by the POSSUM were analyzed by exponential analysis, whereas those by the E-PASS and the P-POSSUM were analyzed by linear analysis as reported **previously**[16]. In the linear analysis, patients were divided into groups according to their predicted risk of death: less than 10, 10-19, 20-29, 30-39, 40-49, 50-59, 60-69, 70-79, 80-89 and greater than 90%. The number of patients falling into each mortality group was multiplied by the average risk of death to give the predicted number of deaths in that group. In the exponential analysis, a cut-off risk is considered in each stage of the calculation. All patients whose predicted risk falls above the cut-off are grouped together. Therefore, if the cut-off level being analyzed is 80% risk of death, the number of predicted deaths in this group is the result of the number of patients with 80% or greater predicted risk of death, multiplied by 0.8. A difficulty arises if the calculated number of deaths above this cut-off falls below the number calculated for a higher cut-off. In this situation, a second calculation should begin again from the lower cut-off. For the lowest cut-off (0%), multiplication by zero is avoided by using the median predicted risk of the below 10% mortality band[16]. Therefore, the POSSUM equation does not provide the risk of death in individual patients[16].

Statistical analyses were performed as previously reported using StatView 5.0 software (SAS Institute Inc., Cary NC 27513)[24]. Various regression analyses, including simple, polynomial, multiple, stepwise, exponential, logarithmic, power, and growth regressions, were tested to best fit the coordinates of the mortality rates and the CRS. The significance of the regression model was determined by analysis of variance.

RESULTS

Fig.1 shows the relation between the morbidity and the Comprehensive Risk Score (CRS) of the E-PASS in 5,212 patients who underwent elective digestive surgery (Group A). For the morbidity rates, it increased at a CRS<1.0 and plateaued thereafter (4.5% at the CRS<0, 20.4% at the CRS of 0 to <0.5, 40.2% at the CRS of 0.5 to <1.0, 66.7% of the CRS of 1.0 to <1.5, and 64.0% of the CRS of 1.5 or greater). However, for the in-hospital mortality rates, there was a steep increase at a CRS greater than 0 (0%at the CRS<0, 0.75% at the CRS of 0 to <0.5, 6.0% at the CRS of 0.5 to <1.0, 15.1% at the CRS of 1.0 to <1.5, and 44.0% at the CRS of 1.5 or greater). 30-day mortality rates increased as the CRS increased (0%at the CRS<0, 0.42% at the CRS of 0 to <0.5, 1.5% at the CRS of 0.5 to <1.0, 4.0% at the CRS of 1.0 to <1.5, and 8.0% at the CRS of 1.5 or greater). Subsequently, we evaluated these rates in individual diseases (Fig. 2). In each case, both the in-hospital mortality and morbidity rates increased as the CRS increased.

When we analyzed the relation between the mortality rates and the CRS in all patients of Group A by various regression models, a polynomial model best fit this relation in both in-hospital and 30-day mortality rates (Fig. 3). It provided an equation of $Y = -0.465+ 1.192X + 10.91X^2$ for in-hospital mortality rates, and $Y = 0.161 + 1.303X + 1.404X^2$ for 30-day mortality rates, where Y is the estimated mortality rate and X is the CRS. However, some problems exist when we simply apply these equations. Although the CRS varies from -0.56 to 3.14 in these patients, the equation for in-hospital mortality gives a minus value for the mortality rates in the range of CRS -0.268 to 0.159. Moreover, the in-hospital mortality rates increase when the CRS decreases below -0.268, even though there were **no patients with died when the CRS was below 0**. In contrast, when the CRS exceeded 2.98, the equation produced rates greater than 100%. Therefore, this equation should be **used only when** 0.159. CRS<2.98. Since the in-hospital mortality rate **when** CRS<0.159 was **0.07%** (two deceased patients of 2,936 operated cases), the estimated mortality rate was determined as almost 0 for this range (Table 2). Similarly, the equation for 30-day mortality produced values that exceeded the estimated in-hospital rates at the CRS range of 0.263 or less. Since the 30-day mortality rates **when** CRS<0.263 was **0.03%** (one deceased patient of 3,123 operated cases), the estimated mortality rate was determined as almost 0 for this range. When we applied these rules, the estimated mortality rates agreed well with the **observed** rates (Table 3). Furthermore, the estimated mortality rates in individual diseases were significantly correlated with the observed rates (Fig. 4).

