accordance with their significance. Evidence of ventricular dysfunction (S3 or elevated JVP), myocardial infarction in the preceding six months, or an abnormal 12-lead ECG, were the most ominous preoperative findings. Patients were divided into four categories based on their total preoperative risk score. Patients in Class IV (CRI > 25) had a 78 per cent incidence of major cardiac complications or death. In this study the CRI was quite specific in identifying high-risk patients. Patients in CRI Class III (CRI > 12) or IV had an incidence of cardiac complications 3.8 times that of the entire sample. However, the index lacked sensitivity. Only 55 per cent of patients at risk were in Class III or IV. The CRI has been prospectively evaluated by other investigators.[4–8] Zeldin followed 1140 patients perioperatively and noted a similar correlation between increasing CRI category and the incidence of major cardiovascular complications.[4] In a study of geriatric patients undergoing elective intrathoracic or intraabdominal surgery Gerson *et al.* found that the presence of one or more of the "Goldman Indicators" listed in Table III was the only independent indicator of risk available from the usual preoperative data base.[5] Several smaller studies have confirmed the specificity and relative insensitivity of the CRI.[6–8] Thus, this index would appear to have a role in the preliminary preoperative screening of geriatric surgical patients. It has the additional advantage of focusing attention on potentially reversible risk factors. Because of the large number of patients studied and the multifactorial statistical approach employed by Goldman *et al.*, the CRI remains the benchmark to which other indices are compared.

Coronary artery disease is the most common and sig-

TABLE II Studies of risk indices

Risk index	*Investigator*	*n*	*Design*	*Sensitivity*	*Specificity*	*Correctly classified*
ASA III or IV	Goldman, 1977	1001	R,M	0.82	0.58	0.59
CRI III or IV	Goldman, 1977	1001	R,M	0.55	0.88	0.86
CRI III or IV	Zeldin, 1984	1140	P,U	0.51	0.93	0.92
CRI III or IV	Jeffrey, 1983	99	P,U	0.27	0.94	0.87
CRI III or IV	Reddy, 1985	160	P,U	0.86	0.94	0.93
CRI III or IV	Domaingue, 1982	100	P,U	0.45	0.88	0.83
≥1 Goldman indicator	Gerson, 1985	155	R,M	0.70	0.67	0.68
Exercise ECG positive	Cutler, 1981	130	R,U	0.80	0.67	0.69
Exercise ECG positive	McCabe, 1981	39	R,U	0.87	0.88	0.87
Exercise <2 min HR < 100	Gerson, 1985	155	R,M	0.83	0.61	0.64
Thallium redistribution	Boucher, 1985	48	R,U	1.00	0.80	0.83
Radionuclide ventriculography EF ≤ 0.55	Pasternack, 1984	50	R,U	1.00	0.60	0.66

CRI = Cardiac Risk Index, R = Retrospective, P = Prospective, U = Univariate, M = Multivariate.

TABLE III Multifactorial index of cardiac risk

S3 or elevated JVP	11
MI within 6 months	10
Rhythm not sinus	7
PVC's (more than 5/min)	7
Age over 70 yrs	5
Aortic stenosis	3
Poor medical condition	3
Emergency operation	4
Thoracic or abdominal surgery	3

From Goldman *et al.*[3]

nificant preoperative cardiovascular complication in the elderly. More sophisticated investigative tools such as the exercise electrocardiogram (ECG) aim to evaluate the severity and significance of coronary artery disease. Although it has been stated that the exercise ECG is not a useful tool for risk assessment,[9] much experimental data suggests that an abnormal exercise ECG is a highly significant univariate predictor of perioperative risk.[10,11] Even patients with occlusive vascular disease of the lower extremities can, in the vast majority of cases, undergo successful treadmill testing or arm ergometry. Cutler *et al.* found that among patients with vascular disease presenting for surgery the incidence of perioperative cardiovascular complications varied from 0–37 per cent depending on the ECG response to exercise.[10] In this population the exercise ECG was both sensitive (0.80) and reasonably specific (0.67). Other investigators obtained similar results.[11] As discussed in more detail below, regardless of the ECG response, the inability to exercise *per se* is associated with significantly increased risk in the elderly.[5] Further investigation should define the precise manner in which exercise testing should be employed in preoperative screening of the elderly.

