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The Utility of the Additive EuroSCORE, RIFLE and AKIN Staging Scores in the Prediction and Diagnosis of Acute Kidney Injury after Cardiac Surgery

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Abstract

Background/Aims—Acute kidney injury (AKI) following cardiac surgery is a complication associated with high rates of morbidity and mortality. We compared staging systems for the diagnosis of AKI after cardiac surgery, and assessed preoperative factors predictive of post-operative AKI.

Methods—Clinical data, surgical risk scores, procedure and clinical outcome were obtained on all 4,651 patients undergoing cardiac surgery to the Royal Infirmary of Edinburgh between April 2006 and March 2011, of whom 4,572 had sufficient measurements of creatinine before and after surgery to permit inclusion and analysis. The presence of AKI was assessed using the AKIN and RIFLE criteria.

Results—By AKIN criteria, 12.4% of the studied population developed AKI versus 6.5% by RIFLE criteria. Any post-operation AKI was associated with increased mortality from 2.2 to 13.5% (relative risk 7.0, $p < 0.001$), and increased inpatient stay from a median of 7 (IQR 4) to 9 (IQR 11) days ($p < 0.05$). Patients identified by AKIN, but not RIFLE, had a mean peak creatinine rise of 34% from baseline and had a significantly lower mortality com pared to RIFLE-'Risk' AKI (mortality 6.1 vs. 9.7%; $p < 0.05$). Pre-operative creatinine, diabetes, NYHA Class IV dyspnoea and EuroSCORE-1 (a surgical risk score) all predicted subsequent AKI on multivariate analysis. EuroSCORE-1 outperformed any single demographic factor in predicting postoperative AKI risk, equating to an 8% increase in relative risk for each additional point.

Conclusion—AKI after cardiac surgery is associated with delayed discharge and high mortality rates. The AKIN and RIFLE criteria identify patients at a range of AKI severity levels suitable for

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trial recruitment. The utility of EuroSCORE as a risk stratification tool to identify high AKI-risk subjects for prospective intervention merits further study.

Keywords

Acute kidney injury; AKIN score; Cardiac surgery; EuroSCORE; RIFLE criteria

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Introduction

Despite advances in percutaneous techniques, cardiac surgery remains the standard of care for the revascularisation of the most severe patterns of coronary artery disease [1,2]. Acute kidney injury (AKI) is a common complication of such surgery, and is associated with markedly increased rates of morbidity and mortality even after adjustment for pre-operative co-morbidities [3]. In addition to its impact on patient outcomes, AKI has marked health-economic implications, with extended inpatient stays and increases in hospital costs [4].

Despite the publication of two consensus statements from the Acute Dialysis Quality Initiative (RIFLE - Risk/ Injury/Failure/Loss/End-Stage) and Acute Kidney Injury Network (AKIN) consortia [5–7] offering standardised criteria for the diagnosis of AKI, there continues to be wide heterogeneity in the reported incidence of AKI after cardiac surgery ranging from as little as 1.2 to 39% [8–11] depending on the diagnostic criteria used. An understanding of incidence rates and outcomes is of key importance to gauge the success of current clinical practices, but also to facilitate appropriate powering of studies designed to investigate novel therapies and interventions targeting AKI prevention and treatment.

This work evaluated the incidence of AKI in a contemporary tertiary cardiac surgical unit using the AKIN and RIFLE staging criteria, assessing the impact of a diagnosis of AKI by either criteria on patient mortality and duration of inpatient stay. Patient factors present pre-operatively that predicted AKI on univariate and multivariate analysis were identified to facilitate the prospective identification of ‘high AKI-risk’ patients for recruitment into future clinical studies of AKI prophylaxis.

Subjects and Methods

Study Population

We identified 4,651 consecutive patients undergoing cardiac surgery in a 5-year period at the Royal Infirmary, Edinburgh, United Kingdom, between April 1, 2006 and March 31, 2011. A range of pre-operative, peri-operative and outcome details for each case had been prospectively recorded as part of unit contributions to an ongoing national audit of cardiac surgical outcomes, with appropriate hospital research ethics committee permissions in place. Follow-up was complete for all participants to time of death or hospital discharge.

