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Intensive Care Society's APACHE II study in Britain and Ireland—II: Outcome comparisons of intensive care units after adjustment for case mix by the American APACHE II method

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Abstract

Objectives—To compare outcome between intensive care units in Britain and Ireland both before and after adjustment for case mix with the American APACHE II method and to validate the American APACHE II method in Britain and Ireland.

Design—Prospective, cohort study of consecutive admissions to intensive care units.

Setting—26 general intensive care units in Britain and Ireland.

Subjects—8796 admissions to the study intensive care units.

Main outcome measure—Death or survival at discharge from intensive care unit and hospital.

Results—At discharge from both intensive care unit and hospital there was a greater than twofold variation in crude mortality between the 26 units. After adjustment for case mix, variations in mortality were still apparent. For four intensive care units the observed numbers of deaths were significantly different from the number predicted by the American APACHE II equation. The overall goodness of fit, or predictive ability, of the APACHE II equation for the British and Irish data was good, being only slightly inferior to that obtained when the equation was tested on the data from which it had been derived. When patients were grouped by various factors such as age and diagnosis, the equation did not adjust across the subgroups in a uniform manner.

Conclusions—The American APACHE II equation did not fit the British and Irish data. Use of the American equation could be of advantage or disadvantage to individual intensive care units, depending on the mix of patients treated.

Introduction

Knaus *et al* described an equation to predict in-hospital mortality in critically ill patients in intensive care.¹ Multiple logistic regression analyses of case mix and outcome data collected on 5030 patients admitted to intensive care units in the United States resulted in the development of the APACHE II equation. The

equation described the relation of case mix, appropriately weighted, to hospital mortality. Case mix was defined by the patient's severity of illness (APACHE II score), surgical status (emergency surgical or elective surgical/non-surgical), and diagnosis (principal system or individual diagnostic category leading to admission to an intensive care unit).

One of the proposed uses of the APACHE II equation was to "prognostically stratify acutely ill patients" to "compare the efficacy of intensive care in different hospitals."¹ The developers applied the equation to the database from which it was derived, both to test the predictive ability of the equation and to compare outcomes between intensive care units from 13 tertiary care hospitals in the United States. They calculated mortality ratios (observed hospital mortality divided by predicted hospital mortality) for each intensive care unit. One unit had significantly better results (41% fewer deaths than predicted) and one unit had significantly inferior results (58% more deaths than predicted).^{2,3} They subsequently applied the American equation to intensive care units in two hospitals in New Zealand⁴ and more recently to units in six hospitals in Japan.⁵ In both studies they found that observed mortality did not differ significantly from that predicted by the American equation.

Mortality ratios estimated by the APACHE II equation have been used by other workers to audit their individual intensive care unit performance⁶⁻⁸ and to compare outcomes for surgical and non-surgical patients from four intensive care units in two hospitals.⁹ Two of these studies were undertaken in single, intensive care units in the United Kingdom.^{6,7}

Inferences cannot be made from differences in mortality between British intensive care units with the American equation to adjust for case mix until the predictive ability of the equation (not only in terms of its overall goodness of fit to British data but also in terms of its ability to account for differences in mortality between subgroups) has been shown. We report the results of comparisons of outcome between 26 intensive care units in Britain and Ireland both before and after adjustment for case mix by the

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American APACHE II equation. We also report the overall fit and uniformity of fit of the equation for our data.

Methods

The study design, timing, methods of data collection, inclusion and exclusion criteria, and precise application of the APACHE II method for this study are described in the previous article.¹⁰ Data on outcome included the date and vital status of the patient at discharge from the intensive care unit and hospital. Mortality in an intensive care unit was measured as the proportion of patients dying within the unit. Mortality in hospital was measured as the overall proportion of patients dying in hospital, including those dying in the intensive care unit.

