ORIGINAL ARTICLE

Outcome prediction in cardiac surgery: the first logistic scoring model for cardiac surgical intensive care patients

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ABSTRACT

Background. In the process of risk stratification, a logistic calculation of mortality risk in percentage is easier to interpret. Unfortunately, there is no reliable logistic model available for postoperative intensive care patients. The aim of this study was to present the first logistic model for postoperative mortality risk stratification in cardiac surgical intensive care units. This logistic version is based on our previously presented and established additive model (CASUS) that proved a very high reliability.

Methods. In this prospective study, data from all adult patients admitted to our ICU after cardiac surgery over a period of three years (2007-2009) were collected. The Log-CASUS was developed by weighting the 10 variables of the additive CASUS and adding the number of postoperative day to the model. Risk of mortality is predicted with a logistic regression equation. Statistical performance of the two scores was assessed using calibration (observed/expected mortality ratio), discrimination (area under the receiver operating characteristic curve), and overall correct classification analyses. The outcome measure was ICU mortality.

Results. A total of 4054 adult cardiac surgical patients was admitted to the ICU after cardiac surgery during the study period. The ICU mortality rate was 5.8%. The discriminatory power was very high for both additive (0.865-0.966) and logistic (0.874-0.963) models. The logistic model calibrated well from the first until the 13th postoperative day (0.997-1.002), but the additive model over- or underestimated mortality risk (0.626-1.193).

Conclusion. The logistic model shows statistical superiority. Because of the precise weighing the individual risk factors, it offers a reliable risk prediction. It is easier to interpret and to facilitate the integration of mortality risk stratification into the daily management more than the additive one. *(Minerva Anestesiol 2012;78:879-86)*

Key words: Mortality - Intensive Care Units - Cardiac surgical procedures.

The Cardiac Surgery Score (CASUS) (Table I) was developed by our group in 2005 as a tool for daily risk stratification in patients admitted to the Intensive Care Unit (ICU) after cardiac surgery.[1] It was recently validated in a population of 6007 patients [2] and proved also high reliability in two other independent patients' subsets.[3, 4] This score is a simple additive model. Its points are allocated for dysfunction of 6 organ systems, whereas the total number of these points provides an estimated risk of mortality (range 0-40). The additive CASUS can be easily calculated. However, although simplicity of an additive version is an important facet, this

TABLE I.—*The additive Cardiac Surgery Score (CASUS).*

Organ system	Descriptor	Score points 0	1	2	3	4
Respiratory	PaO_2 / FiO_2	Extubated	>250	151-250	75-150	<75
Renal	S. creatinine (mg/dL)	<1.2	1.2-2.2	2.3-4.0	4.1-5.5	>5.5
	CVVH/Dialysis	No	—	—	—	Yes
Liver	S. bilirubin (mg/dL)	<1.2	1.2-3.5	3.6-7	7.1-14.0	>14
Cardiovascular	PAR = HR x CVP / MAP	<10.1	10.1-15	15.1-20	20.1-30	>30
	Lactic acid (mmol/L)	<2.1	2.1-4.0	4.1-8	8.1-12	>12
	Intra-aortic balloon pump	No	—	—	—	Yes
	Ventricular assist device	No	—	—	—	Yes
Coagulation	Platelets x 10^3/µL	>120	81–20	51-80	21-50	<21
Central nervous	Neurologic state	Normal	—	Confused	Sedated	Focal neuropathy

CVP: central venous pressure; CVVH: continuous venovenous hemofiltration; FiO_2: fraction of inspired oxygen; HR: heart rate; MAP: mean arterial blood pressure; PAR: pressure-adjusted heart rate; PaO_2: partial oxygen pressure; S: serum.

method of calculation (simple addition) has two main problems; first, it is not easy to interpret; as this risk profile can only be compared between two different patients (*e.g.*, a patient with five CASUS points has a lower risk of mortality than that with nine points). Nevertheless, it is neither easy nor accurate to translate these points into a probability of mortality in percent based only on rough estimation. This expression in percentage is oftentimes useful or even necessary for physicians or patients and their relatives. This can be only achieved by using a reliable logistic model.

