

## Review

# Clinical review: How is risk defined in high-risk surgical patient management?

Owen Boyd and Neil Jackson

The General Intensive Care Unit, The Royal Sussex County Hospital, Brighton, UK

Corresponding author: Owen Boyd, [owen.boyd@bsuh.nhs.uk](mailto:owen.boyd@bsuh.nhs.uk)

Published online: 9 February 2005  
This article is online at <http://ccforum.com/content/9/4/390>  
© 2005 BioMed Central Ltd

*Critical Care* 2005, **9**:390-396 (DOI 10.1186/cc3057)

## Abstract

The definition of risk in surgical patients is a complex and controversial area. Generally risk is poorly understood and depends on past individual and professional perception, and societal norms. In medical use the situation is further complicated by practical considerations of the ease with which risk can be measured; and this seems to have driven much risk assessment work, with a focus on objective measurements of cardiac function. The usefulness of risk assessment and the definition of risk is however in doubt because there are very few studies that have materially altered patient outcome based on information gained by risk assessment. This paper discusses these issues, highlights areas where more research could usefully be performed, and by defining limits for high surgical risk, suggests a practical approach to the assessment of risk using risk assessment tools.

## Introduction

What is a high-risk patient? What do we mean by risk? Why do we want to assess risk? How do we want to use this analysis? As intensivists we use risk assessment to identify a highly selected group of patients who are at such high risk of morbidity and mortality that they might benefit from high-dependency unit or intensive care unit (ICU) care perioperatively, and we seek to identify those patients who might benefit from haemodynamic manipulation to improve these outcomes. The intensivist's perception of risk and aims of risk assessment may well differ from that of the patient, carers and other doctors, leading to communication difficulties. The present paper explores risk, the need for risk assessment, perception of risk, and various methods for assessing risk. We also explore some of the problems and misconceptions about risk assessment.

## The perception of risk

As a society we do not think rationally about risk. Our ability to risk assess is poor and we seem to be driven by fear and hope as much as by rational evidence. The terms applied to

risk are also confusing; it is unlikely that many decision-makers can differentiate the information available from 'relative risk', 'absolute risk' and 'number needed to treat' (see Table 1). There is also little to suggest that the knowledge of risk influences public response – recent examples include the scare over 'mad cow disease' and the MMR vaccine [1] – and there is little research available as to how knowledge of patient risk modifies our behaviour as doctors. Furthermore, there is little evidence of any reduction in morbidity or mortality following the institution offering a risk assessment protocol in the clinical setting [2]. The poor uptake of risk identification strategies and optimisation protocols may be as much to do with our blunted cultural perception of risk as with resource limitations. The patient, their family, the surgeon, the anaesthetist, the intensivist and the hospital administrator are all likely to perceive risk in entirely different ways while labouring under the misapprehension of a common dialogue.

In the context of patient treatment when discussing risk the perspective of the individuals involved will not only receive the risks differently, but will also prioritise and compare the risks in a different way (Table 2). Furthermore, there is confusion between risks when used as a screening tool: it is, for example, probable that most individuals with a poor outcome will not manifest the risk factor, and conversely some individuals with a good outcome will have the risk [3]. The discussion of risk can therefore be fraught with difficulty and in many cases is open to misinterpretation and profound misunderstandings.

## Why is risk assessed?

The reason for risk assessment depends on who is making the assessment. Risk assessment is performed both for the individual patient and for a patient cohort. A doctor may assess the individual patient's risk in order to better inform

**Table 1****Different ways to describe 'risk'**

| Placebo arm ( <i>n</i> = 1000) | Treatment arm ( <i>n</i> = 1000) | Relative risk reduction | Absolute risk reduction | Number needed to treat |
|--------------------------------|----------------------------------|-------------------------|-------------------------|------------------------|
| 200                            | 100                              | 50                      | 10                      | 10                     |
| 20                             | 10                               | 50                      | 1                       | 100                    |
| 2                              | 1                                | 50                      | 0.1                     | 1000                   |

In this example, a treatment trial involving 2000 patients, 'relative risk reduction' remains the same while 'absolute risk reduction' and 'number needed to treat' show differences in the appreciation of risk as the success of the treatment is modelled to change.

