Comparison of risk-scoring systems in predicting hospital mortality after abdominal aortic aneurysm repair

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OBJECTIVE: To compare the Physiological and Operative Severity Score for the enUmeration of Mortality and Morbidity, Portsmouth adjustment (P-POSSUM), the Hardman index and the Glasgow aneurysm score (GAS) in the prediction of hospital mortality after abdominal aortic aneurysm (AAA) repair.

METHODS: Medical charts of 146 AAA patients treated between January 1996 and January 2007 were reviewed. The P-POSSUM, Hardman index and GAS were calculated for each patient. The scores were tested and compared for their discriminatory ability to predict hospital death.

RESULTS: Of the 146 patients with ruptured and unruptured AAAs (133 underwent open repair, five underwent extra-anatomical bypass and eight underwent endovascular aneurysm repair), 18 died (12%) after AAA repair. The areas under the receiver operating characteristic curves for the GAS, Hardman index and P-POSSUM for predicting hospital mortality were 0.740, 0.730 and 0.886, respectively. The area under the receiver operating characteristic curve for the P-POSSUM was significantly higher than those of other scores.

CONCLUSION: In the present study, the P-POSSUM was the best predictor of hospital mortality for patients undergoing AAA repair.

Key Words: EVAR; Glasgow aneurysm score; Hardman index; Operating characteristic curve; P-POSSUM score

The elective repair of abdominal aortic aneurysms (AAAs) is indicated when the largest aneurysm diameter exceeds 5.5 cm (1). Such repairs are also indicated for symptomatic AAA patients with a high risk of rupture but acceptable operative risk. The elective repair of AAA carries a recognized mortality of 2% to 8% (2-4) and a significant complication rate of approximately 10%. The mortality increases to between 8% and 12% in patients with serious comorbidities (5,6).

The mortality rate of ruptured AAAs has been reported to range from 80% to 88% (6,7). The operative mortality rate for ruptured AAAs has been estimated to be approximately 47% (8), but may exceed 50% in some centres (9).

Operative risk indexes and scoring systems are increasingly used to guide clinical decision-making both before surgery and in the intensive care unit after surgery. During the past two decades, several operative risk indexes have been developed, but their widespread use has been hampered by their complexity, lack of validation in large studies and low accuracy (10-12).

There are several candidate scoring systems for estimating the operative risk after AAA repair. The Physiological and Operative Severity Score for the enUmeration of Mortality and Morbidity (POSSUM) (13), with the Portsmouth adjustment (P-POSSUM) (14), is a valid and accurate system for general surgical operations. The Glasgow aneurysm score (GAS) is a simple clinical scoring system for patients undergoing repair of both ruptured (15) and symptomatic but unruptured (16) AAAs. The Hardman index (17) was developed and shown to be a good predictor of immediate postoperative death after open repair for ruptured AAAs.

The aim of the present study was to validate the discriminatory ability of the P-POSSUM, GAS and Hardman index in predicting hospital mortality in a series of AAA patients who underwent both elective and emergency AAA repair, and to compare the scores in terms of their predictive accuracy.

METHODS

From January 1996 to January 2007, 146 AAA patients were treated via open or endovascular repair in both emergency and elective settings at the Department of Surgery, Ramathibodi Hospital, Mahidol University, Thailand. Their medical records were reviewed and the P-POSSUM, GAS and Hardman index were calculated for each patient. The details of the calculations are provided below.

P-POSSUM

The P-POSSUM has two components – a physiological score that involves 12 preoperative physiological variables and an operative score that contains six operative variables (Tables 1 and 2). The following equation is used to convert the raw scores for groups of patients into predicted probabilities of death: $R = (0.1692 \times \text{physiological score}) + (0.1550 \times \text{operative score}) - 9.065$; predicted death rate = $1/(1+e^{-R})$ (13,14).