The second problem of an additive score is that some levels of dysfunction in different organs might receive the same number of points, whilst they have a totally different impact on the outcome. For example, both an implantation of a ventricular assist device (VAD) and a thrombocytic count less than 21000 µL score four points in the additive CASUS. These two conditions have definitively different impacts on the outcome. In contrast to that, these two variables have two different coefficients in the logistic version and produce a totally different probability of mortality. In this study we present the first logistic scoring model specifically developed for postoperative cardiac surgical patients.

Materials and methods

The study included an evaluation of prospectively collected data of all consecutive adult patients admitted to our ICU after cardiac surgery between January 1st, 2007 and December 31st 2009 to create the logistic version of the additive CASUS score. It was approved by the Institutional Review Board of our university (approval number: 2809-05/10).

We considered only the first admission for patients who were readmitted to the ICU during the study period. Demographic and laboratory data were collected from our quality control system QIMS 2.5 (University Hospital of Muenster, Germany) and from our intensive care information system COPRA 5.24 (COPRASYSTEM GmbH, Sasbachwalden, Germany), which is interfaced with the patient monitors (Philips IntelliVue MP70, Amsterdam, Netherlands), ventilators (Draeger Evita IV, Luebeck, Germany and Hamilton Galileo, Bonaduz, Swizerland), blood gas analyzing devices (ABL 800Flex Radiometer, Copenhagen, Denmark) and the central laboratories. The attending physician collected the data daily. Two assigned medical clerks validated the data collection daily. A senior consultant performed a second periodic validation. Inconsistency between the evaluators was resolved by consensus. There were no missing data. Outcome was defined as ICU mortality.

The calculation of both additive and logistic CASUS scores was based on the most abnormal value for each variable per day as described in previous studies.[1-3]

TABLE II.—*A summary of the logistic CASUS descriptors and their β – coefficients and their distribution in the study population.*

Descriptor		β – coefficient	Mean values of continuous variables (ICU day 1)	Number of patients in categorical variables (ICU day 1)
PaO_2 / FiO_2		-0.0	244.4±114.0	
Serum creatinine (mg/dL)		0.3	1.1±0.7	
CVVH/Dialysis	No	0.0		3951 (97.4%)
	Yes	0.4		103 (2.5%)
Serum bilirubin (mg/dL)		0.2	0.7±0.8 (median: 0.6; range: 0.0-26.7)	
PAR = HR x CVP / MAP		0.0	15.6±7.1	
Lactic acid (mmol/L)		0.2	2.8±3.2 (median: 1.5; range: 0.5-28.0)	
IABP	No	0.0		3750 (92.5%)
	Yes	0.6		304 (7.5%)
VAD	No	0.0		3984 (98.2%)
	Yes	2.2		70 (1.7%)
Platelets x 10^3/µL		-0.0	145.7±56.2	
Neurologic state	Normal	0.0		723 (17.8%)
	Confused	0.4		73 (1.8%)
	Sedated	0.7		3222 (79.4%)
	Focal neuropathy	1.4		36 (0.8%)
Postoperative day	1	0.0		4054
	2	0.0		4008
	3	0.8		1847
	4	1.0		1257
	5	1.2		902
	6	1.4		696
	7	1.6		557
	8	1.9		461
	9	2.1		387
	10	2.2		343
	11	2.2		317
	12	2.3		289
	≥13	2.5		269
Constant		-5.6		

CVP: central venous pressure; CVVH: continuous venovenous hemofiltration; FiO_2: fraction of inspired oxygen; HR: heart rate; MAP: mean arterial blood pressure; PAR: pressure-adjusted heart rate; PaO_2: partial oxygen pressure; IABP: intra-òaortic balloon pump; VAD: ventricular assist device.