Subsequently, we evaluated the usefulness of the E-PASS in defining quality of care in another series of 1,934 patients (Group B), compared with the POSSUM, and P-POSSUM. As shown in Fig. 5, all of the systems had significant correlations with the observed rates. However, the POSSUM and the P-POSSUM over-predicted the mortality rates. The E-PASS estimated the 30-day mortality rates by 0.63-fold (linear analysis), whereas the POSSUM was 11.0-fold (exponential analysis). The E-PASS estimated the in-hospital mortality rates by 1.2-fold (linear analysis), whereas the P-POSSUM was 4.5-fold (linear analysis).

Then, we compared the OE ratios among six hospitals using different audit systems (Fig. 6). In estimating 30-day mortality rates, the OE ratios defined by the E-PASS significantly correlated with those by the POSSUM. Similarly, the OE ratios defined by the E-PASS significantly correlated with those by the P-POSSUM when evaluating **in-hospital** mortality rates. The OE ratios defined by the E-PASS to estimate 30-day mortality also correlated with those by the E-PASS to estimate hospital mortality (R=0.881, N=6, P=0.0204). The OE ratios defined by the POSSUM to estimate 30-day mortality correlated with those by the P-POSSUM to estimate in-hospital mortality (R=0.995, N=6, P<0.0001).

To obtain a risk-stratification more conveniently in clinical practice, we generated a point-adding system mimicking the CRS (Table 4) as done in other prediction rules[1,4]. Total Risk Points (TRP) obtained in this system significantly correlated with the CRS in both Groups A and B (Fig. 7).

DISCUSSION

Comparisons of surgical quality between individual hospitals must take into account differences in patient populations and the complexity of surgery performed . We previously generated a scoring system, Estimation of Physiologic Ability and Surgical Stress (E-PASS) that predicts the postoperative risk by estimating the patients' physiologic ability and the surgical stress applied. This study was undertaken to obtain a mortality equation using the E-PASS scoring system and evaluate its usefulness in defining the surgical quality. This study produced equations for estimating in-hospital and 30-day mortality rates by polynomial regression analysis. We did not simply apply these equations as a prediction rule, since these mathematical equations sometimes have contradictory values at the extreme risk ranges[18, 25]. We therefore checked the equations and applied them at ranges with no contradictory values. For example, the equation for in-hospital mortality gave minus values at the range of Comprehensive Risk Score (CRS) less than 0.159 and was not applied at this range. After this manipulation, the rules **correlate well** with the observed mortality rates.

Using these rules, we conducted a prospective comparative study with Physiological and Operative Severity Score for the enUmeration for Mortality and morbidity (POSSUM), and Portsmouth-POSSUM (P-POSSUM). Our data revealed that the POSSUM and the P-POSSUM over-predicted the mortality rates. The reason for this over-prediction is unclear. The POSSUM and P-POSSUM targeted both emergency and elective operations, but there may be significant differences in mortality between them[26]. This may be the reason why these scoring systems over-predicted the mortality rates of the data that included only elective operations. Alternatively, it is possible that there are differences in quality of care across countries. Therefore, these rules may need some adjustment when applied in different countries. Surprisingly, there was a significant correlation between the surgical quality of six hospitals defined by the E-PASS and the POSSUM or its modified version, P-POSSUM. There are only two factors, age and blood loss, that both scoring systems have in common. Therefore, these systems may be reliable and useful for the surgical audit. The E-PASS scoring system requires only 10 variables, whereas the POSSUM or P-POSSUM needs 18 variables. Therefore, the E-PASS **may have** advantages over the POSSUM or P-POSSUM **in amount of data entry needed and the complexity of the analysis.**