TABLE 1—Mortality in 26 intensive care units and corresponding hospitals in Britain and Ireland

Intensive care unit (case No)	No of admissions	No of deaths in intensive care unit	Mortality in intensive care unit (%)	No of deaths in intensive care unit and hospital	Mortality in hospital (%)
1	335	51	15.2	82	24.5
2	412	129	31.3	188	45.6
3	579	86	14.9	137	23.7
4	522	85	16.3	121	23.2
5	223	43	19.3	72	32.3
6	159	29	18.2	42	26.4
7	253	51	20.2	83	32.8
8	282	36	12.8	59	20.9
9	102	15	14.7	22	21.6
10	214	63	29.4	96	44.9
11	350	74	21.1	104	29.7
12	388	79	20.4	106	27.3
13	273	37	13.6	70	25.6
14	170	38	22.4	55	32.4
15	329	46	14.0	66	20.1
16	251	36	14.3	71	28.3
17	237	54	22.8	75	31.7
18	187	50	26.7	63	33.7
19	132	25	18.9	39	29.6
20	460	63	13.7	103	22.4
21	221	39	17.7	52	23.5
22	375	102	27.2	128	34.1
23	492	95	19.3	139	28.3
24	598	96	16.1	145	24.3
25	460	62	13.5	137	29.8
26	792	89	11.2	178	22.5
Total	8796	1573	17.9	2433	27.7

For mortality in intensive care unit $\chi^2=172.2$, $df=25$, $p<0.0001$. For mortality in hospital $\chi^2=173.5$, $df=25$, $p<0.0001$.

TABLE 2—Mortality ratios in 26 intensive care units and corresponding hospitals after adjustment for case mix by American APACHE II equation

Intensive care unit (case No)	No of admissions	No of deaths in intensive care unit and hospital (mortality (%))		Mortality ratio† (95% confidence interval)
		Observed	Predicted	
1	335	82 (24.5)	117.5 (35.1)	0.70 (0.56 to 0.87)**
2	412	188 (45.6)	169.1 (41.0)	1.11 (0.96 to 1.28)
3	579	137 (23.7)	165.4 (28.6)	0.83 (0.70 to 0.98)*
4	522	121 (23.2)	146.2 (28.0)	0.83 (0.69 to 0.99)*
5	223	72 (32.3)	59.7 (26.8)	1.21 (0.94 to 1.52)
6	159	42 (26.4)	37.5 (23.6)	1.12 (0.81 to 1.51)
7	253	83 (32.8)	78.7 (31.1)	1.05 (0.84 to 1.31)
8	282	59 (20.9)	72.7 (25.8)	0.81 (0.62 to 1.05)
9	102	22 (21.6)	30.0 (29.4)	0.73 (0.46 to 1.11)
10	214	96 (44.9)	69.1 (32.3)	1.39 (1.13 to 1.70)**
11	350	104 (29.7)	103.1 (29.5)	1.01 (0.82 to 1.22)
12	388	106 (27.3)	91.1 (23.5)	1.16 (0.95 to 1.41)
13	273	70 (25.6)	60.4 (22.1)	1.16 (0.90 to 1.46)
14	170	55 (32.4)	56.2 (33.0)	0.98 (0.74 to 1.27)
15	329	66 (20.1)	62.9 (19.1)	1.05 (0.81 to 1.33)
16	251	71 (28.3)	63.4 (25.2)	1.12 (0.87 to 1.41)
17	237	75 (31.7)	70.1 (29.6)	1.07 (0.84 to 1.34)
18	187	63 (33.7)	64.4 (34.4)	0.98 (0.75 to 1.25)
19	132	39 (29.6)	33.8 (25.6)	1.15 (0.82 to 1.58)
20	460	103 (22.4)	101.1 (22.0)	1.02 (0.83 to 1.24)
21	221	52 (23.5)	61.1 (27.6)	0.85 (0.64 to 1.12)
22	375	128 (34.1)	110.3 (29.4)	1.16 (0.97 to 1.38)
23	492	139 (28.3)	118.2 (24.0)	1.18 (0.99 to 1.39)
24	598	145 (24.3)	137.9 (23.1)	1.05 (0.89 to 1.24)
25	460	137 (29.8)	133.0 (28.9)	1.03 (0.86 to 1.22)
26	792	178 (22.5)	178.2 (22.5)	1.00 (0.86 to 1.16)
Total	8796	2433 (27.7)	2390 (27.2)	1.02 (0.98 to 1.06)

†Observed number of deaths divided by predicted number.

*Significant at 5% level.