Hardman index

The Hardman index was originally derived from the data of patients with ruptured AAA (17). Five preoperative risk factors were used to predict outcome after surgery – age older than 76 years, serum creatinine level of more than 190 $\mu\text{mol/L}$,

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TABLE 1
Physiological data set and scores the for the Physiological and Operative Severity Score for the enUmeration of Mortality and Morbidity

	Physiological score			
	1	2	4	8
Age, years	<60	61–70	>71	–
Cardiac signs	Normal	Cardiac drugs or steroids	Edema, warfarin, borderline cardiomegaly*	Raised JVP, cardiomegaly*
Respiratory signs	Normal	Shortness of breath on exertion, mild COPD	Short of breath on stairs, moderate COPD	Short of breath at rest, any other
Systolic blood pressure, mmHg	110–129	130–170 or 100–109	>170 or 90–99	<90
Pulse rate, beats/min	50–80	81–100 or 40–49	101–120	>120 or <40
Glasgow coma score	15	12–14	9–11	<9
Serum urea, mmol/L	<7.5	7.5–10	10.1–15.0	>15.0
Serum sodium, mmol/L	>136	131–135	126–130	>126
Serum potassium, mmol/L	3.5–5.0	3.1–3.4 or 5.1–5.3	2.9–3.1 or 5.4–5.9	<2.9 or >5.9
Hemoglobin, g/L	130–160	115–129 or 161–170	100–114 or 171–180	<100 or >180
White blood cell count, $\times 10^9/L$	4.0–10.0	10.1–20.0 or 3.1–3.9	>20.0 or <3.1	–
Electrocardiogram	Normal	–	Atrial fibrillation (60–90 min)	Any other

*On chest radiography. COPD Chronic obstructive pulmonary disease; JVP Jugular venous pressure. Data from references 16 and 17

TABLE 2
Operative severity data set and scores for the Physiological and Operative Severity Score for the enUmeration of Mortality and Morbidity

	Operative score			
	1	2	4	8
Operative category	Minor	Intermediate	Major	Major +
Procedures, n	1	2	>2	
Total blood loss, mL	≤100	101–500	501–999	≥1000
Peritoneal soiling	None	Serous blood (<250 mL)	Local pus	Any other
Malignancy	None	Primary only	Nodal metastases	Distant metastases
Timing operation	Elective		Urgent, within 2 h; resuscitation possible	Emergency, immediate; no resuscitation possible

hemoglobin level less than 90 g/L, the presence of cardiac ischemia on electrocardiography and a history of loss of consciousness. The scores range between 0 (no positive risk factor) and 5 (five positive risk factors).

GAS

The GAS was calculated for each patient according to the following formula (13,14): risk score = age in years + 17 for the presence of shock + 7 for the presence of myocardial disease + 10 for cerebrovascular disease + 14 for renal disease. Myocardial disease refers to previously documented myocardial infarction and/or ongoing angina pectoris. Cerebrovascular disease refers to all grades of stroke including transient ischemic attacks. Renal disease refers to a history of chronic and acute renal failure, and/or a serum urea over 20 mmol/L, and/or a serum creatinine level greater than 150 $\mu\text{mol/L}$.

Assessment of scoring system and statistical analysis

The continuous variables were summarized as the mean $\pm$ SD or median (range) as appropriate. The categorical variables were summarized as counts and percentages. For continuous variables, statistical comparisons between two independent groups were performed using the *t* test or Wilcoxon rank-sum test, as appropriate. For categorical variables, the χ^2 test was used. Discriminatory ability of various aneurysm scores and risk

factors in predicting hospital death was measured using the area under the receiver operating characteristic curve. The 95% CI for the area under the curve (AUC) was estimated using the normal approximation. The comparison between the AUCs was performed using a χ^2 test. After fitting a logistic regression model on the hospital death outcome for each score or risk factor, the calibration of the predicted death to the observed hospital death was measured using the Hosmer-Lemeshow goodness-of-fit statistic for 10 covariate groups, whenever possible. Statistical significance was defined as a two-sided $P \leq 0.05$. All statistical analyses were performed using Stata software, version 9 (StataCorp LP, USA).