Clinical Characteristics and Outcome

Clinical characteristics, cardiovascular risk factors and the urgency and nature of the surgery undertaken were documented. A pre-operative additive and logistic EuroSCORE-1 [12], a validated tool for the prediction of operative mortality, was available for each patient (see

table 1 for breakdown of EuroSCORE-1). Preoperative and post-operative creatinine values were obtained through the TrakCare software application (InterSystems Corporation, Cambridge, Mass., USA), an electronic patient record system used by the Acute Hospitals Division of Lothian National Health Service Health Board, Scotland. The absolute creatinine rise in pmol/l and percentage change from baseline in the 48 h after surgery were calculated and used to establish the presence and severity of AKI, using the criteria proposed by AKIN [6] as follows:

- Stage 1: increase in serum creatinine ≥26.5 μmol/l (≥0.3 mg/ dl) or increase to ≥150-199% (1.5- to 1.9-fold) from baseline
- Stage 2: increase in serum creatinine to 200-299% (>2- to 2.9- fold) from baseline
- Stage 3: increase in serum creatinine to ≥300% (>3-fold) from baseline or serum creatinine 354 μmol/l (≥4.0 mg/dl) with an acute rise of at least 44 μmol/l (0.5 mg/dl) or initiation of renal replacement therapy (RRT).

These were compared to the RIFLE criteria for the diagnosis of early AKI [5], where the 'Risk' definition is based on a creatinine increase to ≥150-199% (1.5- to 1.9-fold) from baseline. Key outcome measures were diagnosis of new AKI, need for RRT, length of inpatient stay and inpatient death.

Statistical Analysis

Data were analysed using SPSS Statistics version 19.0 (IBM, Armonk, N.Y., USA). Univariate analysis to identify predictors of adverse clinical outcome was performed using Pearson's χ^2 tests for categorical variables and a 2-sample t test for continuous variables (e.g. age, weight and creatinine). Variables found to be related to outcomes and those that indicated significance (at the 10% level) were included in a multivariate binary logistic regression model. Statistical significance was set at 2-sided $p < 0.05$, with Bonferroni correction for multiple comparisons.

Results

Baseline Characteristics of the Studied Population

Data were collected from 4,651 consecutive patients undergoing cardiac surgery at the Royal Infirmary of Edinburgh between April 1, 2006 and March 31, 2011, of whom 4,572 had the necessary data relating to baseline renal function and post-operative renal function in the 48 h after surgery. Data were available for all other variables studied in a minimum of 95% of the patients. Baseline pre-operative characteristics stratified by the development of post-operative AKI are summarised in table 2. This illustrates an overall incidence of AKI (AKIN stages 1-3) of 12.8% over the 5-year period studied, with 1.4% of all patients in the study requiring RRT.

Impact of AKI on Length of Inpatient Stay and Mortality following Elective and Emergency Cardiac Surgery

The impact of degree of AKI on length of inpatient stay and risk of mortality is summarised in table 3. This demonstrates that with as little as a 26.5-μmol/l absolute rise (and <100% relative rise) in peak post-operative serum creatinine (AKIN stage 1), there is an increase in length of inpatient stay (7 vs. 9 days; $p < 0.05$; no AKI vs. AKIN 1). Of note, mortality rose by >3-fold in AKIN 1 compared to patients without AKI (2.2 vs. 7.5%, No AKI vs. AKIN 1; $p < 0.05$), with a further rise to 12.5% with AKIN stage 2 ($p < 0.05$ vs. all groups). AKIN stage 3 (including patients requiring RRT) was associated with a >20-fold increased risk of death compared to those with no postoperative AKI (inpatient mortality 2.2 vs. 50%, no AKI vs. AKIN 3; $p < 0.05$).