**Table 2****Important milestones in the perception of high risk**

|               |  |
|---------------|--|
| Patient       | Ability to return to work<br>Possibility of disability<br>Success of operation             |
| Family        | Will patient be able to resume role as carer?<br>Will patient survive?                     |
| Nurse         | Infection transmission<br>Violence towards self  |
| Surgeon       | Likelihood of operative success<br>Possibility of operative misadventure                   |
| Anaesthetist  | Likelihood of surviving 30 days<br>Likelihood of surviving the anaesthetic                 |
| Intensivist   | Likelihood of leaving the intensive care unit<br>Prolonged stay on the intensive care unit |
| Administrator | Outcome poorer than comparative unit<br>Care costing more than allocated                   |

the patient and to allow consensual decisions for procedures to be undertaken. Risk assessment might allow consideration of a change in plan to reduce that individual's risk; for example, a more limited operation, modification of the planned anaesthetic technique or perioperative haemodynamic optimisation. In a more complex format, risk is assessed to allow suitable targeting of therapeutic options and decision-making with regard to treatment choices so that a suitable balance of risks, often between the possible side effects and dangers of surgery and the potential success of treatment, can be made. Implicit in risk assessment for the individual is the intention of subsequent action to achieve risk reduction, but as already noted this is often not achievable.

At an institutional level the assessment of risk for a group of patients can be used to target resources, both financially and in terms of personnel and facilities. In this context, risk assessment is no longer targeted towards the individual patient. Similarly, risk assessment can be used as part of a

standardisation tool to allow comparison of outcomes between different surgeons or hospitals who are undertaking similar procedures. Risk assessment tools need to be able to account for differences in populations such that one hospital's cohort of patients might be more frail at the outset.

**What is a high-risk surgical patient?**

In the context of critical care 'high risk' is used to denote the global risk of mortality or morbidity, particularly with regard to organ failure, compared with other groups at lower risk. As regards surgical patients, information provided by the National Confidential Enquiry into Peri-Operative Deaths helps to address the issue of where a baseline for risk might lie [4]. There are between 2.8 million and 3.3 million operations per year in England, Wales and Northern Ireland. The risk of death within 30 days of any operation has been estimated as between 0.7% and 1.7%. The National Confidential Enquiry into Peri-Operative Deaths also provides information that we are not good at estimating surgical risk; surgeons perceived that was increased risk in only 66% of the patients that actually died, which equally means that an increased risk was not identified in 44% of these patients.

From a practical point of view 'high risk' can probably be defined in two different ways: the first is relevant to an individual and suggests that the risk to an individual is higher than for a population; the second compares the risk of the procedure in question with the risk of surgical procedures as a whole. In the first scenario it would be tempting to state that risk is 'high' if the risk for an individual falls above two standard deviations of the risk for the entire population undergoing that type of surgery. This could be described as a statistical approach but we suggest that this is only rarely applicable due to lack of knowledge of baseline risk and also to general misunderstandings of this type of statistical analysis. We suggest that a far more understandable description of high risk would be if the individual's risk of mortality is either >5% or twice the risk of the population undergoing that procedure. The second description also addresses the second scenario, and we suggest that a high-risk procedure is one with mortality greater than 5%.

Furthermore, we would suggest that surgical patients for whom the probable mortality is greater than 20% should be

**Table 3**

| <b>Control group mortality in four well-known studies that have investigated 'high-risk' surgical patients</b> |               |
|--|---------------|
| Study  | Mortality (%) |
| Shoemaker and colleagues [6]   | 33            |
| Boyd and colleagues [57]   | 22.2          |
| Wilson and colleagues [58]   | 17            |
| Sandham and colleagues [59]  | 7.7           |

considered 'extremely high-risk' patients. Studies show that mortality for this cohort can be improved by haemodynamic optimisation and their care should ideally be discussed with ICU preoperatively. We understand that, at least in the United Kingdom, there are limited ICU resources available for this but we should recognise that there is evidence that pre-emptive strategies could reduce the mortality for this group. There is conflicting evidence that intraoperative haemodynamic optimisation may modify the outcome for surgical patients with a predicted mortality less than 20%. An improved outcome for this cohort may be seen in reduced hospital bed-days rather than a reduction in mortality, but due to the number of surgical patients even modest reductions in length of stay would have huge resource benefits.

We have made some suggestions of general limits for defining 'high risk'. We fully understand, however, that how 'high risk' is actually defined is influenced by all the personal perceptions and expectations already mentioned, as well as the more pragmatic possibilities of influencing change and costs. It is also interesting to compare the presented definitions with the various studies of 'high risk' surgical patients where different levels of risk have been thought to be appropriate (Table 3).