Recently, dipyridamole-Thallium 201 myocardial imaging has been demonstrated to be a univariate correlate of perioperative risk in patients with peripheral vascular disease and a history of angina, myocardial infarction, or an abnormal ECG.[12] This noninvasive test is roughly twice as expensive as exercise testing but has the advantage of being applicable to patients who cannot exercise. Thallium 201 is a radioisotope which is distributed to the myocardium in proportion to regional blood flow, and taken up by viable myocytes. Myocardium distal to a haemodynamically significant coronary obstruction initially appears as a defect on the Thallium perfusion image. Hypoperfused but viable ("vulnerable") myocardium presents as a reversible defect which disappears when the scan is repeated after three hours. Infarcted myocardium appears as a persistent defect. The sensitivity of Thallium imaging is enhanced by increasing blood flow to well perfused myocardium either by exercise or administration of a nonspecific vasodilator like dipyridamole. Boucher *et al.* found that postoperative cardiovascular complications occurred in 50 per cent of patients with reversible defects on Thallium imaging.[12] Patients with no, or persistent, defects had a zero incidence of complications. These data, and the exercise ECG data, suggest that the presence of hypoperfused, as opposed to infarcted, myocardium is the most significant risk factor in patients with coronary disease. The remarkable sensitivity and specificity of dipyridamole-Thallium imaging reported by Boucher *et al.* must be confirmed in larger more broadly based studies. However, these preliminary results suggest that an important investigative tool has been added to the armamentarium of clinicians attempting to assess operative risk in the elderly.

Radionuclide ventriculography has also been suggested as a useful index of risk. Pasternak *et al.*, in a study of 50 patients scheduled for abdominal aortic ancurysm surgery, noted a 32 per cent incidence of postoperative myocardial infarction in patients whose resting preoperative ejection fraction was $\leq$55 per cent, whereas the incidence was zero among patients whose preoperative ejection fraction was normal (i.e., >55 per cent).[13] Gerson *et al.* performed preoperative radionuclide angiography at rest and during exercise in 100 patients aged 65 years and older who were about to undergo major abdominal or thoracic noncardiac surgery.[5] Multivariate analysis revealed that the severity of ventriculographic regional wall motion abnormalities (RWMA) ($p = 0.002$) and the inability of a patient to perform two minutes of supine bicycle exercise and achieve a heart rate of greater than 99 beats/min ($p = 0.005$) were the only independent predictors of postoperative cardiac complications. However, in a subsequent prospective evaluation of 55 patients, inability to exercise was the only independent predictor of risk.

Heart catheterization with coronary angiography and left ventriculography is considered to be the ultimate invasive technique for evaluating cardiac status preoperatively.[14] However, its value relative to other indices of preoperative risk is not clearly established for patients undergoing noncardiac surgery. Foster *et al.* reported follow-up data on 1600 patients who were entered into the Coronary Artery Surgery Study (CASS) registry and who subsequently underwent noncardiac surgical procedures.[15] These data should be interpreted cautiously because the registry includes patients without coronary disease, as well as patients with coronary disease who were randomized to medical or surgical therapy. Multivariate analysis of preoperative clinical and angiographic data revealed that the left ventricular score obtained from evaluation of the ventriculogram was the most significant predictor of postoperative cardiac complications. Angio-

TABLE IV Risk reduction strategies

Cancellation of surgery
Substitution of "low-risk" procedure
Intensive perioperative management
Prophylactic coronary bypass surgery

graphic details of coronary anatomy were not independently predictive. These data suggest that coronary angiography *per se* is of little value in risk assessment for noncardiac surgery. Ventriculographic data obtained at heart catheterization can likely be obtained more safely using radionuclide ventriculography, while information about physiologically significant coronary obstruction can be obtained by exercise electrocardiography or Thallium imaging.

Risk reduction

Table IV lists strategies for risk reduction which may be employed once a high-risk patient has been identified. These alternatives range from cancellation of surgery, to prophylactic coronary bypass surgery. Cancellation of surgery is an attractive alternative for very high-risk patients scheduled for nonlifesaving surgery. However, most high-risk patients will be scheduled for surgery intended to deal with lifethreatening or severely incapacitating disease. In such cases cancellation may not be a viable alternative.