Comparison of RIFLE and AKIN Criteria for Diagnosis of Early-Stage AKI

A key difference between the RIFLE and AKIN systems for the diagnosis of AKI relates to the additional criteria of a rise of ≥26.5 μmol/l in serum creatinine leading to the diagnosis of AKIN stage 1. We re-examined our dataset of early AKI (peak creatinine rise <100% over baseline) and classified patients as ‘no AKI’, AKIN stage 1a (creatinine rise of ≥26.5 μmol/l, but <50% baseline) and AKIN stage 1b/RIFLE-’Risk’ (peak creatinine rise ≥50%, <100% over baseline). Use of the AKIN criteria resulted in an additional 279 patients being diagnosed with AKIN stage 1 (total n = 455) compared to RIFLE-’Risk’ (n = 176), increasing ‘early AKI’ diagnoses from 3.8 to 10.0% of the study population. The characteristics of these ‘early’ AKI groups are summarised in table 4. Individuals who were RIFLE negative but AKIN 1a positive had a significantly lower risk of death than AKIN 1b/RIFLE-’Risk’ (mortality 9.7 vs. 6.1 vs. 2.2%, AKIN 1b vs. AKIN 1a vs. No AKI; $p < 0.05$ AKIN 1b vs. both groups).

Factors Associated with the Development of AKI following Cardiac Surgery

Univariate analysis of pre-operative characteristics was undertaken to assess those associated with subsequent development of AKI. The EuroSCORE composite score of predicted surgical mortality risk was also analysed to assess its potential utility as a predictor of AKI risk (for components of the additive EuroSCORE see table 1). This demonstrated that patient factors such as increasing age, pre-existing CKD (identified by a baseline eGFR <60 ml/min), NYHA IV dyspnoea, LV ejection fraction <30%, diabetes mellitus, a history of hypertension and admission weight, and pre-operative factors such as the presence of cardiogenic shock, pre-operative intra-aortic balloon pump use and a procedure other than coronary artery bypass grafting alone were all associated with subsequent AKI (table 2).

Patients with AKI also had higher pre-operative EuroSCORES (additive EuroSCORE 4.8 ± 3.1 vs. 6.5 ± 3.6, no AKI vs. AKI; $p < 0.05$). Suffering any AKI was associated with a >5-fold increase in risk of death (inpatient mortality 2.2 vs. 13.5%, no AKI vs. AKI; $p < 0.001$).

Multivariate Analysis of Pre-Operative Factors Predicting Subsequent AKI

In order to assess the key factors in predicting AKI outcome after surgery, all pre-operative factors significant on univariate analysis were entered into a binary logistic regression model.

After multiple regression, pre-operative creatinine [relative risk (RR) of AKI 1.009 per μmol/l (95% CI: 1.0061-1.011), $p < 0.001$], diabetes [RR 1.533 (95% CI: 1.239-1.897), $p < 0.001$], NYHA IV dyspnoea [RR 1.873 (95% CI: 1.354-2.591), $p < 0.001$], weight [RR 1.005 per kg (95% CI: 1.001-1.010), $p = 0.01$], cardiac procedure other than valve or cardiac bypass surgery [RR 3.807 (95% CI: 1.7978.067), $p < 0.001$] and additive EuroSCORE-1 [RR 1.083 (95% CI: 1.036-1.132), $p < 0.001$] were significant predictors of the development of post-operative AKI. It is of note that EuroSCORE-1 achieved the most significant correlate on multivariate analysis, with each additional risk point equating to an 8% increase in RR of AKI. Furthermore, on receiver operating characteristic analysis of EuroSCORE-1 as a predictor for post-operative AKI, the area under the curve was 0.634 (95% CI: 0.609-0.658, $p < 0.001$) whilst the Hosmer-Lemeshow test value was 0.08.