### Risk assessment in surgical patients

There are a number of tests that can be used to preoperatively stratify risk in surgical patients. These can be divided into general tests and scores, and those specific for myocardial problems; specifically, postoperative myocardial infarction and sudden cardiac death. There are various risk assessment scores that aim to identify other morbidity-specific outcomes, such as respiratory failure, wound infection or sepsis, but we have limited ourselves to mortality and cardiac outcomes as these constitute the best known scores and tend to be applicable to wider groups of operative procedures.

### General preoperative risk stratification

There are a number of methods by which risk can be assessed preoperatively. These can be related to the type of surgery and the known risks and outcomes of the planned procedures, or they can be related to factors within the patient themselves. Risk factors related to the surgery include

**Table 4**

### Clinical criteria for high-risk surgical patients used by Shoemaker and colleagues [6] and adapted by Boyd and colleagues [7]

|   |
|---|
| Previous severe cardiorespiratory illness – acute myocardial infarction, chronic obstructive pulmonary disease, or stroke |
| Late-stage vascular disease involving aorta   |
| Age > 70 years with limited physiological reserve in one or more vital organs   |
| Extensive surgery for carcinoma (e.g. oesophagectomy, gastrectomy, cystectomy)  |
| Acute abdominal catastrophe with haemodynamic instability (e.g. peritonitis, perforated viscus, pancreatitis)             |
| Acute massive blood loss >8 units   |
| Septicaemia   |
| Positive blood culture or septic focus  |
| Respiratory failure: $\text{PaO}_2 < 8.0 \text{ kPa}$ on $\text{FIO}_2 > 0.4$ or mechanical ventilation >48 hours         |
| Acute renal failure: urea > 20 mmol/l or creatinine > 260 mmol/l  |

the surgical procedure and whether that procedure is undertaken in an elective fashion or as an emergency. A number of databases have demonstrated the higher risk associated with emergency procedures. Risk factors related to the patient can be relatively simple to isolate, such as the patient's age, or can take into account various methods for assessing comorbidity or physiological reserve. The simplest and most widely used method for assessing the comorbidity is the American Society of Anesthesiologists (ASA) grading on a scale of I to IV; this combined with the type of urgency of surgery has been shown to be related to postoperative mortality [5]. Other pragmatic assessments of preoperative comorbidity have been employed by various investigators attempting to identify patients at higher risk of morbidity and mortality following surgery. One method, originally described by Shoemaker and colleagues [6] and adapted by Boyd and colleagues [7], identifies patients by the pre-selected list of criteria presented in Table 4. While these types of preoperative assessment clearly identify patients at much higher risk than those in the general population of patients undergoing surgery, they are open to some subjective interpretation that makes them less robust to use if they are carried outside the original institution.

The ASA classification of physical status was originally introduced in 1941 as a tool for statistical analysis [8]. It was modified in 1963 when the number of grades was reduced from seven to five [9]. More recently an additional suffix 'E' for emergency operation has been added. A high ASA score is predictive of both increased postoperative complications and mortality after non-cardiac surgery. The ASA classification has relatively robustly stood the test of time, probably

**Table 5****American Society of Anaesthesiologists' status classification: modified from Wolters and colleagues [10]**

| Class | Description   | Mortality (%) |
|-------|---|---------------|
| I     | Healthy   | 0.1           |
| II    | Mild systemic disease – no functional limitation                        | 0.7           |
| III   | Severe systemic disease – definite functional limitation                | 3.5           |
| IV    | Severe systemic disease – constant threat to life                       | 18.3          |
| V     | Moribund patient unlikely to survive 24 hours with or without operation | 93.3          |
| E     | Emergency operation   |               |

because it is simple to calculate without requiring additional resources. It may be surprising that it is predictive, as ASA scoring does not take into account age, weight or the nature of the intended operation. Studies show that there may be significant interoperator variability in ASA scoring. Other more complex scoring systems have greater prognostic accuracy but ASA scoring remains useful [10]. It has began to be used outside operating theatres, such as in helping to assess patients fitness for endoscopy, and it is a useful tool to help non-anaesthetists to consider potential procedural-related risks (see Table 5).