RESULTS

A total of 146 patients were identified from the medical records; 82% were men and 18% were women. The baseline characteristics are summarized in Table 3. The mean age of the patients was 68.3 years. Fusiform aneurysms were present in 91% of patients and saccular aneurysms in 9%. Ruptured aneurysms were found in 20% and infected aneurysms were found in 5% of patients. The size of the aneurysms ranged between 3.5 cm and 15 cm.

The operative and outcome data are shown in Table 4. The median aortic clamp time was 60 min. The most common configuration of the vascular graft used was the Y-graft (78%).

TABLE 3
Summary of baseline data

Baseline variables, n=146*	Summary, n (%)*
Age, years, mean $\pm$ SD	68.3 $\pm$ 10.2
Sex, male/female	120/26 (82/18)
Body mass index, kg/m ² , mean $\pm$ SD	22.8 $\pm$ 3.5
Ruptured aneurysm, yes	29 (20)
Infected aneurysm, yes	7 (5)
Shape of aneurysm	
Fusiform	133 (91)
Saccular	13 (9)
Transverse diameter, cm, mean $\pm$ SD (range) (n=143)	6.5 $\pm$ 1.8 (3.5–15)
Renal artery involvement, yes	5 (4)
Iliac artery involvement, yes	57 (39)
Presence of medical illnesses, yes	
Cardiovascular/neurovascular/limb ischemia	105 (72)
Renal failure	22 (15)
Chronic obstructive pulmonary disease	41 (28)
Diabetes mellitus	13 (9)
Presence of malignant disease, yes	7 (5)
Shock before operation, yes	10 (7)

*Unless otherwise stated

TABLE 4
Summary of operative and outcome variables

Variables, n=146*	Summary, n (%)*
Operative time, h, mean $\pm$ SD (range)	4.2 $\pm$ 1.5 (2–10)
Total aortic clamp time, min, median (range)	60 (19–210)
Type of 'grafts' used (n=145)	
Tube graft	19 (13)
Y-graft	113 (78)
Extra-anatomical bypass	5 (3)
Endovascular aneurysm repair	8 (6)
Total blood loss, mL, median (range)	1500 (200–10,000)
Hospital death, yes	18 (12)
Postoperative complications, yes	54 (37)
Reoperation, yes	19 (13)
Length of hospital stay, days, median (range)	16 (1–118)

*Unless otherwise stated

Postoperative complications occurred in 37% of patients. The median total blood loss was 1500 mL. The reoperation rate was 13%. The median length of hospital stay was 16 days. The overall hospital mortality was 12%; for patients with unruptured and ruptured aneurysms, the mortality rates were 41% and 5%, respectively.

The aneurysm scores are summarized in Table 5. The overall median P-POSSUM was 9.6 (ie, the median estimated hospital mortality rate was 9.6%). The median P-POSSUM in patients who survived was 7.9 while the score was 43.9 for patients who died in the hospital.

The mean GAS was 76. The mean score of patients who survived was 74.4; the mean score was 81.1 for the patients who died.

Three of 64 patients (5%) with a Hardman index score of 0 died. The Hardman index scores of 1, 2 and 3 were associated with 13%, 11% and 57% mortality, respectively. No patient with a Hardman index score of 4 survived.