Impact of AKI and RRT on Outcome

Increasing severity grade of AKI was associated with significant stepwise increases in mortality and in length of hospital stay (table 3; $p < 0.05$ between all groups for mortality, $p < 0.05$ AKIN 3 vs. AKIN 1 and $p < 0.05$ AKIN 1/2/3 vs. no AKI). The 62 patients with AKIN stage 3 who required RRT exhibited the highest mortality (54.8 vs. 28.6%, AKIN-3 + RRT vs. AKIN-3 no RRT; $p < 0.001$). Pre-operative factors and peri-operative factors associated with mortality were assessed using univariate analysis (table 5). Notably, many of the factors significantly associated with AKI risk also predicted risk of death and contributed to the score of the additive EuroSCORE-1.

Multivariate analysis of all factors associated with inpatient mortality on univariate analysis was undertaken. Only EuroSCORE-1 [adjusted RR 1.39 per point (95% CI: 1.14-1.72), $p = 0.001$], baseline creatinine [RR 1.004 per μmol/l (95% CI: 1.000-1.008), $p < 0.05$], any post-operative AKI [RR 2.11 (95% CI: 1.27-3.53), $p < 0.005$] bypass time [RR 1.019 per min (95% CI: 1.013-1.025), $p < 0.001$] and requirement for RRT [RR 14.98 (95% CI: 6.54-34.28), $p < 0.001$] remained significant independent predictors of inpatient mortality.

Discussion

These data demonstrate that AKI remains a common sequela of modern cardiac surgical practice and is associated with significant morbidity and mortality. Whilst the majority of AKI resolves without the requirement for RRT, even in its mildest form (AKIN stage 1) it is associated with a >3-fold increase in mortality rates, rising to greater than 50% mortality when renal replacement was required. The pre-operative serum creatinine level, a diagnosis of diabetes, NHYA stage IV dyspnoea, weight and cardiac procedure other than coronary bypass or valve surgery all predicted risk of subsequent AKI on multivariate analysis, with the composite pre-operative risk score additive EuroSCORE-1 offering the strongest correlation with risk of subsequent AKI.

Our data highlights the impact that diagnostic criteria for AKI have on the reported incidence and outcome of AKI. Until the last decade there was a lack of any true consensus on the definition of AKI, short of the absolute requirement for RRT. This has contributed to widespread variation in the reported incidence of AKI after cardiac surgery, with recent reports ranging from 4.3% (using a definition of >100% creatinine increase) [13] to as high

as 39% [8] (using a definition of a rise of ≥0.3 mg/dl in creatinine). Despite the wide variation in reported total AKI incidence between our data (12.8%) and the study of Englberger et al. [13] (4.3%), it is noteworthy that rates of AKI requiring RRT were similar at 1.4 and 1.7%, respectively.

The advent of the RIFLE and AKIN criteria [5,6] have led to greater uniformity in the diagnosis of early AKI; however, as we demonstrate, at their lowest diagnostic threshold, AKIN scoring more than doubles the incidence of 'early' AKI compared to RIFLE criteria. Of particular interest are those patients fulfilling only the 'mildest' of AKIN stage 1 entry criteria and who are negative by RIFLE assessment (here referred to as AKIN stage 1a). These patients have a mortality rate that was not statistically different from those without AKI in the group sizes studied, and less than half that of those patients positive by both the RIFLE and AKIN definitions, calling into question the clinical significance of the finding in these patients.

Whilst it has been suggested that this subgroup of patients represents a misclassification of AKI [13], we would propose it is of diagnostic importance for two reasons. Firstly, the comparatively low mortality rates in 'no AKI' and 'AKIN stage 1a' mean that our study population size did not deliver power to detect a significant difference in mortality at the 80% confidence level. If confirmed in further studies, the percentage difference between the two (204% higher relative mortality in AKIN stage 1a) would be of clinical importance, and similar work in larger cohorts has demonstrated significant mortality differences at these or similar levels in both cardiac surgery [13] and in general hospitalized patients [14]. Secondly, this phase of early AKI, with low associated mortality, represents a more desirable point for therapeutic intervention with the aim of preventing progression and the attendant mortality burden of higher AKI stages.