A slightly different approach has been taken by Older and colleagues, who have performed preoperative cardiopulmonary testing to define an anaerobic threshold in patients in the preoperative period [11,12]. In an initial study of 187 patients, there were 55 patients in whom the anaerobic threshold was <11 ml/min/kg; of these, 10 patients died (a mortality rate of 18%). There were 132 patients with an anaerobic threshold >11 ml/min/kg, and of these one patient died (mortality rate of 0.8%). If a low anaerobic threshold was associated with preoperative ischaemia on the electrocardiogram the results were much worse, with eight of 19 patients dying (giving a mortality rate of 42%). When the ischaemia was associated with the higher anaerobic threshold, one patient out of 25 died (a mortality rate of 4%) [11]. This work has been taken further, by describing different treatment paths for the high and low anaerobic threshold groups, and although this is not a randomised trial the results appear to show that greater degrees of intervention in the low anaerobic threshold group reduce mortality [12].

Many of these methods used for assessing risk in the preoperative period are labour intensive and require expensive and specialised equipment; this is particularly so for the assessment of anaerobic threshold. While these efforts may be good at assessing risk, there is a paucity of clinical studies showing how this has changed the management of either individual patients or groups of patients. We hope that soon data will appear showing how preoperative risk assessments have changed individual

patient management; for example, how surgical anaesthetic perioperative practice has changed for an individual patient. While this would be a good start and would allow decision-makers to place the techniques for assessing preoperative risk in a decision-making context, we still really require studies to show how preoperative assessments have changed outcomes as part of a clinical trial. The only literature with which we are familiar in this context comes from the work concerning goal-directed therapy, which shows that when risk is assessed based on very simple preoperative scores, and when treatment is targeted to various goals of cardiorespiratory function, both mortality and morbidity are reduced [13].

**Preoperative risk stratification for myocardial events**

Two cardiac risk indices are well known. The first is the Goldman Index [14], which represents a practical and inexpensive method for identifying cardiac risk [15], but over time may need to be modified to represent the true mortality rate [16]. A second score was developed by Detsky and colleagues [17], and both this score and the Goldman Index are good predictors of perioperative cardiac events with odds ratios of 0.642 (95% confidence interval, 0.588–0.695) for the Goldman index and of 0.601 (95% confidence interval, 0.544–0.657) for the modified Detsky index [18]. Other factors such as comorbidity and intraoperative factors influence outcome, however, and no preoperative system will be completely accurate [19,20].

There are many methods to investigate cardiac function and coronary artery perfusion, and it is hardly surprising that many have been investigated for their ability to stratify risk in surgical patients undergoing non-cardiac surgery [21,22]. It is disappointing that while many of these can clearly identify different risks, there is very little information that outcome is improved by knowing the risk [23–25].

A recent study has confirmed that exercise stress testing can be a useful method of risk stratification. Gauss and colleagues shown that an ST-segment depression of 0.1 mV or more in the exercise electrocardiogram had an odds ratio

of 5.2 (95% confidence interval, 1.5–18.5;  $P=0.01$ ) of predicting a myocardial infarction or postoperative myocardial cell injury in non-cardiac surgery patients [26]. A combination of clinical variables and exercise electrocardiography improved preoperative risk stratification.

Other studies have used echocardiography [27] and stress echocardiography to risk-stratify surgical patients. But adding echocardiographic information to established predictive models may not alter the sensitivity, specificity or predictive values in a clinically important way [28]. Dobutamine stress echocardiography resulting in hypotension [29], ischaemia [30] or wall motion abnormalities [31,32] can have predictive value for postoperative cardiac events [33–37]. Dipyridamole echocardiography has also been used with good predictive results [38,39]. Furthermore, echocardiography without pharmacological stress can also be a useful screening test [40], and can be used during surgery and can give useful information on cardiac status [41,42].

As has already been discussed there is a paucity of clinical information describing how any of these preoperative risk assessments has either influenced the management of individual patients or of patient groups in the context of a clinical study. One notable exception is a study by Poldermans and colleagues [43]. Patients undergoing major vascular surgery were identified as being of particularly high risk by dobutamine echocardiography and were then randomised to receive perioperative care or standard care plus perioperative  $\beta$ -blockade with bisoprolol. A total of 1351 patients were screened and 112 patients suitable for randomisation were identified. Study results showed that mortality from cardiac causes was significantly reduced in the bisoprolol group [43]. The lack of further clinical data, however, has not prevented professional and learned groups from producing written guidelines for patient management. The American College of Cardiology published guidelines in 1996 on the preoperative assessment of patients having non-cardiac surgery and gave specific indications for the use of blockade in these patients [44]. Although the most recently published version of these guidelines is less didactic [45], they still show how consensus opinion can influence clinical management even though the evidence base is so poor.