Score calculation

The Log-CASUS provides a percentage of predicted mortality risk. It is calculated using the formula (probability of outcome):

Predicted mortality= $exp(\beta_0 + \beta_1 {*} x_1 + \beta_2 {*} x_2 + \ldots + \beta_i {*} x_i) / (1 + exp(\beta_0 + \beta_1 {*} x_1 + \beta_2 {*} x_2 + \ldots + \beta_i {*} x_i))$, where β_0 is the constant of the logistic regression equation and β_i is the coefficient of a variable (Table II). In the Log-CASUS we have two different kinds of variables. There are six continuous variables (partial oxygen pressure/fraction of inspired oxygen, serum creatinine, serum bilirubin, pressure-adjusted heart rate, lactic acid and platelets count) and five categorical variables (continuous venovenous hemofiltration/dialysis, intraaortic balloon pump, ventricular assist device, neurological status and ICU-day). The X_i of the continuous variables corresponds to the given value of this variable. For the categorical variables, X_i = 1 when this category of the variable present and X_i = 0 when it is absent.

Statistical analyses

All analyses were performed using SPSS software version 18 (SPSS Inc, Chicago, IL, USA). The graphics were constructed using SigmaPlot software version 11.0 (Systat Software Inc, San Jose, CA, USA). Continuous scale data are presented as mean ± standard deviation and were analyzed by the two-tailed Student's *t*-test for independent samples. A value of $p < 0.05$ was considered significant.

Discrimination (ability of a scoring model to differentiate between survival and mortality) was evaluated with receiver-operating-characteristic (ROC) curves, which plot the sensitivity (true positive) against 1-specificity (false positive). The area under the curve (AUC) indicates the discriminative ability of parameters, which means the ability to discriminate survivors from non-survivors. An AUC of 0.5 (a diagonal line) is equivalent to random chance,[5] whereas an AUC of 1.0 implies perfect discrimination.[6] Comparison of ROC curves was performed using the method of DeLong *et al.*[7]

Overall correct classification (OCC) (the ratio of correctly predicted survival and mortality to the total number of patient) values were calculated. Calibration was analyzed according to the observed/expected ratio (O/E ratio), which represents the ratio of the actual observed (O) mortality (ICU mortality in this study) to the predicted (expected) mortality (E) by the score model. Statistical analyses were performed from ICU day 1 (operative day) (N.=4054) to day 13 (N.=269).

Results

This study included 4054 ICU patients admitted over a period of three years (2007-2009). The preoperative characteristics of the study population and the types of operative procedures are shown in Table III. Table II demonstrates the number of patients in each category and the mean values of continuous variables of the logistic CASUS model.

Table IV summarizes the overall correct classification, the discriminatory power (AUCs) and the calibration of both additive and logistic CASUS models. Both scores had good discrimination on all days with AUCs of ≥0.874 for the logistic and ≥0.865 for the additive model; the best results were on day 2 (additive: 0.966; logistic: 0.963). Figure 1 demonstrates the ROC curves of both models in the first two postoperative days. The DeLong analysis showed a significant p-value in favor of the logistic model on ICU days 5-8 and 11-13. For the day 1-4 and 9-10 the differences between AUCs of both score models were not significant.

The best OCC levels were on the second day (logistic: 96.8 %; additive: 96.6%). However, the minimum OCC value for additive CASUS was on the 12th day (83.7) and for the logistic CASUS was on the tenth day (84.8). The calibration of the logistic model was excellent for all days (Table IV). It ranged between 0.9973 and 1.0020. In contrast, the additive model overestimated the risk of mortality from the first until the seventh postoperative day (O/E <1), but underestimated it from ninth until the 13th postoperative day (O/E >1). Figure 2 compares the O/E ratios of both models from the first until the 13th postoperative day. This overview shows the stability of the logistic model in comparison to the additive version throughout the study period. The β-coefficients for the given ICU-days were high (Table II) and showed a steep increase progressively from the first until the 13th postoperative day, after which it remained stable. This