Cardiac surgery, and its unavoidable haemodynamic stresses on the perfusion of the kidneys, represents a prototype of a predicable acute renal injury. Attention has been directed to the utility of novel urinary biomarkers such as neutrophil gelatinase-associated lipocalin and kidney injury molecule-1 in this setting as tools to permit the early identification of significant AKI [15–17]. Whilst these assays allow earlier identification of post-operative AKI [17], it is unproven whether this is of solely prognostic interest or can translate into improved outcomes. It may be that identifying patients at elevated AKI risk before surgery represents the most realistic opportunity to improve patient outcome by protecting the kidney via prophylactic interventions [18]. It is worthwhile acknowledging that whilst many pre-emptive interventions have shown efficacy in animal models of AKI [19–21], attempts to improve outcome by translating interventions such as diuretic or dopamine infusion to clinical practice have failed to replicate their success in rodent models [22]. A recent retrospective registry study has suggested that use of pre-operative statins was associated with a reduced risk of post-surgical AKI after multivariate analysis of risk factors [23]. Whilst this finding echoes reports of statin-induced protection in rodent models of AKI [24], whether this effect will persist in prospective studies remains to be established, as does the underlying mechanism in man.

A number of AKI risk estimation systems have been proposed based on pre-operative and peri-operative patient factors. The Cleveland Score [10,25] and Society of Thoracic Surgeons (STS) Bedside Risk Tool [26] have been developed specifically for the prediction of AKI in cardiac surgery patients, and subsequently externally validated. However, their primary outcome is the need for RRT rather than AKI by the AKIN or RIFLE criteria. As the clinical importance of even mild post-operative AKI in this patient cohort becomes apparent, so does the need for identifying those patients at risk. Models do exist to predict non-RRT requiring AKI [8,27,28], but similarly these aim to identify patients at risk of 'severe' AKI - the definition of which varies from a serum creatinine >2 mg/ dl (with an increase of at least 0.7 mg/dl from baseline) or RRT, to a post-operative eGFR <30 ml/min/ 1.73 m^2. None use the AKIN or RIFLE definitions for AKI, thereby again potentially underestimating those who could be identified as being at risk of AKI.

We have demonstrated that, in addition to its primary application in mortality risk prediction, increasing points on the additive EuroSCORE are predictive of subsequent AKI risk. The ease of calculation (and availability of online calculators) coupled with the large cohorts of retrospective EuroSCORE data in registries adds to its potential utility for comparing AKI incidence across centres and the focused recruitment of 'high AKI-risk' patients into prospective clinical studies, given the score can be calculated in the outpatient setting prior to elective surgery.

Whilst scoring systems such as the additive EuroSCORE-1 can allow some estimation of future AKI risk, regrettably there is currently no clinically validated intervention that can be applied to those patients to prevent progression to higher stage AKI, requirement for RRT or mortality. Accordingly, a major driver for better predictors of AKI risk should be to identify suitable patients for further clinical trials aimed at improving outcome for this devastating clinical problem.

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Table 1
The additive EuroSCORE-1 scoring system