**Significant at 1% level.

Applying the American APACHE II equation, we estimated a predicted risk of dying in hospital for each patient in our database (see appendix).¹ When a patient had a diagnosis that was not represented in the American equation the system diagnostic category coefficient was applied. Summing of individual patient risks yielded a predicted number of deaths for groups of patients. The observed number of deaths within groups was compared with the predicted number of deaths and a mortality ratio (number of observed deaths divided by number of deaths predicted by APACHE II) calculated. Ninety five per cent confidence intervals were calculated for each mortality ratio.¹¹ Differences between observed and predicted numbers of deaths were tested with the simple continuity corrected χ^2 statistic.

No single standard measure has been used to describe the overall goodness of fit or predictive ability of multiple logistic regression equations. We used four different methods: calibration curves, classification tables, analysis of receiver operating characteristic curves,¹² and a χ^2 statistic proposed by Lemeshow and Hosmer.¹³ These are described in the appendix.

Results

In addition to the patients already excluded from our database,¹⁰ a further 276 (2.4%) patients who had had coronary artery bypass grafting and 27 (0.2%) patients with burns were removed as the APACHE II equation was not proposed for use in these two groups. This left a database of 8796 patients, with a mean number of patients per intensive care unit of 338 and a range between units of 102 to 792 patients (table I).

COMPARISONS OF OUTCOME BEFORE AND AFTER ADJUSTMENT FOR CASE MIX

The overall proportion of patients dying in the intensive care unit was 17.9%. Mortality in the intensive care unit varied 2.8-fold between the 26 units from 11.2% in unit 26 to 31.3% in unit 2 (table I). The overall proportion of patients dying in hospital was 27.7%, varying 2.3-fold, from 20.1% in unit 15 to 45.6% in unit 2.

The mortality ratios (observed divided by predicted deaths) for the units ranged from 0.70 in unit 1 to 1.39 in unit 10 (table II). For four units (1, 3, 4, and 10), the observed numbers of deaths were significantly different from the numbers predicted by the APACHE II equation (3 and 4, $p<0.05$; 1 and 10, $p<0.01$).

VALIDATION OF THE APACHE II EQUATION

Overall goodness of fit

The calibration curve for the APACHE II equation applied to our data is shown in figure 1. This showed that as the predicted risk of dying in hospital increased (x axis) the proportion of patients who died also increased (y axis, right hand side). The observed mortality for two of the predicted risk groups (15-20% and 30-35%), however, lay significantly above the diagonal line (which represents the relation where observed and predicted deaths are equal). In contrast, for four predicted risk groups (75-80% and above 85%) the observed mortality fell significantly below the diagonal line.

Table III shows the classification tables. With a decision criterion of 10% the proportion of the observed deaths predicted by the model was high (93.7%). This result was, however, associated with a high false positive rate, with 54.9% of survivors predicted to die. At the other extreme with a decision criterion of 90% only 7.4% of the observed deaths were predicted, but this was associated with a low false positive rate (0.6%). When decision criteria were applied at 5% intervals from 5% to 95% the highest overall proportion correctly

FIG 1—Observed proportion of patients dying in hospital in Britain and Ireland according to their predicted risk of dying estimated by American APACHE II equation. Line of perfect predictive ability, when observed and predicted mortality are equal, is given to show overall goodness of fit of the equation

FIG 2—Receiver operating characteristic curves showing predictive ability of American APACHE II equation applied to data from Britain and Ireland

TABLE III—Classification tables for American APACHE II equation applied to data from British and Irish intensive care units and corresponding hospitals

	No predicted to live	No predicted to die	Total
Decision criterion of 10%			
No of observed survivors	2867	3496	6363
No of observed dead	153	2280	2433
Total	3020	5776	8796
True positive rate (95% confidence interval) (%) 93.7 (92.7 to 94.7).			
False positive rate (95% confidence interval) (%) 54.9 (53.7 to 56.1).			
Overall correct classification (95% confidence interval) (%) 58.5 (57.5 to 59.5).			
Decision criterion of 50%			
No of observed survivors	5824	539	6363
No of observed dead	1261	1172	2433
Total	7085	1711	8796
True positive rate (95% confidence interval) (%) 48.2 (46.2 to 50.2).			
False positive rate (95% confidence interval) (%) 8.5 (7.8 to 9.2).			
Overall correct classification (95% confidence interval) (%) 79.5 (78.7 to 80.3).			
Decision criterion of 90%			
No of observed survivors	6327	36	6363
No of observed dead	2252	181	2433
Total	8579	217	8796
True positive rate (95% confidence interval) (%) 7.4 (6.4 to 8.4).			
False positive rate (95% confidence interval) (%) 0.6 (0.4 to 0.8).			
Overall correct classification (95% confidence interval) (%) 74.0 (73.1 to 74.9).			