Table III.—*Preoperative and operative characteristics in study population.*

Variable	All patients (N.=4054)
Age in years (mean ± SD)	66.7±10.9
Female (%)	1175 (29)
Body mass index (kg/m²)	27.8±4.4
Elective operations (%)	2569 (63.4)
Urgent operations (%)	868 (21.4)
Emergent operations (%)	617 (15.2)
NYHA I	362 (8.9)
NYHA II	1207 (29.8)
NYHA III	2014 (49.7)
NYHA IV	471 (11.6)
On-pump CABG (%)	1421 (35.1)
Off-pump CABG (%)	723 (17.8)
Isolated conventional valve surgery (%)	698 (17.2)
Minimal access valve surgery (%)	225 (5.6)
Combined CABG and Valve surgery (%)	538 (13.3)
Ascending aorta surgery (%)	254 (6.2)
Cardiac transplantation (%)	42 (1)
Other cardiac operations (%)	153 (3.8)

CABG: coronary artery bypass grafting; NYHA: New York Heart Association classification of heart failure.

Table IV.—*Statistical results.*

Day (n)	Scoring model	OCC %	ROC-analysis AUC	ROC-analysis 95%-CI	DeLong P-value*	O/E ratio
Preoperative	Add-Euro	94.1	0.734	0.699-0.769	0.8749	0.9206
(4054)	Log-Euro	94.1	0.732	0.697-0.767		0.5859
ICU-day¶ 1	Add-CASUS	95.4	0.915	0.896-0.935	0.1631	0.6304
(4054)	Log-CASUS	96.0	0.921	0.901-0.940		1.0006
ICU-day 2	Add-CASUS	96.6	0.966	0.956-0.975	0.8541	0.6264
(4008)	Log-CASUS	96.8	0.963	0.952-0.974		0.9973
ICU-day 3	Add-CASUS	93.6	0.941	0.926-0.956	0.5311	0.7946
(1847)	Log-CASUS	94.0	0.946	0.931-0.961		0.9984
ICU-day 4	Add-CASUS	91.6	0.931	0.913-0.949	0.2066	0.8320
(1257)	Log-CASUS	92.8	0.939	0.921-0.957		0.9992
ICU-day 5	Add-CASUS	89.8	0.918	0.896-0.941	0.0269	0.8735
(902)	Log-CASUS	90.9	0.932	0.911-0.953		0.9984
ICU-day 6	Add-CASUS	88.4	0.903	0.876-0.931	0.0021	0.9394
(696)	Log-CASUS	90.5	0.919	0.894-0.945		1.0020
ICU-day 7	Add-CASUS	87.1	0.903	0.875-0.930	0.0093	0.9593
(557)	Log-CASUS	88.2	0.916	0.889-0.942		0.9995
ICU-day 8	Add-CASUS	85.9	0.903	0.873-0.933	0.0210	1.0190
(461)	Log-CASUS	88.1	0.914	0.885-0.944		1.0004
ICU-day 9	Add-CASUS	85.3	0.881	0.842-0.920	0.0509	1.0904
(387)	Log-CASUS	86.3	0.890	0.854-0.926		0.9994
ICU-day 10	Add-CASUS	84.5	0.867	0.822-0.912	0.1324	1.1050
(343)	Log-CASUS	84.8	0.874	0.832-0.916		1.0004
ICU-day 11	Add-CASUS	84.5	0.868	0.822-0.915	<0.0001	1.1076
(317)	Log-CASUS	85.9	0.889	0.847-0.931		1.0011
ICU-day 12	Add-CASUS	83.7	0.865	0.815-0.915	<0.0001	1.1564
(289)	Log-CASUS	85.5	0.885	0.843-0.928		1.0004
ICU-day 13	Add-CASUS	86.2	0.877	0.828-0.925	<0.0001	1.1934
(269)	Log-CASUS	86.2	0.901	0.861-0.941		1.0015

