Continuing Medical Education

Clinical application of cardiac risk indices: how to avoid misleading numbers

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Perioperative cardiac complications are associated with a high mortality rate. During the preoperative assessment the anaesthetist must determine if the patient is at risk so that appropriate interventions can be made to ensure the best possible outcome. Over the past three decades several indices have been proposed to identify the surgical patient at risk of cardiac morbidity or mortality. These indices can be thought of as diagnostic tests which determine the likelihood of perioperative cardiac complication. In this article the authors review the epidemiological basis of diagnostic tests and apply this theory to three currently available indices of perioperative risk: the American Society of Anesthesiologists physical status classification, the Goldman multifactorial cardiac risk index and a modified version devised by Detsky. A case history describing a surgical patient with unstable angina is first presented to show how different indices can lead to different predictions. These indices are then analysed as if they were diagnostic tests to predict cardiac complications after surgery. The characteristics of diagnostic tests such as sensitivity, specificity, positive and negative predictive values, and receiver operating characteristic curves are described and applied to the indices. Basic principles such as odds ratio, likelihood ratio and their relation to prevalence and post-test probability are also presented. This overview will

help the anaesthetist to understand the limitations of risk indices as predictors of adverse cardiac outcome and to apply these scales more effectively to individual patients at different institutions.

Les complications cardiaques durant la période périopératoire sont associées à une mortalité élevée. Au cours de l'évaluation préopératoire, l'anesthésiste doit déterminer les risques d'un patient afin de pouvoir prendre les mesures qui favoriseront la meilleure évolution possible après la chirurgie. Plusieurs échelles d'évaluation de risque cardiaque ont été proposées afin d'améliorer la prédiction de la morbidité et de la mortalité périopératoires. Ces échelles peuvent être considérées comme des tests diagnostiques déterminant la probabilité de complications cardiaques. Dans cet article, les auteurs présentent les principes épidémiologiques essentiels à la compréhension et l'utilisation de tout test diagnostique et ils appliquent ces concepts à trois échelles d'évaluation de risque périopératoire : la classification de l'état physique telle que définie par la Société Américaine des Anesthésistes, l'échelle multifactorielle de risque cardiaque décrite par Goldman ainsi que sa version modifiée proposée par Detsky. Une histoire de cas décrivant un patient chirurgical avec angine instable est d'abord présentée afin de démontrer comment différentes échelles donnent des prédictions différentes. Ces échelles sont par la suite analysées comme si elles étaient des tests diagnostiques de prédiction de complications cardiaques périopératoires. Certaines notions propres aux tests diagnostiques telles la sensibilité, la spécificité, la valeur prédictive positive et négative, ainsi que les courbes de rapport vrai positifs sur faux positif sont décrites et appliquées à ces échelles. Les principes de base des rapports de probabilité et leur relation avec la prévalence et la prédiction d'un test sont aussi présentées. Cette révision permettra à l'anesthésiste de mieux comprendre les limites des échelles d'évaluation du risque de complications cardiaques et l'aidera dans l'application clinique de ces échelles.

Key words

COMPLICATIONS: myocardial infarction;
HEART: ischaemia;
STATISTICS.

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TABLE I Definitions of the epidemiological characteristics of a diagnostic test (with permission³)

		Disease		
		Present	Absent	
Test result	Positive	a true-positive	b false-positive	$\frac{a}{a+b}$ = positive predictive value or post-test likelihood of disease
	Negative	c false-negative	d true-negative	$\frac{d}{c+d}$ = negative predictive value or post-test likelihood of no disease
		$a/a+c$ = sensitivity or Tp rate or PiD	$d/b+d$ = specificity or TN rate or NiH	

PiD = Positivity in Disease; NiD = Negativity in Disease; TP rate = true positive rate; TN rate = true negative rate.