TABLE IV—Goodness of fit of American APACHE II equation for data from Britain and Ireland by Lemeshow-Hosmer χ^2 statistic

Predicted risk of dying in hospital (%)	No of cases	No of deaths		No of survivors	
		Observed	Expected	Observed	Expected
0-	3020	153	157.40	2867	2862.60
10-	1797	313	260.64	1484	1536.36
20-	1021	274	252.04	747	768.96
30-	699	275	243.97	424	455.03
40-	548	246	247.46	302	300.54
50-	464	260	255.42	204	208.58
60-	358	234	232.94	124	125.06
70-	333	230	249.31	103	83.69
80-	339	267	287.85	72	51.15
90-100	217	181	203.90	36	13.10

Sum of χ^2 = 79.81, df = 8.

TABLE V—Mortality ratios by age group for patients in 26 intensive care units after adjustment for case mix by American APACHE II equation

Age group (years)	No of admissions	No of deaths in intensive care unit and hospital (mortality %)		Mortality ratio† (95% confidence interval)
		Observed	Predicted	
16-25	887	103 (11.6)	117.2 (13.2)	0.88 (0.72 to 1.07)
26-35	776	102 (13.1)	119.9 (15.4)	0.85 (0.69 to 1.03)
36-45	777	164 (21.1)	156.0 (20.1)	1.05 (0.90 to 1.22)
46-55	950	244 (25.7)	250.0 (26.3)	0.98 (0.86 to 1.11)
56-65	1887	535 (28.4)	549.4 (29.1)	0.97 (0.89 to 1.06)
66-75	2344	803 (34.3)	787.7 (33.6)	1.02 (0.95 to 1.09)
76-85	1071	429 (40.1)	373.4 (34.9)	1.15 (1.04 to 1.26)**
≥86	104	53 (51.0)	37.1 (35.7)	1.43 (1.07 to 1.87)*

†Observed number of deaths divided by predicted number.

*Significant at 5% level.

**Significant at 1% level.

classified (predicted survivors who survive plus predicted non-survivors who die) was 79.5% with a 50% decision criterion, with a true positive rate of 48.2% and a false positive rate of 8.5%.

Figure 2 shows the receiver operating characteristic curve for the APACHE II equation applied to our data. The area under the curve was 0.83. Table IV presents the data for calculation of the Lemeshow-Hosmer statistic. The significant departure from the null hypothesis, measured by the Lemeshow-Hosmer χ^2 statistic for our data, does not necessarily imply a bad fit, just that its imperfections are of such a size that they can be detected in this large sample size.

Uniformity of fit

Observed hospital mortality was similar to that predicted by the APACHE II equation for patients grouped by age up to 75 years (table V). For patients 76 years and older the observed numbers of deaths were greater than those predicted. Patients without any of the chronic health conditions defined in APACHE II had a slightly raised significant mortality ratio of 1.05 ($p < 0.05$). This was, however, in a large group of 6814 patients.

The number of deaths predicted by the APACHE II equation was similar to the number observed for both surgical and non-surgical patients (table VI). The independent variable in the APACHE II equation reflecting surgical status is whether the patient has had emergency surgery or not. The observed and predicted number of deaths was similar for the two groups.

When patients were grouped by diagnosis (principal system diagnostic category leading to admission to an intensive care unit) by the American diagnostic categories of the APACHE II method the mortality ratios were significantly raised for surgical patients with diagnoses pertaining to the cardiovascular system and for both surgical and non-surgical patients with diagnoses pertaining to the neurological system. In contrast, the mortality ratio was significantly lowered for surgical patients with respiratory disease (table VI).

For patients grouped by the acute physiology score of the APACHE II score the observed number of deaths was similar to the predicted number for all groups. When patients were grouped by APACHE II score, however, the predicted number of deaths was significantly greater than the number observed for the two lowest score bands. The opposite was true for the patients with scores between 20 and 24, when the observed number of deaths was significantly greater than the number predicted (table VII).