Results of overall correct classification, discrimination (receiver operating characteristic), AUC comparison by DeLong method and calibration (O/E ratio) for the two preoperative EuroSCOREs and for additive and logistic CASUS from day 1 until day 13. 95%-CI: 95%-confidence interval; Add-CASUS: additive CASUS; Add-Euro: additive EuroSCORE; AUC: area under ROC-curve; ICU-day: intensive care unit day; Log-CASUS: logistic CASUS; Log-Euro: logistic EuroSCORE; O/E ratio: observed/expected ratio; OCC: overall correct classification; ROC: receiver operating characteristic. * P-value of the DeLong method, which compares the additive and the logistic models.

course (steep and then plateau) is clearly demonstrated in Figure 3. The ICU mortality was 5.8% (N.=235). Figure 4 shows the distribution of mortality on ICU length of stay (length of stay among the deceased patients).

Discussion

Mortality risk stratification in cardiac surgical patients

In this study we present the first intensive care logistic scoring model (logistic CASUS) specifically developed for postoperative risk stratification in cardiac surgical patients. This logistic version represents an improvement and facilitates the interpretation of the additive CASUS score that already proved a very high reliability in previous studies.[1-4]

Cardiac surgical patients show temporary adverse effects and patho-physiological consequences,[8, 9] which may influence many variables in ICU scoring systems.[10] However, most of these patho-pysiological changes after cardiac surgery are temporary and even self-limiting and do not have much influence on the outcome of these patients. The additive CASUS [1, 2] was proposed as a specialized scoring system which took into account these particular circumstances. It was considered to be the first ICU scoring system that was specifically developed for cardiac surgical ICUs. A previous comparison of CASUS

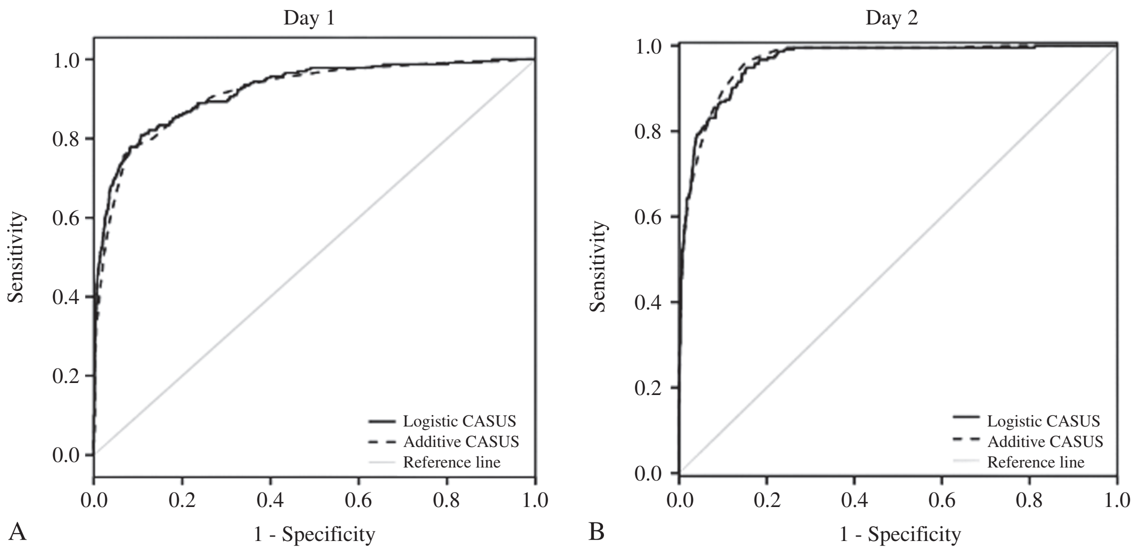

Figure 1.—Receiver operating characteristic curves of both additive- and logistic-CASUS in the first two postoperative days.