	Criteria	Score
Patient-related factors		
Age	(per 5 years or part thereof over 60 years)	1
Sex	female	1
Chronic pulmonary disease	long-term use of bronchodilators or steroids for lung disease	1
Extracardiac arteriopathy	any one or more of the following: claudication, carotid occlusion or >50% stenosis, previous or planned intervention on the abdominal aorta, limb arteries or carotids	2
Neurological dysfunction	severely affecting ambulation or day-to-day functioning	2
Previous cardiac surgery	requiring opening of the pericardium	3
Serum creatinine	>2.3 mg/dl pre-operatively	2
Active endocarditis	patient still under antibiotic treatment for endocarditis at the time of surgery	3
Critical pre-operative state	any one or more of the following: ventricular tachycardia or fibrillation or aborted sudden death, pre-operative cardiac massage, pre-operative ventilation before arrival in the anaesthetic room, pre-operative inotropic support, intra-aortic balloon counter-pulsation or pre-operative acute renal failure (anuria or oliguria <10 ml/h)	3
Cardiac-related factors		
Unstable angina	rest angina requiring i.v. nitrates until arrival in the anaesthetic room	2
LV dysfunction	moderate or LV ejection fraction 30 - 50%	1
	poor or LV ejection fraction <30	3
Recent myocardial infarction	(<90 days)	2
Pulmonary hypertension	systolic PA pressure >60 mm Hg	2
Operation-related factors		
Emergency	carried out on referral before the beginning of the next working day	2
Other than isolated CABG	major cardiac procedure other than or in addition to CABG	2
Surgery on thoracic aorta	for disorder of ascending, arch or descending aorta	3
Post-infarction septal rupture		4

Patients are assessed and scored on pre-operative factors to generate a total additive EuroSCORE-1 [12]. Online calculators can be accessed at http://www.euroscore.org/calcold.html. Reproduced with permission of Sam Nashef. CABG = Coronary artery bypass grafting; PA = pulmonary artery.

Table 2
Characteristics of patient cohorts with and without post-operative AKI

	No AKI (n = 3,985)		Any AKI (n = 587)		P
	mean ± SD/count	column, %	mean ± SD/count	column, %	
Age, years	66.6 ± 11.0		68.7 ± 10.9		<0.001
Sex					0.846
Male	2,819	70.7	413	70.4	
Pre-operative creatinine, pmol/l	94.5 ± 31.5		117.7 ± 68.7		<0.001
eGFR group (MDRD)					<0.001
GFR <60	1,206	31	316	55.1	
GFR 60+	2,687	69	257	44.9	
NYHA					<0.001
I	998	25	105	17.9	
II	1,005	25.2	128	21.8	
III	1,639	41.1	240	40.9	
IV	343	8.6	114	19.4	
Previous MI					<0.001
None	2,689	67.5	364	62	
1	1,031	25.9	157	26.7	
2 or more	257	6.4	66	11.2	
Unknown	8	0.2	0	0	
Last MI					0.031
MI <6 h	0	0.0	1	0.2	
MI >90 days	644	16.2	105	17.9	
MI 1 - 30 days	441	11.1	81	13.8	
MI 31 - 90 days	186	4.7	31	5.3	
MI 6 - 24 h	17	0.4	3	0.5	
No previous MI	2,696	67.7	366	62.4	
LV ejection fraction					<0.001
Good (>50%)	1,772	44.5	228	38.8	
Fair (30 - 49%)	646	16.2	107	18.2	
Poor (<30%)	179	4.5	50	8.5	
Not measured	1,378	34.6	202	34.4	
Hypertension					<0.001
No hypertension	1,023	25.7	90	15.3	
Treated or BP >140/90 on 1 occasion before admission	2,767	69.4	456	77.7	
Claudication					0.128
No	3,472	87.4	498	85.1	
Yes	501	12.6	87	14.9	
Carotid occlusion					0.629
No	3,873	98.2	575	98.5	

	No AKI (n = 3,985)		Any AKI (n = 587)		P
	mean ± SD/count	column, %	mean ± SD/count	column, %	
Yes	72	1.8	9	1.5	
Diabetes mellitus					<0.001
Not diabetic	3,251	81.6	422	71.9	
Diabetic	734	18.4	165	28.1	
Weight, kg	81.2 ± 21.5		83.5 ± 17.2		0.013
Smoking					0.984
Current smoker	567	14.2	84	14.3	
Ex-smoker	2,025	50.8	300	51.1	
Never smoked	1,393	35.0	203	34.6	
Cardiogenic shock					0.02
No	3,944	99.0	572	97.4	
Yes	41	1	15	2.6	
Pre-operative IABP					<0.001
No	3,813	95.7	533	90.8	
Yes	172	4.3	54	9.2	
Cardiac procedure					<0.001
CABG	2,300	57.7	276	47.0	
CABG + other	25	0.6	6	1.0	
CABG + valve	482	12.1	91	15.5	
CABG + valve + other	26	0.7	9	1.5	
Other	89	2.2	34	5.8	
Valve	933	23.4	157	26.7	
Valve + other	130	3.3	14	2.4	
Additive EuroSCORE	4.8 ± 3.1		6.5 ± 3.6		<0.001