Typical case history

A 68-yr-old man was admitted for an elective cholecystectomy the following morning. He had an uncomplicated inferior wall myocardial infarction (MI) one year before admission. Since his heart attack he has had angina on exertion and is being treated with beta blockers and oral nitroglycerin. In the last six weeks he has experienced angina while shaving. Otherwise the history is noncontributory as is the physical examination. Preoperative chest x-ray is normal and the ECG shows a normal sinus rhythm at 65 bpm with Q-waves in the inferior leads. Should this patient be anaesthetized as booked? Applying Goldman's cardiac risk index¹ this patient would gather no points and would be considered as class I which means minimal risk of a life-threatening perioperative complication. This suggests that it might be unreasonable to inconvenience the surgeon and patient by delaying surgery for further evaluation and treatment. On the other hand, according to the American Society of Anesthesiologists (ASA) physical status classification,² he would be in class IV with a high perioperative mortality. When two well-established techniques to assess perioperative morbidity and mortality give contradictory results how is the anaesthetist to decide on a course of action? How is he/she to defend it in the face of surgeons and patients anxious to proceed with surgery?

In order to answer these questions, epidemiological criteria which are generally used to assess diagnostic tests will be reviewed. This information will then be applied to three risk assessment indices: the ASA physical status classification, Goldman's, and Detsky's multifactorial cardiac risk indices. This exercise will show how epidemiological data can be used to assess postoperative outcome risk indices. It is hoped that an understanding of the principles presented in this article will help individual practitioners to apply epidemiological data to individual patients.

Epidemiological criteria for assessment of diagnostic tests

Diagnostic tests are used to decrease uncertainty regarding the presence or absence of disease in a patient. The clinician should choose the test that decreases this uncertainty the most. Although the ability to choose the "best test" is often called "clinical intuition" it results from an understanding of the characteristics of the test itself and the population to which it is most appropriately applied. These concepts will be described briefly as a background for a criticism of cardiac risk indices which can be considered as tests to predict adverse outcome after surgery. The reader is referred to Sackett,³ on which much of the following material is based, for an excellent discussion of these principles.

How to determine the accuracy of a diagnostic test

The accuracy of a diagnostic test can be determined by applying the test to a population in which the presence or absence of disease has been confirmed by some "gold standard" (e.g., biopsy). Most tests are imperfect and will not assign every individual to the correct category. Patients with the disease who test positive are termed "true positives." Those without the disease who test negative are "true negatives." Incorrectly assigned patients include "false positives" (positive test in the absence of disease) and "false negatives" (negative tests in the presence of disease). The accuracy of the test can be quantified by analyzing the numbers in the columns of Table I. The proportion of patients with the disease who test positive is $(a/a+c)$: this is called "sensitivity," "positivity in disease" (PiD) or "true positive rate" (TP rate). The proportion of patients without disease who test negative $(d/b+d)$ is known as "specificity," "negativity in health" (NiH) or "true negative rate" (TN rate). The sensitivity and specificity of a test can be changed depending on the criteria for a positive test. For example,

FIGURE 1 A "receiver operating characteristic" curve for CK values in myocardial infarction (reproduced with permission)³.

in the diagnosis of MI using creatinine kinase, if one chooses only high CK values (>200) as positive, there will be few false positive tests (high specificity) but many false negatives (low sensitivity). The appropriate choice of critical value will depend on the relative harm caused by diagnosing disease in a healthy patient versus missing disease in an affected patient.

Influence of prevalence of disease on the predictive values of a diagnostic test

More relevant to the use of cardiac risk indices is an evaluation of their predictive values. An analysis of the two rows of Table I allows a definition of these values. The proportion of patients with positive tests who have the disease is $a/a+b$. This is known as the "positive predictive value" or "post-test likelihood of disease." The proportion of patients with negative tests who are disease-free is $d/c+d$; this represents the "negative predictive value" or "post-test likelihood of no disease." Examining the predictive values reveals how the usefulness of a test will depend on the "prevalence" of the disease in the population to be tested; that is, the "pretest probability of the disease" in a patient. The prevalence or pretest probability is the value $a+c/a+b+c+d$. If the prevalence is low then the values of b and d will be large compared with $a+c$. This will cause the positive predictive value to fall and the negative predictive value to rise. The usefulness of a test lies in how much the clinician's uncertainty is changed by

TABLE II True and false positive rates for different CK concentrations ($\text{IU} \cdot \text{L}^{-1}$) in the diagnosis of MI with permission³

	CK cutoff			
	≥ 280	≥ 80	≥ 40	≥ 1
TP rate (sensitivity, PiD rate)	42%	93%	99%	100%
Specificity (NiH rate, TN rate)	99%	88%	68%	0%
FP rate (100%-specificity)	1%	12%	32%	100%

the result of the test, that is, how different the post-test probability of disease is from the pretest probability. In general the greatest reductions in uncertainty will occur when the pretest probability is 50% which reflects the least possible certainty.