Discussion

When measuring the outcome of intensive care as crude mortality in intensive care units we found a large variation between the units. Some of this variation might, however, reflect different discharge practices between the units such that a patient who would remain and die within a unit in one hospital may be discharged and die on the ward in another. Differences in discharge practices can result from such factors as pressure for intensive care beds or variations in units' discharge policies. The observed decrease in variation between the units for crude hospital mortality relative to intensive care unit mortality suggests these biases might exist. Whereas the ultimate outcome may be best measured at some point after hospital discharge, mortality in hospital rather than the intensive care unit may be more sensitive to true variation.

Examination of differences in case mix between units may further inform the variations which remain between hospital mortality. Indeed, in 22 of the 26 units studied adjustment for case mix by the APACHE II method explained the observed differences

in crude hospital mortality. Before the results with such a tool can be accepted, however, the tool must be rigorously validated, especially when it was originally developed within another medical culture. Validation must include testing not only the overall goodness of fit but also the uniformity of fit of the equation for our data.

In the absence of a single, agreed method to measure overall goodness of fit we used four different methods. The overall goodness of fit of the American equation for the British and Irish data was good with each method and it was only slightly inferior to the goodness of fit obtained by the developers of APACHE II.¹

On investigation of the uniformity of fit of the American APACHE II equation for our data, we found that when patients were grouped by characteristics, such as age and diagnosis, the equation did not adjust across the subgroups uniformly. This lack of uniformity of fit is illustrated by underprediction of deaths for patients 76 years or older, which has also been reported by other groups,^{14 15} and by overprediction of deaths for patients with, for example, a respiratory condition treated surgically.

Potential factors that could give rise to the lack of uniformity of fit of the American equation for our data are: (a) systematic differences in medical definitions and diagnostic labelling between the two countries¹⁶; (b) true differences in the diagnostic mix between the countries; (c) systematic differences in

Clinical implications

- Crude death rates in hospital vary more than twofold between intensive care units in Britain and Ireland
- In this study the American APACHE II equation was used to adjust for the differences in the case mix of patients
- The outcome in four intensive care units remained significantly different from that expected even after adjustment for case mix
- Although the overall goodness of fit of the American APACHE II equation for British and Irish data is satisfactory, the equation does not fit the data uniformly
- Before the American APACHE II equation can be widely adopted the uniformity of fit needs to be improved for British and Irish patients

the measurement of physiological variables between the countries; (d) systematic differences in the effectiveness of treatment; and (e) the possibility that differences exist in the age specific health status between the countries.

Our results show that before an existing case mix measure is applied, especially those developed in other countries, it must first be rigorously validated. This is true not only for intensive care but for all areas of health care. If the case mix measure used does not fit the data to which it is applied the wrong conclusions may be drawn from the results. In addition, some measures of case mix may produce good overall goodness of fit but may still not fit uniformly, as we found with the American APACHE II equation. We will consider in a subsequent paper whether an APACHE II equation derived from British data would provide better case mix adjustment than the existing American equation.

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Appendix

PREDICTING RISK OF DYING IN HOSPITAL

Table VIII shows the weighting for the diagnostic categories according to surgical status in the American APACHE II equation. The predicted risk of dying in hospital was calculated from the equation $\ln(P/1-P) = -3.517 + 0.146 \times \text{APACHE II score} + 0.603$ if after emergency surgery + weight of diagnostic category, where P is the predicted risk of dying in hospital.

METHODS FOR TESTING OVERALL GOODNESS OF FIT

Calibration curves display observed hospital mortality in patients grouped by predicted risk of dying in hospital. Patients were divided into groups on the basis of their

TABLE VI—Mortality ratios by surgical status and system diagnostic category for patients in 26 intensive care units after adjustment for case mix by American APACHE II equation