Both the E-PASS and POSSUM were devised to be applied to a wide variety of procedures. However, it is possible that procedures for individual diseases differ in their mortality rules[27], although this study demonstrated significant correlations between the observed and estimated mortality rates defined by the E-PASS in the individual diseases. Therefore, it would be better to develop a curve for each procedure. This study had insufficient patients to generate mortality curves in individual diseases. In patients with gastric carcinoma and colorectal carcinoma, whose numbers exceeded more than 1,000 with sufficient deaths, there were polynomial correlations between the CRS and in-hospital mortality rates (gastric carcinoma R=0.985, N=5, P=0.0053; colorectal carcinoma R=0.991, N=5, P=0.0024). Further studies will be performed to analyze if there were significant differences in mortality rates between individual diseases.

For the comparison of surgical quality, 30-day or in-hospital mortality was usually used as an endpoint[28]. This study demonstrated that the outcome of six hospitals for 30-day mortality as defined by the E-PASS was significantly correlated with that for hospital mortality by the same scoring system. Although 30-day mortality represents only a small percentage of the operated patients, it is more objective and easier to investigate than the in-hospital mortality. Therefore, 30-day mortality should be used as the endpoint for surgical audit. On the other hand, avoiding in-hospital mortality is the most important goal for clinicians. This rule for in-hospital mortality will be useful as a prediction guideline in clinical practice. It is surely difficult to remember and calculate the equations. Therefore, we use a computer program in a surgical ward so as to calculate the estimated mortally rates within 10 seconds. Such programs are indispensable for the E-PASS scoring system and will be delivered in the future.

The POSSUM or P-POSSUM scoring system cannot be used as a prediction guideline, since the estimated mortality rates can be determined only after the pathological results are obtained[14]. Moreover, the POSSUM, devised for exponential analysis, does not provide accurate predicted mortality rates for individual patients. The E-PASS scoring system was originally generated as a prediction guideline and the present estimated mortality rates can be computed just after surgery completion. A quick chart of the Total Risk Points (TRP) presented in this paper may predict the postoperative course and be useful to promote the outcome management. However, when surgeons **make** risk stratification using the CRS or TRP, they should be aware of a broad range of mortality for the various numerical ranges of the risk.

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Table 1. Number of patients for each procedure in Group A

Surgical procedure	No. of patients	No. of patients with nonmalignant conditions
Transthoracic esophagectomy	95	95
Pancreaticoduodenectomy	93	6
Hepatectomy	184	14
Total gastrectomy	301	9
Laparoscopic-assisted distal gastrectomy	44	1
Open distal gastrectomy	624	20
Open cardiofundectomy	36	1
Laparoscopic wedge resection of the stomach	21	6
Laparoscopic-assisted colon resections	87	14
Open colon resections	656	38
Laparoscopic cholecystectomy	1,900	1,898
Open cholecystectomy	177	172
Laparoscopic choledochotomy	34	34
Open choledochotomy	72	72
Rectal resections	309	10
Rectal amputation	110	10
Laparoscopic splenectomy	34	34
Others	435	210
Total	5,212	2,644

Table 2. Parameters of the E-PASS, POSSUM and P-POSSUM

E-PASS	POSSUM, P-POSSUM
Age	**Age**
Presence or absence of severe heart disease	Cardiac signs
Presence or absence of severe pulmonary disease	Respiratory signs
Presence or absence of diabetes mellitus	Systolic blood pressure
Performance status	Pulse rate
ASA class	Glasgow coma scale
Blood loss	Serum urea
Body weight	Serum sodium
Operation time	Serum potassium
Extent of skin incision	Hemoglobin
	White cell count
	Electrocardiogram
	Operation category (minor, intermediate, major, major+)
	No. of procedures
	Total blood loss
	Peritoneal soiling
	Malignancy
	Timing of operation