Cutoff points and receiver operating characteristic curve

Information is lost if only one value of a diagnostic test is chosen as a cutoff point to define a positive test. Usually the more positive the test result (example: higher CK, more ST-depression at lower exertion on treadmill test) the higher the probability that the patient has the disease. Table II shows the result of using four cutoff levels for CK concentrations in the diagnosis of MI. The TP rate, specificity, and false positive rate ($b/b+d$) are expressed for each cutoff point. As lower cutoffs are used, the TP rate increases and more patients with disease have a positive test, but at the cost of increasing the false positive rate (FP rate). If the TP rate is plotted against the FP rate (for the four cutoffs and 0 for convenience), a "receiver operating characteristic" (ROC) curve is generated for the diagnostic test (Figure 1). The point closest to the upper left corner of the diagram is the single best cutoff point where the test assigns the fewest patients to the wrong category. Different diagnostic tests can be compared for the same disease by overlaying their ROC curves on the same plot. The test with the ROC curve enclosing the largest area below it is the most accurate. A perfect test would combine a TP rate of 100% and an FP rate of 0%, and the area under the curve would be 1.0. At the opposite, a test offering prediction no better than chance would have a TP rate always equal to its FP rate and it would plot a line at a 45° angle, with an area under the curve of 0.5. Which test is more useful depends on the relative harm of a false negative compared with a false positive result.

Likelihood ratio for conversion of pretest to post-test probability

Using "likelihood ratios" is a still more powerful way to use diagnostic test results to determine the probability of

FIGURE 2 Receiver operating characteristic curves for the ASA classification of physical status and the Goldman cardiac risk index in the prediction of perioperative cardiac complications. Different cutoff points were determined by combining the classes as indicated in parentheses on each curve.

TABLE III ASA classification of physical status

Class I	A normal, healthy individual
Class II	A patient with a mild systemic disease
Class III	A patient with a severe systemic disease that limits activity, but is not incapacitating
Class IV	A patient with an incapacitating systemic disease that is a constant threat to life
Class V	A moribund patient who is not expected to survive 24 hours with or without surgery

disease in a patient. This ratio is TP rate/FP rate, or referring to Table I, $(a/a+c) \div (b/b+d)$. This expresses the relative frequency with which a given level of test value occurs in patients with the disease compared with its occurrence in healthy patients. From Table II the likelihood ratio for a CK result of 80 or higher is $0.93/0.12 = 7.6$. This ratio can be used to determine the probability of disease in a patient. The probability that the patient has the target disorder is derived from the prevalence of disease in the population from which he comes (pretest probability) and the likelihood ratio for his level on the diagnostic test. This is done first by converting pretest probability into "pretest odds": for example, for a patient in whom we think there is a 50% chance of myocardial infarction, the pretest odds are 1:1 [pretest odds = (pretest probability)/(1 - pretest probability)]. In the presence of a CK result over 80, the post-test odds can be calculated: they

TABLE IV Correlation between preoperative ASA classification of physical status and cardiac complications found by Goldman *et al.*¹

ASA classifications	No. of patients with major cardiac complications or cardiac deaths	No. of patients with no or only minor complications
IV	25	87
III	21	302
	a	b
	c	d
II	10	398
I	0	129
	(46)	(389)
	(10)	(527)

Numbers in parentheses represent the total in each box. The letters can be used to determine sensitivity ($a/a+c$) and specificity ($d/b+d$) when classes III and IV of the ASA classification of physical status are used as cutoff point indicating high risk.

are equal to pretest odds multiplied by the likelihood ratio, that is $1:1 \times 7.6 = 7.6:1$. Finally, the post-test odds are converted into post-test probability: that is (post-test odds)/(1 + post-test odds) or $7.6/(1 + 7.6) = 88\%$. Thus, in a patient who before testing had a 50% probability of disease, a positive test indicates an 88% probability of disease, a considerable improvement in certainty. The calculations are easily avoided by using a nomogram which associates pretest to post-test probability through likelihood ratios. It is now obvious that not only the values of a test result matter in the prediction of disease, but also the prevalence or pretest probability of having the disease are important. Estimating pretest probability of disease when published data are unavailable distinguishes the experienced clinician from the novice. The reader will have a chance to use these concepts when Detsky's approach to risk prediction is explained later.