System diagnostic category	No of admissions	No of deaths in intensive care unit and hospital (mortality (%))		Mortality ratio† (95% confidence interval)
		Observed	Predicted	
Surgical				
Cardiovascular	2182	441 (20.2)	375.4 (17.2)	1.17 (1.07 to 1.29)**
Gastrointestinal	1286	354 (27.5)	375.1 (29.2)	0.94 (0.85 to 1.05)
Neurological	180	45 (25.0)	28.7 (15.9)	1.57 (1.14 to 2.10)**
Respiratory	1030	109 (10.6)	178.6 (17.3)	0.61 (0.50 to 0.74)**
Renal	211	27 (12.8)	31.5 (14.9)	0.86 (0.56 to 1.25)
Haematological	13	2 (40.0)	1.6 (32.0)	1.25 (0.15 to 4.52)
Metabolic	13	2 (15.4)	2.1 (16.2)	0.95 (0.12 to 3.44)
Total	4907	980 (20.0)	993.0 (20.2)	0.99 (0.93 to 1.05)
Non-surgical				
Cardiovascular	1489	643 (43.2)	668.6 (44.9)	0.96 (0.89 to 1.04)
Gastrointestinal	217	125 (57.6)	122.8 (56.6)	1.02 (0.85 to 1.21)
Neurological	844	225 (26.7)	150.6 (17.8)	1.49 (1.31 to 1.70)**
Respiratory	1200	424 (35.3)	418.7 (34.9)	1.01 (0.92 to 1.11)
Renal	46	17 (37.0)	15.5 (33.7)	1.10 (0.64 to 1.76)
Haematological	25	11 (44.0)	6.9 (27.6)	1.59 (0.80 to 2.85)
Metabolic	68	8 (11.8)	15.0 (22.0)	0.53 (0.23 to 1.05)
Total	3889	1453 (37.4)	1398.1 (35.9)	1.04 (0.99 to 1.09)

†Observed number of deaths divided by predicted number.

**Significant at 1% level.

TABLE VII—Mortality ratios by acute physiology and APACHE II scores for patients in 26 intensive care units after adjustment for case mix by American APACHE II equation

	No of admissions	No of deaths in intensive care unit and hospital (mortality (%))		Mortality ratio† (95% confidence interval)
		Observed	Predicted	
Acute physiology score:				
0-4	563	32 (5.7)	28.0 (5.0)	1.14 (0.78 to 1.61)
5-9	2189	192 (8.8)	218.4 (10.0)	0.88 (0.76 to 1.01)
10-14	2600	482 (18.5)	484.9 (18.7)	0.99 (0.91 to 1.09)
15-19	1585	552 (34.8)	510.5 (32.2)	1.08 (0.99 to 1.18)
20-24	881	463 (52.6)	434.8 (49.4)	1.06 (0.97 to 1.17)
25-29	555	383 (69.0)	362.0 (65.2)	1.07 (0.95 to 1.17)
30-34	247	178 (72.1)	193.8 (78.5)	0.92 (0.79 to 1.06)
≥ 35	176	151 (85.8)	158.6 (90.1)	0.95 (0.81 to 1.12)
APACHE II score:				
0-4	275	1 (0.4)	7.3 (2.7)	0.14 (0.0 to 0.76)*
5-9	1048	43 (4.1)	59.7 (5.7)	0.72 (0.52 to 0.97)*
10-14	2064	210 (10.2)	217.5 (10.5)	0.97 (0.84 to 1.11)
15-19	2079	395 (19.0)	395.7 (19.0)	1.00 (0.90 to 1.10)
20-24	1492	568 (38.1)	510.3 (34.2)	1.11 (1.02 to 1.21)*
25-29	878	499 (56.8)	457.9 (52.2)	1.09 (1.00 to 1.19)
30-34	507	353 (69.6)	349.8 (69.0)	1.01 (0.91 to 1.12)
≥ 35	453	364 (80.4)	392.8 (86.7)	0.93 (0.83 to 1.03)

†Observed number of deaths divided by predicted number.

*Significant at 5% level.

TABLE VIII—Coefficients for diagnostic categories according to surgical status with American APACHE II equation