Table 3. Number of patients for each procedure in Group B

Surgical procedure	No. of patients	No. of patients with nonmalignant conditions
Transthoracic esophagectomy	33	0
Pancreaticoduodenectomy	34	4
Hepatectomy	107	6
Total gastrectomy	109	1
Laparoscopic-assisted distal gastrectomy	25	0
Open distal gastrectomy	231	6
Open cardiofundectomy	9	1
Laparoscopic wedge resection of the stomach	9	3
Laparoscopic-assisted colon resections	49	6
Open colon resections	248	18
Laparoscopic cholecystectomy	538	532
Open cholecystectomy	96	92
Laparoscopic choledochotomy	10	10
Open choledochotomy	34	33
Rectal resections	123	4
Rectal amputation	43	0
Laparoscopic splenectomy	16	16
Others	220	112
Total	1,934	844

Table 4. Equations for estimated mortality rates in gastrointestinal surgery

A. In-hospital mortality rate

$X < 0.159$	$Y \fallingdotseq 0$
$0.159\ .\ X < 2.98$	$Y = -0.465 + 1.192X + 10.91X^2$
$X\ .\ 2.98$	$Y = 100$

X: CRS, Y: In-hospital mortality rates

B. 30-day mortality rate

$X < 0.263$	$Y \fallingdotseq 0$
$X\ .\ 0.263$	$Y = 0.161 + 1.303X + 1.404X^2$

X: CRS, Y: 30-day mortality rates

Table 5. Comparison between estimated- and observed-mortality rates

Range of CRS	N	Average of CRS	In-hospital death rates (%)		30-day death rate (%)	
			Observed	Estimated	Observed	Estimated
< 0	2,238	- 0.314	0	0	0	0
0 - <0.5	2,137	0.237	0.75	0.70	0.42	0.29
0.5 - < 1.0	686	0.689	6.0	5.7	1.5	1.7
1.0 - < 1.5	126	1.17	15.1	16.0	4.0	3.9
. 1.5	25	1.96	44.0	45.7	8.0	7.8

The estimated- and observed-mortality rates were compared in 5,212 patients who underwent elective gastrointestinal surgery.

Table 6. Determination of Total Risk Points (TRP)

Factors	Points
1) Age	×3
2) Presence of severe heart disease	+ 300
3) Presence of severe pulmonary disease	+ 190
4) Presence of diabetes mellitus	+ 140
5) Performance status (0-4)	×140
6) ASA class (1-5)	×60
7) Blood loss (g) / body weight (kg)	×14
8) Operation time (h)	×40
9) Extent of skin excision (0-2)	×340
Total Risk Points (TRP)	Pts.

TRP is computed by the sum of 1) to 9) points. Factors 1) to 6) can be determined preoperatively and 7) to 9) immediately after the operation. Criteria for factors 2), 3), 4), 5) and 9) are shown in the Materials and Methods. The in-hospital mortality rates were 0% at the TRP<500 (N=1,681), 0.26% at the TRP of 500 to 1,000 (N=1,943), 3.0% at the TRP of 1,000 to 1,500 (N=1,253), 9.3% at the TRP of 1,500 to 2,000 (N=280), and 32.7% at the TRP of 2,000 or greater (N=55) in Group A.

Figure legends

Fig.1. Relation between Comprehensive Risk Score (CRS) and morbidity in all patients of Group A.

The rates of morbidity, in-hospital mortality and 30-day mortality **after** elective gastro-intestinal surgery were analyzed according to the CRS range in 5,212 patients of Group A.

Fig.2. Relation between Comprehensive Risk Score (CRS) and morbidity in individual diseases

The morbidity and in-hospital mortality rates following surgery were analyzed in individual diseases. □: Morbidity rate, ■: Mortality rate, * indicates a column where the rates were not indicated, since the number of patients were less than 20.