#### Postoperative risk stratification

In the global context of critical care medicine there is a number of scoring systems in general use. Many of these systems are used for severity of illness scoring so that standardised comparisons can be made between patient groups and between ICUs; however, to some extent they can be used to assess risk for patient groups if not for individual patients. Severity of illness scoring systems such as Sepsis-related Organ Failure Assessment and Therapeutic intervention scoring system are widely known, but perhaps the most widely used scoring system is the Acute Physiology

and Chronic Health Evaluation (APACHE) scoring system [46]. The APACHE system includes chronic health data concerning the individual patient and physiological data collected during the patients first 24 hours of intensive care treatment. The APACHE system, in common with other general scoring systems, can only be used after an operation, and therefore any risk assessment ability within these scores can only be applied post hoc to groups of patients. In the APACHE system, risk comparisons are frequently undertaken by comparing standardised mortality ratios, and there is some doubt about the standardised mortality ratio to robustly allow comparisons to be made [47].

The scoring system that has been specifically designed for surgical patients is the Physiological and Operative Severity Score for the enUmeration of Mortality and morbidity (POSSUM) score [48]. This is generally accepted to be a good scoring system for routine use [49], and is better than the APACHE system for a general surgical group of patients [50]. But in specific situations such as ruptured abdominal aortic aneurysms POSSUM scoring is not a good predictor of outcome and APACHE scoring is better [51]. POSSUM scoring was also inaccurate in laparoscopic colectomy [52]. Variations of POSSUM scoring have been suggested that may work better in gastrointestinal surgery [53], specifically in oesophageal surgery [54] and vascular surgery [55]. Furthermore, in one study POSSUM scoring has been used as part of a risk stratification analysis to identify patients who might benefit from postsurgical high-dependency care or ICU care [56].

#### Conclusion

Risk is a term that is understood differently by different individuals depending on expectation and previous experience. There are methods that can be used to assess risk in various patient groups, but these provide population risks and are not directly applicable to individual patients. Frequently the cut off between those patients assessed as being at high risk and those at lower risk depends on the cost and complexity of providing treatment to correct the risk, rather than on the risk itself. It remains extremely disappointing that there is little evidence that any change in patient outcome has been driven by the pre-existing knowledge of risk for that patient. In the future, risk assessment in medical practice, particularly in intensive care medicine where risks of the ultimate negative outcome are so high, will only be advanced by the following: an inclusive debate involving patients, medical staff and other religious, ethical and cultural groups to understand the nature of medical risk and to form priorities in its assessment and management; the development of more accurate methods to assess and predict risk prior to the onset of an index event, which can be directed towards identifying risk for the individual; and the conduct of clinical trials to show that prior knowledge of individual risk can allow treatment and management decisions to be adapted to treat different

patients in different ways with a benefit in patient outcome, however that is to be defined.

In our opinion the two most useful scoring systems in surgical risk assessment remain the ASA score and the clinical criteria as used by Shoemaker/Boyd and colleagues. Both of these assessments are simple to use and do not require additional resources. The purpose of an effective scoring system is to highlight potential high-risk patients for busy hospital practitioners and to act as a focus for generating a multidisciplinary risk/benefit discussion between interested parties.

## Competing interests

The author(s) declare that they have no competing interests.