Summary of key pre-operative characteristics of subjects stratified by the presence of post-operative AKI. p values quoted were calculated using Pearson χ^2 tests and unpaired t tests with Bonferroni correction. CABG = Coronary artery bypass grafting; IABP = intraaortic balloon pump; MI = myocardial infarction.

Table 3
Patient outcomes stratified by AKIN classification of AKI

	No AKI (n = 3,985)		AKIN stage 1 (n = 455)		AKIN stage 2 (n = 56)		AKIN stage 3 (n = 76)	
	mean ± SD/ count	column	mean ± SD/ count	column	mean ± SD/ count	column	mean ± SD/ count	column
Age, years	66.6 ± 11.0		68.6 ± 11.0[a]		67.7 ± 11.5		70.2 ± 9.6[a]	
Additive EuroSCORE	4.9 ± 3.1		6.2 ± 3.6[a]		7.3 ± 3.9[a]		7.5 ± 3.7[a, b]	
Median length of stay, days	7 (IQR 4)		9 (IQR 8)[c]		11 (IQR 13)[c]		17 (IQR 34)[c]	
Died as inpatient	87	2.2%	34[c]	7.5%	7[c]	12.5%	38[c]	50%

AKIN stage 1: increase in serum creatinine ≥26.5 μmol/l (0.3 mg/dl) or increase to ≥150–199% from baseline. AKIN stage 2: increase in serum creatinine to 200–299% (>2- to 2.9-fold) from baseline. AKIN stage 3: increase in serum creatinine to ≥300% (≥3-fold) from baseline or serum creatinine ≥354 μmol/l (4.0 mg/dl) with an acute rise of at least 44.25 μmol/l (0.5 mg/dl) or initiation of RRT. Stepwise increases in median length of stay and inpatient mortality were noted with increasing AKIN grade.

[a] $p < 0.05$ when compared to no AKI

[b] $p < 0.05$ when compared to AKIN 1

[c] $p < 0.001$ all groups.

Table 4
Comparison of early AKI diagnosis and patient outcome using AKIN and RIFLE criteria

	No AKI (n = 3,985)		AKIN 1a/RIFLE negative (n = 279)		AKIN 1b/RIFLE-'Risk' (n = 176)	
	mean ± SD/count	column, %	mean ± SD/count	column, %	mean ± SD/count	column, %
Age, years	66.6 ± 11.0		68.6 ± 10.6[a]		68.2 ± 11.7	
Pre-operative creatinine, pmol/l	94.5 ± 31.5		127.1 ± 79.8[b]		105.9 ± 44.4[b]	
Peak percentage creatinine rise	−4.2 ± 18.7%		34.1 ± 8.9%[b]		65.7 ± 13.3%[b]	
Median length of stay, days	7 (IQR 4)		9 (IQR 8)[a]		9 (IQR 8)[a]	
Died as inpatient	87	2.2	17[a]	6.1	17[a]	9.7

Patients with peak creatinine rises <100% above pre-operative baseline were classified into groups stratified by positivity by both RIFLE-'Risk' and AKIN stage 1 criteria (peak creatinine ≥50% above baseline), or those positive only by the extended AKIN criteria (increase in serum creatinine of 26.5 μmol/l, referred to as AKIN '1a'). Significant differences between groups on χ^2 testing or comparison of column means are highlighted by superscript.

[a] $p < 0.05$ vs. no AKI

[b] $p < 0.05$ vs. all groups.