Risk assessment indices

ASA physical status classification

The ability of anaesthetists to predict perioperative cardiac complications has not been studied. However, during the preoperative evaluation the anaesthetist makes a judgement of the patient's condition and risk by using the ASA physical status classification. Retrospective and prospective studies have shown that the ASA physical status score (Table III) has a strong correlation with major intraoperative and postoperative cardiac complications^{1,4} as well as with perioperative mortality.⁵⁻⁸

The original ASA classification⁹ and the current version² were designed to facilitate the tabulation of statistical data in anaesthesia and not to estimate operative risk. However, as will be shown, the ASA classification can contribute to the prediction of adverse cardiac outcome. Goldman provided the ASA scores of the patients of his original study¹ (Table IV). From these

TABLE V Goldman multifactorial risk index score and its modified version as proposed by Detsky *et al.*

Goldman multifactorial risk index score	Points	Detsky multifactorial risk index score	Points
History		Coronary artery disease	
– Myocardial infarction within 6 months	10	– Myocardial infarction within 6 months	10
		– Myocardial infarction older than 6 months	5
		– Canadian Cardiovascular Society Angina	
		– Class III	10
		– Class IV	20
		– Unstable angina within 6 months	10
– Age over 70 years	5	Age over 70 years	5
Physical examination		Alveolar pulmonary oedema	
– Third heart sound or jugular venous distension	11	– Within 1 week	10
		– Ever	5
– Important aortic stenosis	3	Suspected critical aortic stenosis	20
Electrocardiogram		Electrocardiogram	
– Rhythm other than sinus or sinus plus atrial premature beats on last electrocardiogram	7	– Rhythm other than sinus or sinus plus atrial premature beats on last electrocardiogram	5
– More than 5 premature ventricular beats per minute at any time preoperatively	7	– More than 5 premature ventricular beats at any time preoperatively	5
Poor general medical status*	3	Poor general status*	5
Emergency operation	4	Emergency operation	10
Intraperitoneal, intrathoracic or aortic surgery	3		
	53		120

* $\text{PaO}_2 < 60 \text{ mmHg}$, $\text{PaCO}_2 > 50 \text{ mmHg}$, $\text{K}^+ < 3.0 \text{ mEq} \cdot \text{l}^{-1}$, $\text{HCO}_3^- < 20 \text{ mEq} \cdot \text{l}^{-1}$, $\text{BUN} > 50 \text{ mg} \cdot \text{dL}^{-1}$ ($18 \text{ mmol} \cdot \text{L}^{-1}$), creatinine $> 3 \text{ mg} \cdot \text{dL}^{-1}$ ($260 \text{ mmol} \cdot \text{L}^{-1}$), abnormal SGOT, signs of chronic liver disease, bedridden from noncardiac causes.

With permission.^{1,19,20}

numbers an ROC curve can be drawn to illustrate the predictive value of the ASA classification for cardiac complications (Figure 2). Using the equations from Table I, TP rate (sensitivity) and false positive rate (1-specificity) are obtained for each possible cutoff point of the ASA classification (e.g., I (= negative) vs II, III, IV (= positive); then I + II vs III + IV; then I + II + III vs IV). This gives three pairs of TP and FP rates which are placed on the plot and added to the 0,0 and 1,1 points to complete the ROC curve. The curve for the ASA score encloses an area larger than 0.5 and therefore is a useful estimate of cardiac risk.

The characteristics of the ASA classification as a predictor of outcome need to be understood. The nature of the surgery being performed is ignored. This can lead to considerable differences in outcome for the same class of patients when different types of surgery are compared. This results in a high sensitivity with a lack of specificity for prediction of cardiac complications. When ASA physical status classes III and IV (see Table IV) are used as a cutoff point for the diagnosis of high risk, the index has an 82% sensitivity. Thus 4/5 patients are identified. The specificity is only 58%, so 42% of patients are falsely identified as being at risk.

Goldman multifactorial cardiac risk index

This index was designed to predict death, myocardial

infarction, pulmonary oedema and ventricular tachycardia in patients undergoing noncardiac surgery.¹ Multivariate discriminant analysis identified nine independent correlates of life-threatening and fatal cardiac complications. Points were assigned to each of the nine variables according to their discriminant-function coefficient (Table V). Patients are separated into four classes of increasing risk by their total score (Table VI). In contrast to the ASA scale this index has a low sensitivity (55%) but a high specificity (88%) when classes III and IV are considered positive tests. This means that a low score is useful in indicating a low probability of an adverse outcome. Using the data from Table VI an ROC curve for the Goldman cardiac risk index can be plotted (Figure 2). As demonstrated by the curves, the multifactorial index, when used as a diagnostic test, performs slightly better than the ASA classification.