Substitution of a "low-risk" procedure for a more invasive one is another option.[16] For example, in patients with vascular disease one might consider an extra-anatomical bypass procedure such as axillofemoral grafting,[17] or amputation,[18] as alternatives to a major intra-abdominal vascular procedure such as aortobifemoral grafting. Although such a strategy is appealing, preliminary data do not suggest that large reductions in perioperative risk accompany its use. Arous *et al.* noted a 20 per cent perioperative myocardial infarction rate among 25 patients with positive exercise ECG responses in whom extra-anatomic bypass procedures were performed.[16] This was not significantly different from the 28 per cent infarction rate in 77 similar patients who underwent standard vascular procedures. However, adequately controlled, randomized, prospective evaluations of this strategy have not been conducted.

"Intensive perioperative management" is an applicable term for a risk reduction strategy that has been advocated by some anaesthetists.[19] This term refers to a combination of techniques, including postponement of surgery while all potentially remediable risk factors are intensively treated, use of invasive haemodynamic monitoring intraoperatively, and a prolonged period of postoperative monitoring in an intensive care unit. Proponents of this strategy point to the remarkably low rate of myocardial reinfarction reported by Rao *et al.*[19] using this approach. The reinfarction rate was 1.9 per cent among 733 patients who were intensively managed, compared to 7.7 per cent for 364 historical controls who were not so treated. Although these are promising statistics, the hypothesis that intensive management is responsible for the lower infarction rate remains to be tested prospectively. Because of the potential cost of an intensive management strategy it should not be indiscriminately applied. Rao *et al.* inserted over 600 pulmonary artery catheters in their treatment group, and kept most patients in intensive care for five days postoperatively. The enormous cost of such an endeavour highlights the importance of refining techniques of risk assessment so that expensive strategies can be applied to select subgroups of high-risk patients. For example, had Rao *et al.* limited their application of intensive management to patients with angina or congestive heart failure, the same results would theoretically have been achieved at greatly reduced expense.

A final approach to risk reduction which can be applied to the large population of patients with coronary artery disease is the use of prophylactic coronary artery bypass grafting prior to elective noncardiac surgery. A number of studies have indicated a low incidence of perioperative cardiac complications among patients who have undergone coronary artery bypass grafting who subsequently undergo major noncardiac surgery.[20,21] For example, among patients from the CASS registry, operative mortality for noncardiac surgical procedures was significantly lower in patients with coronary disease who had undergone coronary artery bypass grafting compared to those whose coronary disease was managed medically (0.9 per cent vs 2.4 per cent.[15] However, before accepting these results as definitive proof of the efficacy of prophylactic coronary artery surgery, one should consider the 2.4 per cent operative mortality associated with coronary artery bypass grafting procedures among patients from the same age group in the CASS.[22] Thus, the cumulative mortality for both coronary artery and noncardiac surgical procedures of approximately 3.3 per cent probably exceeds that for patients undergoing noncardiac surgery only. Others have noted disappointingly high operative mortality among patients undergoing prophylactic coronary artery surgical procedures prior to major noncardiac surgery. Hertzer *et al.* noted a prohibitive 5.3 per cent mortality among 226 vascular surgery candidates with "severe correctable" coronary disease who underwent prophylactic coronary artery bypass grafting at the Cleveland Clinic.[14] Despite conclusions to the contrary by the authors, data from both these studies[14,15] are most compatible with the hypothesis that prophylactic coronary surgery constitutes little more than a "survival test" which weeds

out patients who would have died during noncardiac surgery, but who now die as a result of coronary surgery. Only a careful prospective investigation can establish the efficacy of prophylactic coronary artery surgery in reducing the mortality of subsequent noncardiac surgery or prolonging long-term survival. Until such studies have been performed, prophylactic coronary surgery should be reserved for those patients in whom it is indicated by conventional criteria.

In conclusion, a number of indices of perioperative cardiac risk are available. It is currently unclear as to how these may most efficiently be applied to screening a large geriatric surgical population. A number of strategies for risk reduction are available but none have been subjected to prospective investigation. Until a great deal more investigation has been done, risk assessment and reduction will remain matters for subjective interpretation by individual clinicians.

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Anaesthetic management of the geriatric patient

By the early twenty-first century, 16 per cent of the United States population will be over age 65 and this group will account for over one-third of all health care