Surgical	Coefficient	Non-surgical	Coefficient
Cardiovascular	-0.797	Cardiovascular	0.470
Multiple trauma	-1.684	Multiple trauma	-1.228
Heart valve surgery	-1.261	Coronary artery disease	-0.191
Peripheral vascular surgery	-1.315	Thoracic or abdominal aneurysm	0.731
Haemorrhagic shock	-0.682	Congestive heart failure	-0.424
Chronic cardiovascular disease	-1.376	Hypertension	-1.798
Gastrointestinal	-0.613	Rhythm disturbance	-1.368
Neoplasm	-0.248	Cardiogenic shock	-0.259
Bleeding	-0.617	Sepsis*	0.113
Perforation or obstruction	0.060	Haemorrhagic shock or hypovolaemia	0.493
Haematological	-0.196	After cardiac arrest*	0.393
Renal	-0.196	Gastrointestinal	0.501
Neoplasm	-1.204	Bleeding	0.334
Transplant	-1.042	Haematological	-0.885
Metabolic	-0.196	Renal	-0.885
Neurological	-1.150	Metabolic	-0.885
Craniotomy for neoplasm	-1.245	Diabetic ketoacidosis	-1.507
Head trauma	-0.955	Neurological	-0.759
Craniotomy for intracerebral, subdural, or subarachnoid haemorrhage	-0.788	Head trauma	-0.517
Respiratory	-0.610	Drug overdose	-3.353
Thoracic surgery for neoplasm	-0.802	Intracerebral, subdural, or subarachnoid haemorrhage	0.723
Respiratory insufficiency after surgery	-0.140	Seizure disorder	-0.584
		Respiratory	-0.890
		Infection	0
		Neoplasm	0.891
		Pulmonary embolus	-0.128
		Non-cardiogenic lung oedema	-0.251
		After respiratory arrest*	-0.168
		Asthma or allergy	-2.108
		Chronic obstructive lung disease	-0.367
		Aspiration, poisoning, or toxic	-0.142

*If surgical patient use non-surgical coefficient.

predicted risk of dying in hospital estimated by the APACHE II equation. Risks from 0% to 100% were grouped in intervals of 5%. The observed proportion of deaths within each risk group and its 95% confidence interval were plotted and compared with the diagonal line that represented the relation where observed and predicted death rates were equal (perfect predictive ability).

Classification tables constructed for predictive models compare observed with predicted outcomes. Individual predicted risks were converted to predicted outcomes with different decision criteria. For example, with a decision criterion of 50% probability predicted risks of dying greater than 50% were considered to predict hospital mortality and predicted risks of 50% or less to predict survival. These predicted outcomes were then compared with the observed outcomes. Similarly, a decision criterion of 25%, 75%, or any other value can be used. The true positive rate or sensitivity (the proportion of the observed non-survivors who were correctly predicted to die); the false positive rate or 100% minus the specificity (the proportion of observed survivors incorrectly predicted to die); and the overall correct classification rate (proportion of patients correctly classified as survivors or non-survivors) can be compared for different predictive models applying different decision criteria.

Receiver operating characteristic curves show the relation between the true positive rate (sensitivity) and the false positive rate (100% minus the specificity) as the decision criterion for prediction is systematically varied from 0 to 100%. They therefore depict the trade offs between the true positive rate and the false positive rate for a given predictive model. The total area under a curve is an expression of the overall discrimination across the range of risks and is a good summary measure of predictive ability. It has a minimum value of 0.5 represented by a diagonal line, which would be expected if the model was no better than chance at predicting

hospital mortality. It has a maximum value of 1.0 represented by a line superimposed on the y axis from the origin to the upper left hand corner of the graph for perfect prediction. The value of the area under the curve represents the likelihood that a non-survivor randomly chosen from the database will have a greater predicted probability of dying in hospital than a randomly chosen survivor. The true positive rates and false positive rates were calculated from the classification tables using decision criteria ranging from 0 to 100% in 5% intervals. Receiver operating characteristic curves were constructed by plotting the false positive rate along the x axis against the true positive rate on the y axis for each decision criterion.

Lemeshow-Hosmer χ^2 statistic—As for the calibration curve, observations were divided into mortality risk groups on the basis of their predicted risk of dying in hospital. The groups ranged from 0 to 100% in 10% intervals. Both the observed number of survivors and non-survivors and the predicted number of survivors and non-survivors were calculated for each risk group. The χ^2 statistic comparing the observed with the expected (predicted) frequencies was calculated for each of the 10 groups for both survivors and non-survivors. The 20 χ^2 values were summed and the resultant Lemeshow-Hosmer statistic had a distribution that was closely approximated by a χ^2 distribution, with the number of degrees of freedom equal to the number of risk groups minus two, when observed mortality is accurately predicted across the range of risk (this is the null hypothesis). For a given sample size the overall χ^2 values are therefore smaller the better the goodness of fit. A high (and significant) χ^2 value can, however, be achieved with increasing sample sizes despite an excellent fit as the power for detecting departures from the null hypothesis increases.

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