TABLE 5
Summary of aneurysm scores and prevalence of ruptured aneurysm

Score or risk factor	Overall summary (n=146)	Died in hospital (n=18)	Survived (n=128)	P*
Glasgow aneurysm score				
Mean $\pm$ SD	76.1 $\pm$ 14.5	88.1 $\pm$ 17.6	74.4 $\pm$ 13.3	<0.001
Range	46–120	53–120	28–111	
Hardman index score, n (%)				
0	64 (44)	3 (17)	61 (48)	0.001
1	55 (38)	7 (39)	48 (38)	
2	18 (12)	2 (11)	16 (13)	
3	7 (5)	4 (22)	3 (2)	
4	2 (1)	2 (11)	0	
P-POSSUM				
Mean $\pm$ SD	19.0 $\pm$ 22.5	52.9 $\pm$ 31.8	14.3 $\pm$ 16.0	
Median	9.60	43.9	7.85	<0.001
Range	1.10–98.1	7.6–98.1	1.10–98.1	
Ruptured aneurysm, yes				
n (%)	29 (20)	12 (67)	17 (13)	<0.001

*P for comparisons between patients who died in the hospital and those who did not. P-POSSUM Physiological and Operative Severity Score for the enUmeration of Mortality and Morbidity, Portsmouth adjustment

TABLE 6
Comparing discriminatory ability and calibration among various aneurysm scores and risk factors for the outcome hospital death: All patients

Score or risk factor	Area under ROC curve* (95% CI)	H-L statistic (10 groups†)	P‡
Glasgow aneurysm score	0.740 (0.608–0.872)	5.25	0.731
Hardman index	0.730 (0.601–0.860)	2.76 (4 groups)	0.252
P-POSSUM	0.886 (0.813–0.958)	8.31	0.404
Ruptured aneurysm, yes	0.767 (0.651–0.883)	NA	NA

*There are significant differences between the estimates of the area under the receiver operating characteristic (ROC) curve, χ^2 P <0.001; †Only four covariate groups could be formed for the Hardman index; ‡P for the Hosmer-Lemeshow (H-L) goodness-of-fit statistic. NA Not applicable; P-POSSUM Physiological and Operative Severity Score for the enUmeration of Mortality and Morbidity, Portsmouth adjustment

Comparisons among each aneurysm score in terms of mortality prediction are shown in Tables 6, 7 and 8. Table 6 reveals that the overall area under the receiver operating characteristic curve for presence of ruptured aneurysm, GAS, Hardman index and P-POSSUM score were 0.767, 0.74, 0.73 and 0.886, respectively. The area under the P-POSSUM curve was significantly higher (0.886) than those of other scores and risk factors (Figure 1).

An identical analysis for the AAA patients who underwent operative repairs only (133 patients) revealed similar results to those presented above (analysis not shown).

In the subgroup of patients without ruptured AAAs, the AUC of the GAS, Hardman index and P-POSSUM were 0.746, 0.574 and 0.812, respectively. In patients who had ruptured AAAs, the AUC of the GAS, Hardman index and P-POSSUM were 0.748, 0.787 and 0.777, respectively (Tables 7 and 8). Apparently, the Hardman index was little better than chance at predicting hospital mortality for patients without ruptured aneurysms. For patients with ruptured aneurysms, the predictive accuracy was similar for all scoring systems.

TABLE 7
Comparing discriminatory ability and calibration among various aneurysm scores and risk factors for the outcome hospital death: Unruptured aneurysms

Score or risk factor	Area under ROC curve* (95% CI)	H-L statistic (10 groups [†])	P [‡]
Glasgow aneurysm score	0.746 (0.627–0.864)	9.39	0.311
Hardman index	0.574 (0.355–0.792)	0.67 (4 groups)	0.714
P-POSSUM	0.812 (0.681–0.943)	15.1	0.057

*There is no significant difference between the estimates of the area under the receiver operating characteristic (ROC) curve, χ^2 $P=0.119$; [†]Only four covariate groups could be formed for the Hardman index; [‡]P for the Hosmer-Lemeshow (H-L) goodness-of-fit statistic. NA Not applicable; P-POSSUM Physiological and Operative Severity Score for the enUmeration of Mortality and Morbidity, Portsmouth adjustment

TABLE 8
Comparing discriminatory ability and calibration among various aneurysm scores and risk factors for the outcome hospital death: Ruptured aneurysms