A review of the studies in which the multifactorial risk index was analyzed confirms that the high specificity of the index is consistent (Table VII and Figure 3). Zeldin¹⁰ evaluated 1140 consecutive and non-selected patients undergoing a wide range of noncardiac surgical procedures, a population similar to the one studied by Goldman. Therefore the complication rates compare well with those found by Goldman. Domaingue *et al.*¹¹ studied patients undergoing vascular surgery and Jeffrey *et al.*¹² studied only those undergoing abdominal aortic aneurysm

TABLE VI Goldman cardiac risk index Reproduced (with permission)¹

Class		Point total	No or only minor complications (n = 943)	Life-threatening complications* (n = 39)	Cardiac deaths (n = 19)
I	(n = 537)	0–5	532 (99)†	4 (0.7)	1 (0.2)
II	(n = 316)	6–12	295 (93)	16 (5)	5 (2)
III	(n = 130)	13–25	112 (86)	15 (11)	3 (2)
IV	(n = 18)	≥26	4 (22)	4 (22)	10 (56)

*Documented intraoperative or postoperative myocardial infarction, pulmonary oedema, or ventricular tachycardia without progression to cardiac death.

†Figures in parentheses denote %.

TABLE VII Incidence of major cardiac complications in various studies analyzing the multifactorial cardiac risk index

Cardiac risk class	Goldman <i>et al.</i> ¹ (various non-cardiac surgery)	Zeldin ¹¹ (various non-cardiac surgery)	Domaingue <i>et al.</i> ¹² (various vascular procedures)	Jeffrey <i>et al.</i> ¹³ (abdominal aortic surgery)
I	1% (5/537)	0.7% (4/590)	8% (4/50)	7% (4/56)
II	7% (21/316)	3% (13/453)	15% (5/34)	11% (4/35)
III	14% (18/130)	15% (11/74)	50% (8/16)	38% (3/8)
IV	78% (14/18)	39% (7/23)	—	—

surgery. As can be seen in Table VII the complication rates in all classes are much higher in those last two series. This illustrates a general principle of diagnostic tests mentioned in the previous section: as prevalence or pretest probability of disease increases, the positive predictive value of the test (number of patients testing positive being truly at risk) also increases (Figure 3).

Why is angina not among the variables used by Goldman to predict cardiac complications? In his ten-year status report¹³ Goldman explained that class I and II angina was a univariate correlate of risk but did not achieve significance after including other markers of heart disease. His findings are corroborated by the data of the Coronary Artery Surgery Study (CASS) which showed a mortality rate of 2.4% in patients who had severe coronary artery disease undergoing noncardiac surgery.¹⁴ The CASS results support the relative safety of undertaking major surgery in patients with stable angina. In such patients the mortality rate of the sequence of coronary artery bypass grafting followed by noncardiac surgery was 2.3%. On the other hand, Goldman states "The multifactorial index was not derived on a sufficient number of patients who had class III or IV angina and was never intended to apply to such patients, who normally should undergo further evaluation and treatment before noncardiac surgery."¹³

It is now possible to understand why the patient described in the beginning of this article was misclassified (class I) by the Goldman index. The test failed not because of its low sensitivity but because it is not applicable to patients with severe or unstable angina. The history of a

previous myocardial infarction alone places the patient at higher risk than predicted by the Goldman cardiac risk index. A preoperative myocardial infarction one year before surgery has a reinfarction rate from 1.5–6% with an associated mortality rate of 20–70%.^{14–18} Therefore, when high risk is suspected in a patient, the use of the Goldman index should not allay that suspicion even in the presence of a low score. On the other hand, a high score should influence management decisions, as 28 of the 53 points in the Goldman scale are potentially controllable. Heart failure, time elapsed between surgery and a previous myocardial infarction, emergency surgery, and poor medical condition can in some circumstances be altered. Perhaps the most useful feature of the index is to draw the clinician's attention to these factors.