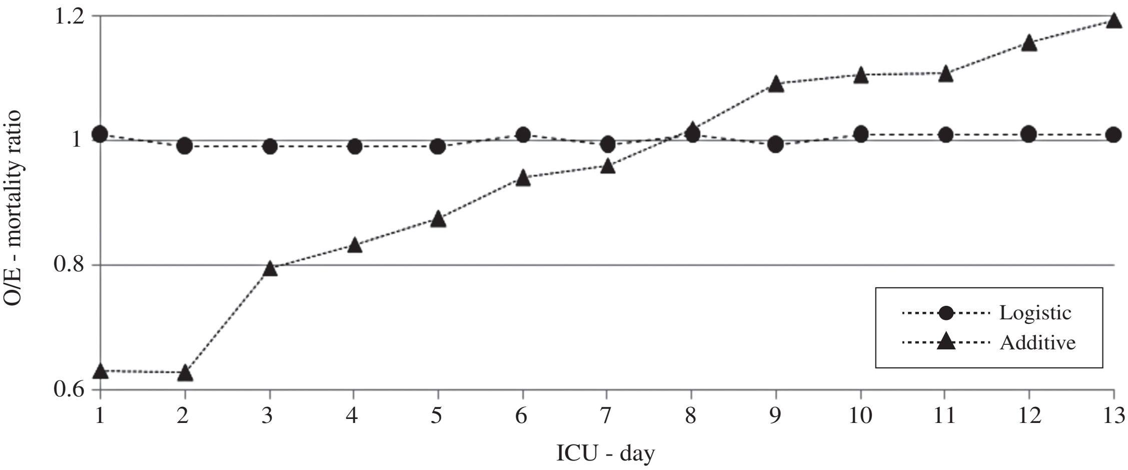

Figure 2.—Observed/Expected mortality ratio of both additive- and logistic-CASUS from day one until day 13.

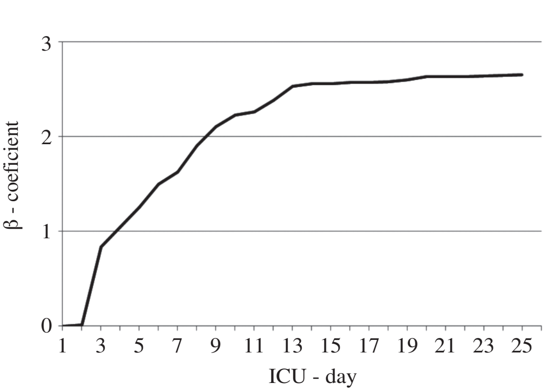

Figure 3.—β-coefficients of intensive care unit day.

with the very popular SOFA model [4] concluded the superiority and the better applicability of the additive CASUS in this patients' subset. However, we believe that even a very reliable additive scoring model can never overcome the statistical accuracy and the practical applicability of a logistic one.

Why do we need a logistic scoring model?

Interest in measuring mortality and outcome in patients undergoing cardiac surgery is increas-

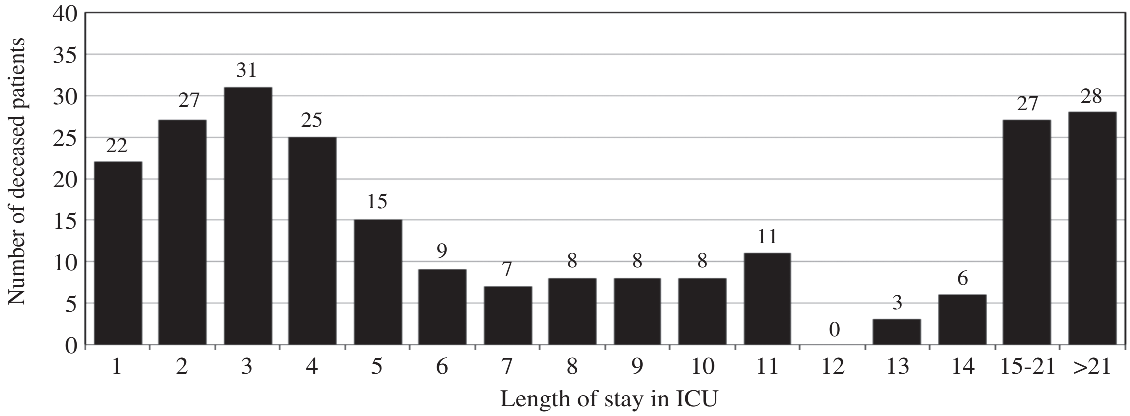

Figure 4.—Length of ICU-stay among the deceased patients.