## References

- Alaszewski A, Horlick-Jones T: How can doctors communicate information about risk more effectively? *Br Med J* 2003, **327**: 728-731.
- Galland RB: Severity scores in surgery: what for and who needs them? *Langenbecks Arch Surg* 2002, **387**:59-62.
- Wald NJ, Hackshaw AK, Frost CD: When can a risk factor be used as a worthwhile screening test? *Br Med J* 1999, **319**: 1562-1565.
- Camping EA, Devlin HB, Hoile RW, Lunn JN: *The Report of the National Confidential Enquiry into Perioperative Deaths 1991/1992*. London: The National Confidential Enquiry into Perioperative Deaths; 1993.
- Mella J, Biffin A, Radcliffe AG, Stamatakis JD, Steele RJ: Population-based audit of colorectal cancer management in two UK health regions. Colorectal Cancer Working Group, Royal College of Surgeons of England Clinical Epidemiology and Audit Unit. *Br J Surg* 1997, **84**:1731-1736.
- Shoemaker WC, Appel PL, Kram HB, Waxman K, Lee T-S: Prospective trial of supranormal values of survivors as therapeutic goals in high-risk surgical patients. *Chest* 1988, **94**: 1176-1186.
- Boyd O, Grounds RM, Bennett ED: A randomized clinical trial of the effect of deliberate perioperative increase of oxygen delivery on mortality in high-risk surgical patients. *JAMA* 1993, **270**:2699-2707.
- Saklad M: Grading of patients for surgical procedures. *Anesthesiology* 1941, **2**:281-284.
- American Society of Anesthesiologists: New classification of physical status. *Anesthesiology* 1963, **24**:111-115.
- Wolters U, Wolf T, Stutzer H, Schroder T: ASA classification and perioperative variables as predictors of postoperative outcome. *Br J Anaesth* 1996, **77**:217-222.
- Older P, Smith R, Courtney P, Hone R: Preoperative evaluation of cardiac failure and ischemia in elderly patients by cardio-pulmonary exercise testing. *Chest* 1993, **104**:701-704.
- Older P, Hall A, Hader R: Cardiopulmonary exercise testing as a screening test for perioperative management of major surgery in the elderly. *Chest* 1999, **116**:355-362.
- Boyd O, Hayes M: The oxygen trail - the goal. *Br Med Bull* 1999, **55**:125-139.
- Goldman L, Caldera DL, Nussbaum SR, Southwick FS, Krogstad D, Murray B, Burke DS, O'Malley TA, Goroll HA, Caplan CH, et al.: Multifactorial index of risk in noncardiac surgical procedures. *N Engl J Med* 1977, **297**:845-850.
- Halabe-Cherem J, Malagon J, Wacher-Rodarte N, Nellen-Hummel H, Talavera-Pina J: Usefulness of the ASA scale and thoracic radiography as indicators of perioperative cardiovascular risk. *Gac Med Mex* 1998, **134**:27-32.
- Jeffrey CC, Kunsman J, Cullen DJ, Brewster DC: A prospective evaluation of cardiac risk index. *Anesthesiology* 1983, **58**: 462-464.
- Detsky AS, Abrams HB, Forbath N, Scott JG, Hilliard JR: Cardiac assessment for patients undergoing noncardiac surgery. A multifactorial clinical risk index. *Arch Intern Med* 1986, **146**: 2131-2134.
- Gilbert K, Larocque BJ, Patrick LT: Prospective evaluation of cardiac risk indices for patients undergoing noncardiac surgery. *Ann Intern Med* 2000, **133**:356-359.
- Brady AR, Fowkes FG, Greenhalgh RM, Powell JT, Ruckley CV, Thompson SG: Risk factors for postoperative death following elective surgical repair of abdominal aortic aneurysm: results from the UK Small Aneurysm Trial. On behalf of the UK Small Aneurysm Trial participants. *Br J Surg* 2000, **87**:742-749.
- Becquemin JP, Chemla E, Chatellier G, Allaire E, Melliere D, Desgranges P: Perioperative factors influencing the outcome of elective abdominal aorta aneurysm repair. *Eur J Vasc Endovasc Surg* 2000, **20**:84-89.