Fig.3. Postoperative mortality curves defined by Comprehensive Risk Score (CRS)

The relation between the CRS and mortality rates was analyzed by polynomial regression analysis. Each coordinate indicates the average CRS and mortality rate at each range of the CRS. Equations for estimated mortality rates were obtained as $Y= -0.465 + 1.192(CRS) + 10.91(CRS)^2$ for in-hospital mortality (R=0.9996, N=5, P=0.0008) and $Y = 0.161 + 1.303(CRS) + 1.404(CRS)^2$ for 30-day mortality (R=0.997, N=5, P=0.0060)

Fig.4. Relation between the observed- and estimated-mortality rates in individual diseases

The estimated- and observed-rates for in-hospital mortality were 0.18% and 0.18% in patients with gallstones and common bile duct stones (N=2,179), 2.1% and 1.4% in patients with colorectal carcinoma (N=1,130), 2.0% and 3.1% in patients with gastric carcinoma (1,076), 6.3% and 5.6% in patients with liver carcinoma (N=124), 8.7% and

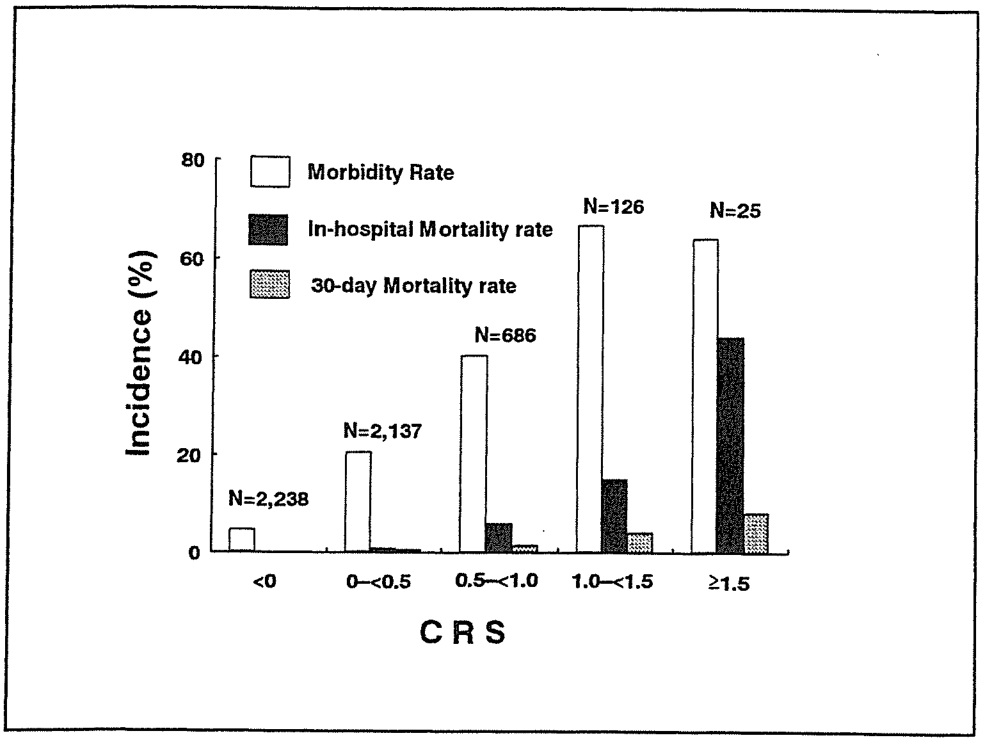
8.0% in patients with carcinoma of pancreas and bile duct (N=112), and 9.7% and 12.4% in patients with esophageal carcinoma (N=121), respectively. The estimated- and observed- rates for 30-day mortality were 0.059% and 0.046% in patients with gall-stones and common bile duct stone, 0.58% and 0.53% in patients with colorectal carci-noma, 0.60% and 0.94% in patients with gastric carcinoma, 1.7% and 1.6% in patients with liver carcinoma, 2.0% and 1.8% in patients with carcinoma of the pancreas and bile duct, and 2.5% and 3.3% in patients with esophageal carcinoma, respectively. Dotted lines indicate the 95% confidence limits.