Detsky's modified cardiac risk index

More recently, Detsky *et al.* proposed a modification of Goldman's multifactorial cardiac risk index.^{19,20} The modified index was based on a prospective study of patients referred by the surgical team to the internal medicine service because of suspected cardiac disease. This selected group of patients differs from the general surgical population studied by Goldman. Detsky added and changed some variables in the index (Table V). The most important addition is the attribution of points to patients with Canadian Cardiovascular Society²¹ angina Classes III or IV, or unstable angina within six months. The definition of unstable angina given by Detsky is: angina at rest, crescendo angina or new-onset angina within one month occurring with minimal exertion. Points

FIGURE 3 The diagnostic characteristics of the multifactorial cardiac risk index as determined in four different studies. Patients assigned to class I or II are considered to test negative, those in class III and IV are positive. The specificity and negative predictive value (NPV) are high in all series indicating that a negative test accurately predicts a favourable outcome. Inversely, the sensitivity and positive predictive values (PPV) are always low. Note the tendency for the sensitivity to decrease and the PPV to increase when the index is applied to patients undergoing procedures with a higher prevalence of complications.

are also assigned for MI older than six months. An important change in the index is the replacement of a third heart sound or jugular venous distention by a previous history of pulmonary oedema which may reflect left ventricular function better. The modified index uses only three levels of points (5, 10 and 20) which makes it easier to remember. How these points were attributed to each risk factor was not well explained. The scoring system was validated in their institution.

Detsky makes use of likelihood ratios in the index. Rather than use the site of the surgery as a variable in the risk index he, more appropriately, used the nature of the surgery to calculate the pretest probability of an adverse outcome (Table VIII). This was done by grouping patients seen by the internal medicine service into several categories according to the nature of their surgery and then documenting the incidence of adverse outcomes in each group. As expected, patients undergoing abdominal aneurysm surgery as a group have a higher incidence of morbidity and mortality than those undergoing less stressful procedures. Once the population is stratified according to the nature of the surgery, the risk index is then applied (within strata) to calculate the post-test probability of an adverse outcome. Detsky provides a nomogram whereby the pretest probability can be converted to a post-test probability using a likelihood ratio (Figure 4).

APPLICATION OF DETSKY'S RISK INDEX

The modified cardiac risk index will now be applied to the patient described at the beginning of this article, using

TABLE VIII Pretest probabilities by type of surgery (with permission²⁰)

	Major cardiac complications No. (%) [*]	95% confidence limits
Major surgery		
- Vascular	10/76 (13.2)	6.5-19.7
- Orthopedic	9/66 (13.6)	6.0-21.2
- Intrathoracic/intraperitoneal	7/88 (8.0)	3.4-13.6
- Head and neck	1/38 (2.6)	0.3-16.4
Minor surgery		
- (e.g., transurethral prostatectomies, cataracts)	3/187 (1.6)	0.5-1.6

Detsky's data. Eight percent of patients with suspected cardiac disease who are seen preoperatively by the internal medicine service in Toronto have an adverse event after cholecystectomy (Table VIII). The patient receives 35 points on the basis of a previous infarct, class IV angina, and unstable angina. The nomogram in Figure 4 can be used starting from a pretest probability of 8%, crossing the likelihood ratio at 35 points, to reach a post-test probability of 45%. This patient has a 45% probability of a cardiac event following his cholecystectomy. Since one-third of the events are death, this patient's risk of death would be 15%. This information represents considerable improvement in prediction of outcome compared with risk assessment based on an index which ignores the pretest probability of complications.

Detsky's approach to risk assessment illustrates good use of the epidemiological principles discussed in this article. However, it has not been tested in other institutions. Before introducing this type of risk index in any institution the first step is to determine the local pretest probabilities. These may be very different from one institution to another and depend on many factors such as the patient population to which the index is applied, surgical and anaesthetic experience, perioperative care facilities and the nature of the institution itself (e.g., secondary or tertiary care centre). The likelihood ratios are theoretically prevalence-independent, that is, apply equally well to all strata, and can be applied using the nomogram in Figure 4 in most institutions.