- Romero L, de Virgilio C: Preoperative cardiac risk assessment: an updated approach. *Arch Surg* 2001, **136**:1370-1376.
- Grayburn PA, Hillis LD: Cardiac events in patients undergoing noncardiac surgery: shifting the paradigm from noninvasive risk stratification to therapy. *Ann Intern Med* 2003, **138**:506-511.
- Palda VA, Detsky AS: Perioperative assessment and management of risk from coronary artery disease. *Ann Intern Med* 1997, **127**:313-328.
- Froehlich JB: Clinical determinants in perioperative cardiac evaluation. *Prog Cardiovasc Dis* 1998, **40**:373-381.
- Bui H, Lee JT, Greenway S, Donayre C, de Virgilio C: Validation of an updated approach to preoperative cardiac risk assessment in vascular surgery. *Am Surg* 2003, **69**:923-926.
- Gauss A, Rohm HJ, Schaufelen A, Vogel T, Mohl U, Straehle A, Meierhenrich R, Georgieff M, Steinbach G, Schutz W: Electrocardiographic exercise stress testing for cardiac risk assessment in patients undergoing noncardiac surgery. *Anesthesiology* 2001, **94**:38-46.
- Rohde LE, Polanczyk CA, Goldman L, Cook EF, Lee RT, Lee TH: Usefulness of transthoracic echocardiography as a tool for risk stratification of patients undergoing major noncardiac surgery. *Am J Cardiol* 2001, **87**:505-509.
- Halm EA, Browner WS, Tubau JF, Tateo IM, Mangano DT: Echocardiography for assessing cardiac risk in patients having noncardiac surgery. Study of Perioperative Ischemia Research Group. *Ann Intern Med* 1996, **125**:433-441.
- Day SM, Younger JG, Karavite D, Bach DS, Armstrong WF, Eagle KA: Usefulness of hypotension during dobutamine echocardiography in predicting perioperative cardiac events. *Am J Cardiol* 2000, **85**:478-483.
- Das MK, Pelikka PA, Mahoney DW, Roger VL, Oh JK, McCully RB, Seward JB: Assessment of cardiac risk before nonvascular surgery: dobutamine stress echocardiography in 530 patients. *J Am Coll Cardiol* 2000, **35**:1647-1653.
- Krivokapich J, Child JS, Walter DO, Garfinkel A: Prognostic value of dobutamine stress echocardiography in predicting cardiac events in patients with known or suspected coronary artery disease. *J Am Coll Cardiol* 1999, **33**:708-716.
- Bach DS, Eagle KA: Dobutamine stress echocardiography. Stressing the indications for preoperative testing [editorial; comment]. *Circulation* 1997, **95**:8-10.
- Marcozzi PA: Prognostic issues in stress echocardiography. *Prog Cardiovasc Dis* 1997, **39**:533-542.
- Van Damme H, Pierard L, Gillain D, Benoit T, Rigo P, Limet R: Cardiac risk assessment before vascular surgery: a prospective study comparing clinical evaluation, dobutamine stress echocardiography, and dobutamine Tc-99m sestamibi tomosintigraphy. *Cardiovasc Surg* 1997, **5**:54-64.
- Ryckwaert F, Leclercq F, Colson P: Dobutamine echocardiography for the preoperative evaluation of patients for surgery of the abdominal aorta. *Ann Fr Anesth Reanim* 1998, **17**:13-18.
- Motreff P, Pierre-Justin E, Dauphin C, Lusson JR, Lamaison D, Marcollet P, Ribal JP, Cassagnes J: Evaluation of cardiac risk before vascular surgery by dobutamine stress echocardiography. *Arch Mal Coeur Vaiss* 1997, **90**:1209-1214.
- Poldermans D, Arnese M, Fioretti PM, Boersma E, Thomson IR, Rambaldi R, van Urk H: Sustained prognostic value of dobutamine stress echocardiography for late cardiac events after major noncardiac vascular surgery [see comments]. *Circulation* 1997, **95**:53-58.
- Tischler MD, Lee TH, Hirsch AT, Lord CP, Goldman L, Creager MA, Lee RT: Prediction of major cardiac events after peripheral vascular surgery using dipyridamole echocardiography. *Am J Cardiol* 1991, **68**:593-597.