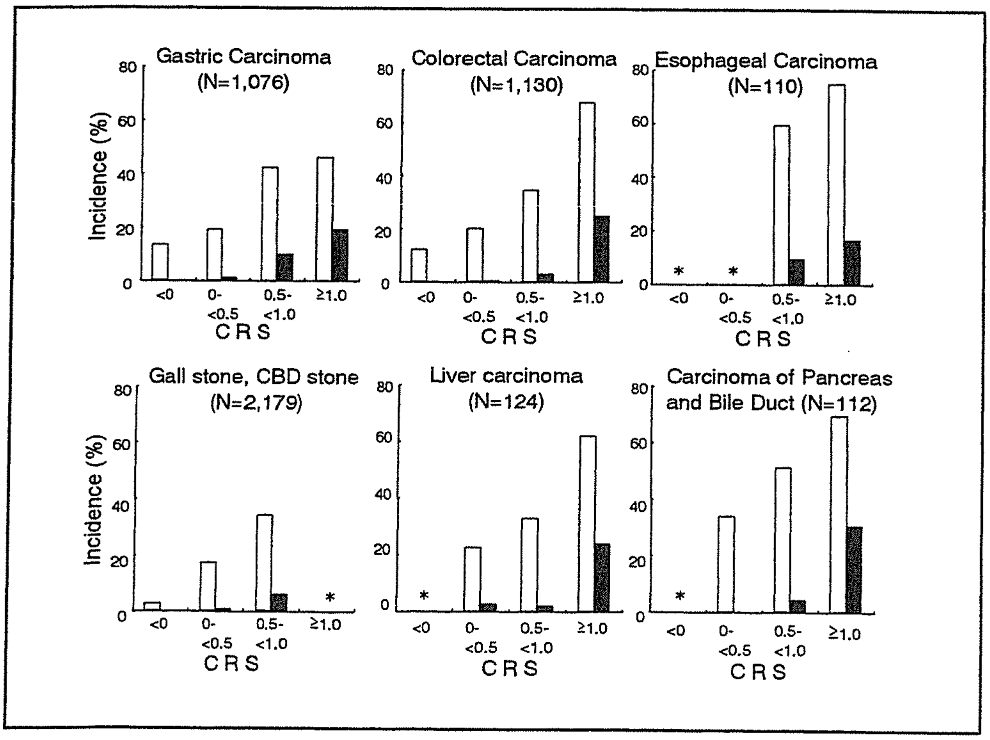
Fig.5. Accuracy of the estimated mortality rates in Estimated Physiologic Ability and Surgical Stress (E-PASS), Physiological and Operative Severity Score for the enUmera-tion for Mortality and morbidity (POSSUM), and Portsmouth-POSSUM (P-POSSUM)
The observed- to estimated-mortality rates at five ranges of risk were computed in 1,934 patients of Group B.

Fig.6. Results of quality care determined by the Estimated Physiologic Ability and Sur-gical Stress (E-PASS), Physiological and Operative Severity Score for the enUmeration for Mortality and morbidity (POSSUM), and Portsmouth-POSSUM (P-POSSUM)
The observed- to estimated ratios (OE ratio) among six hospitals of Group B were de-termined by the E-PASS for 30-day and in-hospital mortality, the POSSUM for 30-day mortality and the P-POSSUM for in-hospital mortality. Each coordinate indicates the OE ratio of each hospital. Left: The OE ratios determined by the E-PASS for 30-day mortality had a significant correlation with those by the POSSUM for 30-day mortality. Right: The OE ratios determined by the E-PASS for in-hospital mortality had a signifi-cant correlation with those by the P-POSSUM for in-hospital mortality. Dotted lines indicate the 95% confidence limits.

Fig.7. Relation between Comprehensive Risk Score (CRS) and TRP (Total Risk Points)

In both groups A and B, there were significant correlations between the CRS and TRP.


Morbidity Rate
In-hospital Mortality rate
30-day Mortality rate
Incidence (%)
N=2,238
N=2,137
N=686
N=126
N=25
<0
0–<0.5
0.5–<1.0
1.0–<1.5
≥1.5
C R S


Gastric Carcinoma (N=1,076)
Colorectal Carcinoma (N=1,130)
Esophageal Carcinoma (N=110)
Gall stone, CBD stone (N=2,179)
Liver carcinoma (N=124)
Carcinoma of Pancreas and Bile Duct (N=112)
Incidence (%)
<0
0-<0.5
0.5-<1.0
≥1.0
C R S

1