Conclusions

Cardiac risk indices ignore many important perioperative factors which may indirectly contribute to cardiac complications, such as difficult intubation, blood loss, positioning, infection and many other events. The information obtained from risk indices can only be part of an overall preanaesthetic evaluation of the patient and cannot be a final determinant of postoperative outcome precluding consideration of other factors. The anaesthetist may opt to

FIGURE 4 Likelihood ratio nomogram. Anchor a straight edge at the value on the pretest side of the nomogram determined by the surgical procedure. Direct the straight edge through the point in the center column reflecting the patient's index score and associated likelihood ratio. The point where the straight edge meets the right-hand column denotes the post-test probability or risks of perioperative cardiac complications. (Reproduced with permission.)^{19,20}

use a risk assessment index in a particular patient in order to support clinical decisions regarding the use of invasive monitoring, postoperative care, consultation with another specialist or even cancellation of the surgery for further investigation or treatment. In order to avoid incorrect

decisions based on misleading numbers, the anaesthetist must make sure that the index applies to his patient. The application of Goldman's multifactorial cardiac risk index to a patient with unstable angina is an example of the misleading information obtained from the application of a risk index not valid for that particular patient.

The anaesthetist must also give consideration to the probability of complications associated with certain diseases and surgical procedures, and he must be able to appreciate the prevalence of postoperative complications inherent in his/her own institution. Combining all this information in one risk evaluation is a difficult task which clinicians often resolve by referring to their previous experiences. However, epidemiological tools exist which allow the use of much of the available information to estimate an overall probability. Likelihood ratios used for the conversion of pretest into post-test probability are an example of such tools. Detsky's modifications to Goldman's cardiac risk index are a good application of such epidemiological tools. This approach brings the clinician one step further in the prediction of outcome.

The risk assessment provided by any cardiac risk index can hardly be communicated to patients and their relatives in terms of percentages. Identifying the important factors by applying a risk index can help the anaesthetist to inform the patient fully as well as the surgeon. These factors deserve consideration in the anaesthetist's plan of perioperative care. Although this approach will not correctly predict outcome for every patient, the exercise will always encourage the anaesthetist and surgeon to answer the ultimate question of preoperative assessment: has everything possible been done to ensure that the patient has an uncomplicated perioperative course?

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References.

- 1 Goldman L, Caldera DL, Nussbaum SR et al. Multifactorial index of cardiac risk in noncardiac surgical procedures. *N Engl J Med* 1977; 297: 845-50.
- 2 New classification of physical status. *Anesthesiology* 1963; 24: 111.
- 3 Sackett DI, Haynes RB, Tugwell P. The interpretation of diagnostic data. In: *Clinical Epidemiology*, 1st ed. Boston: Little, Brown and Company, 1985: 59-138.
- 4 Cohen MM, Duncan PG. Physical status score and trends in anesthetic complications. *J Clin Epidemiol* 1988; 41: 83-90.
- 5 Vacanti CJ, Van Houten RJ, Hill RC. A statistical analysis of the relationship of physical status to postoperative mortality in 68,388 cases. *Anesth Analg* 1970; 49: 564-6.

- 6 Marx GF, Mateo CV, Orkin LR. Computer analysis of postanesthetic deaths. *Anesthesiology* 1973; 39: 54–8.
- 7 Cohen MM, Duncan PG, Tate RB. Does anesthesia contribute to operative mortality? *JAMA* 1988; 260: 2859–63.
- 8 Turnbull KW, Fancourt-Smith PF, Banting GC. Death within 48 hours of anaesthesia at the Vancouver General Hospital. *Can Anaesth Soc J* 1980; 27: 159–63.
- 9 Saklad M. Grading of patients for surgical procedures. *Anesthesiology* 1941; 2: 281–4.
- 10 Zeldin RA. Assessing cardiac risk in patients who undergo noncardiac surgical procedures. *Can J Surg* 1984; 27: 402–4.
- 11 Domaingue CM, Davies MJ, Cronin KD. Cardiovascular risk factors in patients for vascular surgery. *Anaesth Intensive Care* 1982; 10: 324–7.
- 12 Jeffrey CC, Kunsman J, Cullen DJ, Brewster DC. A prospective evaluation of cardiac risk index. *Anesthesiology* 1983; 58: 462–4.
- 13 Goldman L. Multifactorial index of cardiac risk in noncardiac surgery: ten-year status report. *Journal of Cardiothoracic Anesthesia* 1987; 1: 237–44.
- 14 Foster ED, Davis KB, Carpenter JA *et al.* Risk of noncardiac operation in patients with defined coronary disease: the Coronary Artery Surgery Study (CASS) registry experience. *Ann Thorac Surg* 1986; 41: 42–50.
- 15 Tarhan S, Moffitt EA, Taylor WF, Giuliani ER. Myocardial infarction after general anesthesia. *JAMA* 1972; 220: 1451–4.
- 16 Steen PA, Tinker JH, Tarhan S. Myocardial reinfarction after anesthesia and surgery. *JAMA* 1978; 239: 2566–70.
- 17 Rao TLK, Jacobs KH, El-Etr AA. Reinfarction following anesthesia in patients with myocardial infarction. *Anesthesiology* 1983; 59: 499–505.
- 18 Shah KB, Kleinman BS, Sami H, Patel J, Rao TLK. Re-evaluation of perioperative myocardial infarction in patients with prior myocardial infarction undergoing noncardiac operations. *Anesth Analg* 1990; 71: 231–5.
- 19 Detsky AS, Abrams HB, McLaughlin JR *et al.* Predicting cardiac complications in patients undergoing noncardiac surgery. *J Gen Intern Med* 1986; 1: 211–9.
- 20 Detsky AS, Abrams HB, Forbath N, Scott JG, Hilliard JR. Cardiac assessment for patients undergoing noncardiac surgery. *Arch Intern Med* 1986; 146: 2131–4.
- 21 Campeau L. Grading of angina pectoris. *Circulation* 1976; 54: 522–3.