39. Pasquet A, D'Hondt AM, Verhelst R, Vanoverschelde JL, Melin J, Marwick TH: Comparison of dipyridamole stress echocardiography and perfusion scintigraphy for cardiac risk stratification in vascular surgery patients. *Am J Cardiol* 1998, **82**:1468-1474.
40. Henein MY, Anagnostopoulos C, Das SK, O'Sullivan C, Underwood SR, Gibson DG: Left ventricular long axis disturbances as predictors for thallium perfusion defects in patients with known peripheral vascular disease. *Heart* 1998, **79**:295-300.
41. Suriani RJ, Neustein S, Shore-Lesserson L, Konstadt S: Intraoperative transesophageal echocardiography during noncardiac surgery. *J Cardiothorac Vasc Anesth* 1998, **12**:274-280.
42. Nomura M, Hillel Z, Shih H, Kuroda MM, Thys DM: The association between Doppler transmitral flow variables measured by transesophageal echocardiography and pulmonary capillary wedge pressure. *Anesth Analg* 1997, **84**:491-496.
43. Poldermans D, Boersma E, Bax JJ, Thomson IR, van de Ven LL, Blankensteijn JD, Baars HF, Yo TI, Trocino G, Vigna C, et al.: The effect of bisoprolol on perioperative mortality and myocardial infarction in high-risk patients undergoing vascular surgery. Dutch Echocardiographic Cardiac Risk Evaluation Applying Stress Echocardiography Study Group. *N Engl J Med* 1999, **341**:1789-1794.
44. Eagle KA, Brundage BH, Chaitman BR, Ewy GA, Fleisher LA, Hertzer NR, Leppo JA, Ryan T, Schlant RC, Spencer WH 3rd, et al.: Guidelines for perioperative cardiovascular evaluation for noncardiac surgery. Report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. Committee on Perioperative Cardiovascular Evaluation for Noncardiac Surgery [see comments]. *Circulation* 1996, **93**:1278-1317.
45. Eagle KA, Berger PB, Calkins H, Chaitman BR, Ewy GA, Fleischmann KE, Fleisher LA, Froehlich JB, Gusberg RJ, Leppo JA, et al.: ACC/AHA guideline update for perioperative cardiovascular evaluation for noncardiac surgery — executive summary a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee to Update the 1996 Guidelines on Perioperative Cardiovascular Evaluation for Noncardiac Surgery). *Circulation* 2002, **105**:1257-1267.
46. Knaus WA, Wagner DP, Draper EA, Zimmerman JF, Bergner M, Bastos PG, Sirio CA, Murphy DJ, Lotring T, Damiano A, et al.: The APACHE III prognostic system: risk prediction of hospital mortality for critically ill hospitalized adults. *Chest* 1991, **100**:1619-1636.
47. Marsh HM, Krishan I, Naessens JM, Strickland RA, Gracey DR, Campion ME, Nobrega FT, Southorn PA, McMichan JC, Kelly MP: Assessment of prediction of mortality by using the APACHE III scoring system in intensive-care units. *Mayo Clin Proc* 1990, **65**:1549-1557.
48. Copeland GP, Jones D, Walters M: POSSUM: a scoring system for surgical audit. *Br J Surg* 1991, **78**:355-360.
49. Jones HJ, de Cossart L: Risk scoring in surgical patients. *Br J Surg* 1999, **86**:149-157.
50. Jones DR, Copeland GP, de Cossart L: Comparison of POSSUM with APACHE II for prediction of outcome from a surgical high-dependency unit. *Br J Surg* 1992, **79**:1293-1296.
51. Lazarides MK, Arvanitis DP, Drista H, Staramos DN, Dayantas JN: POSSUM and APACHE II scores do not predict the outcome of ruptured infrarenal aortic aneurysms. *Ann Vasc Surg* 1997, **11**:155-158.
52. Senagore AJ, Delaney CP, Duepree HJ, Brady KM, Fazio VW: Evaluation of POSSUM and P-POSSUM scoring systems in assessing outcome after laparoscopic colectomy. *Br J Surg* 2003, **90**:1280-1284.
53. Tekkis PP, Kocher HM, Bentley AJ, Cullen PT, South LM, Trotter GA, Ellul JP: Operative mortality rates among surgeons: comparison of POSSUM and p-POSSUM scoring systems in gastrointestinal surgery. *Dis Colon Rectum* 2000, **43**:1528-1532, discussion 1532-1534.
54. Tekkis PP, McCulloch P, Poloniecki JD, Prytherch DR, Kessaris N, Steger AC: Risk-adjusted prediction of operative mortality in oesophagogastric surgery with O-POSSUM. *Br J Surg* 2004, **91**:288-295.
55. Midwinter MJ, Tytherleigh M, Ashley A: Estimation of mortality and morbidity risk in vascular surgery using POSSUM and the Portsmouth predictor equation. *Br J Surg* 1999, **86**:471-474.
56. Curran JE, Grounds RM: Ward versus intensive care management of high-risk surgical patients. *Br J Surg* 1998, **85**:956-961.
57. Boyd O, Grounds RM, Bennett ED: A randomized clinical trial of the effect of deliberate perioperative increase of oxygen delivery on mortality in high-risk surgical patients [see comments]. *JAMA* 1993, **270**:2699-2707.
58. Wilson J, Woods I, Fawcett J, Whall R, Dibb W, Morris C, McManus E: Reducing the risk of major elective surgery: randomised controlled trial of preoperative optimisation of oxygen delivery. *Br Med J* 1999, **318**:1099-1103.
59. Sandham JD, Hull RD, Brant RF, Knox L, Pineo GF, Doig CJ, Laporta DP, Viner S, Passerini L, Devitt H, et al.: A randomized, controlled trial of the use of pulmonary-artery catheters in high-risk surgical patients. *N Engl J Med* 2003, **348**:5-14.