Table 5
Characteristics of patient cohorts stratified by inpatient mortality

	Alive (n = 4,406)		Died as inpatient (n = 166)		p
	mean ± SD/count	column, %	mean ± SD/count	column, %	
Pre-operative creatinine	96.6 ± 37.5		120.5 ± 66.2		<0.001
Age, years	66.8 ± 11		70.4 ± 11		<0.001
Sex					<0.05
Female	1,273	28.9	67	40.4	
Male	3,133	71.1	99	59.6	
Dyspnoea status					<0.001
NYHA I	1,073	24.4	30	18.1	
NYHA II	1,110	25.2	23	13.9	
NYHA III	1,807	41	72	43.4	
NYHA IV	416	9.4	41	24.7	
Previous MI					<0.05
None	2,954	67	99	56.9	
One	1,141	25.9	47	28.3	
Two or more	304	6.9	19	11.4	
Unknown	7	0.2	1	0.6	
Active endocarditis					<0.001
yes	87	2	13	7.8	
Last MI					<0.001
MI <6 h	0	0	1	0.6	
MI >90 days	724	16.4	25	15.1	
MI 1 – 30 days	492	11.2	30	18.1	
MI 31 – 90 days	209	4.7	8	4.8	
MI 6 – 24 h	18	0.4	2	1.2	
No previous MI	2,962	67.2	100	60.2	
Hypertension					<0.01
No hypertension	1,084	24.6	29	17.5	
Treated or BP >140/90 on >1 occasion prior to admission	3,102	70.4	121	72.9	
Unknown	220	5	16	9.6	
Smoking					0.93
Current smoker	626	14.2	25	15.1	
Ex-smoker	2,240	50.8	85	51.2	
Never smoked	1,540	35	56	33.7	
Diabetic?					0.143
Not diabetic	3,547	80.5	126	75.9	
Diabetic	859	19.5	40	24.1	
Carotid occlusion					0.985
No	4,285	98.2	163	98.2	

	Alive (n = 4,406)		Died as inpatient (n = 166)		p
	mean ± SD/count	column, %	mean ± SD/count	column, %	
Yes	78	1.8	3	1.8	
Claudication					<0.05
No	3,836	87.3	134	80.7	
Yes	556	12.7	32	19.3	
Additive EuroSCORE	4.9 ± 3.1		9.0 ± 3.8		<0.001
Logistic EuroSCORE (% predicted mortality)	5.9 ± 8.3		18.9 ± 18.2		<0.001
Cardiogenic shock					<0.001
No	4,363	99	153	92.2	
Yes	43	1	13	7.8	
Pre-operative IABP					<0.001
No	4,206	95.5	200	84.5	
Yes	200	4.5	26	15.7	
Cardiac procedure					<0.001
CABG	2,525	57.3	51	30.7	
CABG + other	26	0.6	5	3	
CABG + valve	540	12.3	33	19.9	
CABG + valve + other	28	0.6	7	4.2	
Other	100	2.3	23	13.9	
Valve	1,055	23.9	35	21.1	
Valve + other	132	3.0	12	7.2	
Operative priority					<0.001
Elective	3,288	74.6	89	53.6	
Emergency	132	3	24	14.5	
Salvage	2	0	3	1.8	
Urgent	984	22.3	50	30.1	
Bypass time, min	109 ± 48		160.7 ± 92.7		<0.001
Cross-clamp time, min	79.3 ± 89.5		97.4 ± 54.8		<0.05
Bloods transfused total (red cell concentrate units)	2.1 ± 38.7		4.4 ± 5.8		0.45
Post-operative AKI					<0.001
No	3,906	88.7	97	58.4	
Yes	500	11.3	69	41.6	

Summary of key pre-operative and peri-operative characteristics of subjects stratified by post-operative survival vs. mortality. p values quoted were calculated using Pearson χ^2 tests and unpaired t tests with Bonferroni correction. CABG = Coronary artery bypass grafting; IABP = intra-aortic balloon pump; MI = myocardial infarction.