Multiple-Choice Questions

SELECT THE SINGLE BEST ANSWER

- 1 The sensitivity of a diagnostic test represents:
 - A The proportion of patients with a positive test who have the disease.
 - B The proportion of patients with the disease who test positive for the disease.
 - C The proportion of patients with a negative test who have the disease.
 - D The proportion of patients without the disease who test negative for the disease.
 - E None of the above.
- 2 Angina is not among the variables used by Goldman in the multifactorial cardiac risk index because
 - A It does not represent a significant risk.
 - B It is not proven that an appropriate pre-operative treatment of angina decreases the risk of perioperative myocardial infarction.
 - C Patients with severe angina should undergo coronary artery surgery before undergoing any other surgical procedure.
 - D The multifactorial risk index was not derived on sufficient number of patients with severe angina and therefore does not apply to them.
 - E None of the above.
- 3 Patients undergoing noncardiac surgery at least six months after a myocardial infarction have a quoted perioperative reinfarction rate of
 - A 1.5 to 6%
 - B 20 to 35%
 - C 40 to 50%
 - D 50 to 70%
 - E None of the above.
- 4 The ASA classification of physical status is
 - A Designed to facilitate tabulation of statistical data in anaesthesia.
 - B A good correlate of perioperative mortality.
 - C A good correlate of perioperative cardiac complications.
 - A Not a very specific predictor of perioperative cardiac complications.
 - E All of the above.

SELECT THE BEST COMBINATION OF ANSWERS

- A When 1, 2 and 3 are true
- B When 1 and 3 are true
- C When 2 and 4 are true
- D When 4 only is true
- E When all are true

- 5 It can be said about receiver operating characteristic (ROC) curves that:
- 1 They are constructed by plotting the true positive rate (sensitivity) against the false positive rate of a test.
 - 2 They can help to determine which value of a diagnostic test is the best cutoff point differentiating between presence or absence of disease.
 - 3 They can be used to compare the accuracy of different diagnostic tests for the same disease.
 - 4 An area under the ROC curve of 0.5 or less indicates a high predictive value.
- 6 In his modified cardiac risk index, Detsky used likelihood ratio. This ratio is:
- 1 The true positive rate over the false positive rate.
 - 2 Dependent on the prevalence of perioperative cardiac complications in the surgical population.
 - 3 Useful when the prevalence of complications in the surgical population is known.
 - 4 Dependent on the negative predictive value of a diagnostic test.
- 7 Specificity is also known as:
- 1 Negative predictive value.
 - 2 True negative rate.
 - 3 False positive rate.
 - 4 Negativity in health.
- 8 The Goldman multifactorial cardiac risk index was designed to predict the following perioperative complications:
- 1 Cardiac death.
 - 2 Pulmonary oedema.
 - 3 Myocardial infarction.
 - 4 Ventricular tachycardia.

ANSWERS:

1	B	3	A	5	A	7	C
2	D	4	E	6	B	8	E