ing.[11] This necessitates a model that is reliable and reproducible; a model with clear output value that avoids any misinterpretation or imprecise estimation.

Most intensivists intuitively know that combining the risk factors of blood lactate level of for example 28,5 mmol/l with two weeks ICU length of stay would result in a situation of virtually zero survival. However, additive CASUS would only reflect the mortality risk as 4 points out of 40 for such a patient, whilst the logistic CASUS gives a more realistic prediction of an 82.6% mortality rate.

Integration of postoperative day into the logistic CASUS

A shortcoming of the additive CASUS is that it does not include the number of the postoperative day. Many organ dysfunctions do not evolve in the early phase after cardiac surgery, particularly among elective surgical patients who are often free of organ dysfunction when admitted to the ICU.[12] The new logistic CASUS predicts risk of mortality by combining the weighted organ dysfunction variables from the additive model with the weighted coefficient of the given postoperative day (present ICU length of stay). From Table II, we can conclude that the ICU day has a relatively high coefficient that is comparable or even exceeds those of other very important variables such as VADs and IABP. This value can not be overlooked in the process of mortality risk stratification. It is true that the long ICU stay could be considered as morbidity itself that could be observed retrospectively after death or ICU discharge, which limits its role in foretelling the probability of mortality. We overcame this limitation in our logistic CASUS score by calculating the effect of ICU length of stay on outcome daily and not retrospectively after ICU discharge. This means that the number of the present ICU day is considered and not the length of stay collectively, which allows this logistic version to be used on daily basis and not once after ICU discharge.

Value of logistic scores in previous studies

O/E-ratio has been used for qualitative calibration of scoring models, and this method has been used to compare different additive and logistic EuroSCORE subgroups.[13] Jin *et al*. reported that the additive EuroSCORE gave larger O/E differences than the logistic model in high-risk patients.[14] Michel *et al*. analyzed the difference between the logistic EuroSCORE and the standard additive model. They observed an accurate mortality prediction of the logistic EuroSCORE and a less precise statistical performance of the additive EuroSCORE.[15] Similar to Michel *et al*. we observed the superiority of the logistic version. The analyses showed that the additive CASUS overestimated mortality risk on ICU days 1-7 and underestimated it on ICU days 9-13, while the logistic CASUS had a steady estimation of mortality risk all through (Figure

2). Our direct comparison of the logistic EuroSCORE and the additive CASUS showed a clear superiority of our new logistic CASUS model (Table IV). This should not be surprising since the EuroSCORE is limited to preoperative variables whereas our logistic models are based on postoperative variables, in which the influence of surgery is reflected in the score variables.

Limitations of the study

The presented results of this single centre study are based on a population of 4054 patients. An external validation of the logistic CASUS in an external independent patient subset is strongly recommended.

Conclusions

The Log-CASUS is the first logistic model for daily risk stratification in postoperative cardiac surgical ICU patients. In contrast to an additive model a logistic score offers a precise and realistic percentage of mortality risk for a given ICU-day. This has a clear advantage in the communication with patients and relatives.

Key messages

— We present the worldwide first true ICU logistic scoring model with β – coefficients for each descriptor.

— The consideration of the ICU day in the new scoring model is very valuable, and so far not a descriptor of any other general ICU score.

— The new score may serve as an Expert System for diagnosing organ failure, decision making, resource evaluation, and predicting mortality in ICU cardiac surgical patients.

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