Score or risk factor	Area under ROC curve* (95% CI)	H-L statistic (10 groups [†])	P [‡]
Glasgow aneurysm score	0.748 (0.550–0.945)	6.90	0.547
Hardman index	0.787 (0.616–0.957)	2.11 (5 groups)	0.55
P-POSSUM	0.777 (0.604–0.950)	6.53	0.589

*There is no significant difference between the estimates of the area under the receiver operating characteristic (ROC) curve; χ^2 $P=0.932$; [†]Only five covariate groups could be formed for the Hardman index; [‡]P for the Hosmer-Lemeshow (H-L) goodness-of-fit statistic. P-POSSUM Physiological and Operative Severity Score for the enUmeration of Mortality and Morbidity, Portsmouth adjustment

DISCUSSION

AAA repair is a major surgical procedure. The outcome depends on many factors, including the patient's condition, disease-related factors and the type of operation. Indeed, some centres have reported an in-hospital postoperative mortality rate after elective operations ranging from 2.8% to 8.2% (1,3,19,20) and the operative mortality rate has been estimated at approximately 47% (8) in ruptured AAAs. Although hospital volume (21) and the surgeon's experience (22) are important factors contributing to the postoperative outcome, the general medical condition of the patient has a major impact on the immediate and late results of elective open repair of an AAA (21-29).

Many predictive scoring systems are derived from a combination of demographic, physiological and therapeutic variables. It is ideal to try to generate the most accurate risk scores from the least number of predictors by excluding variables that do not influence outcome. Such a system may provide the surgeon as well as the patients and their relatives with accurate and objective information about their survival chances (30).

Previous studies found that the GAS was a good predictor of hospital mortality after surgery in patients with ruptured (31) and unruptured AAAs (1). The Hardman index and P-POSSUM have been used to predict outcomes only in patients with ruptured AAAs (32).

The present study found that the P-POSSUM score was a good predictor of hospital mortality after aneurysm repair for patients with ruptured and unruptured AAAs. For the same

Figure 1 Comparing the receiver operating characteristic (ROC) curves for the outcome hospital death, for all patients. GAS Glasgow aneurysm score; HIS Hardman index score; PDR Predicted death rate scores, or Physiological and Operative Severity Score for the enUmeration of Mortality and Morbidity, Portsmouth adjustment; Rupture Ruptured aneurysm

group of patients, the Hardman index score and GAS were no better than the knowledge that the patient has a ruptured AAA in the prediction of hospital death.

Interestingly for the subgroup of patients without ruptured AAAs, the Hardman index was hardly better than chance in predicting hospital mortality. This finding may not be surprising given that the Hardman index was developed for predicting hospital death in patients with ruptured AAAs. It can also be seen that the P-POSSUM, a risk score developed for use in general surgical patients, performed best for patients without ruptured AAAs.

All scoring systems in the present study were able to predict hospital mortality after ruptured AAA repair equally well. The Hardman index score, however, was easiest to calculate. Although an electrocardiogram and laboratory tests are needed for calculating the Hardman index score, these are often routinely available (3).

In patients who are predicted to have a high probability of death following AAA repair, this risk must be compared with a possible higher risk if no repair is attempted. Each patient will have different estimated RRs, and the surgeon must be skilled in estimating these risks so that the patient and his or her relatives can make informed judgments on the need for AAA repair.

The scoring systems will not replace the surgeon's, patient's or relatives' judgment of the need for AAA repair. However, the scores and the corresponding survival estimates allow the patients and their relatives to make decisions based on reasonably accurate, objective and valid information.

CONCLUSION

The P-POSSUM was the best overall predictor of hospital death following AAA repair. For ruptured AAAs, all risk scores including the P-POSSUM, GAS and Hardman index were equally but only moderately successful in predicting hospital mortality. The P-POSSUM, perhaps with some modifications, may be used as an objective and valid estimator of the risk of hospital death following AAA repair.

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