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Acute kidney injury after infrarenal abdominal aortic aneurysm surgery: a comparison of AKIN and RIFLE criteria for risk prediction

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Editor's key points

- Acute kidney injury (AKI) is common after aortic aneurysm surgery, but different diagnostic criteria are used to define AKI.
- In this retrospective analysis, the incidence of AKI defined by different criteria was compared.
- Postoperative AKI, defined by either AKIN or RIFLE criteria, predicted overall mortality.
- However, the AKIN criteria appeared to be more sensitive at predicting risk.

Background. Although both Acute Kidney Injury Network (AKIN) and risk, injury, failure, loss, and end-stage (RIFLE) kidney disease criteria are frequently used to diagnose acute kidney injury (AKI), they have rarely been compared in the diagnosis of AKI in patients undergoing surgery for infrarenal abdominal aortic aneurysm (AAA). This study investigated the incidence of, and risk factors for, AKI, defined by AKIN and RIFLE criteria, and compared their ability to predict mortality after infrarenal AAA surgery.

Methods. This study examined 444 patients who underwent infrarenal AAA surgery between January 1999 and December 2011. Risk factors for AKI were assessed by multivariable analyses, and the impact of AKI on overall mortality was assessed by a Cox's proportional hazard model with inverse probability of treatment weighting (IPTW). Net reclassification improvement (NRI) was used to assess the performance of AKIN and RIFLE criteria in predicting overall mortality.

Results. AKI based on AKIN and RIFLE criteria occurred in 82 (18.5%) and 55 (12.4%) patients, respectively. The independent risk factors for AKI were intraoperative red blood cell (RBC) transfusion and chronic kidney disease (CKD) by AKIN criteria, and age, intraoperative RBC transfusion, preoperative atrial fibrillation, and CKD by RIFLE criteria. After IPTW adjustment, AKI was related to 30 day mortality and overall mortality. NRI was 15.2% greater (P=0.04) for AKIN than for RIFLE criteria in assessing the risk of overall mortality.

Conclusions. Although AKI defined by either AKIN or RIFLE criteria was associated with overall mortality, AKIN criteria showed better prediction of mortality in patients undergoing infrarenal AAA surgery.

Keywords: abdominal aorta aneurysm; acute kidney injury; risk factors, morbidity, mortality

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Acute kidney injury (AKI) is a common and serious complication in surgical patients or critically ill patients. It is accompanied by a length of hospital stay prolongation and increased morbidity and mortality after cardiac or non-cardiac surgery.[1–3] A previous report demonstrated that an increase in serum creatinine (sCr) concentrations by >44 μmol litre^{-1} above the baseline level is a predictor of poor outcomes, since it resulted in a three-fold increase in the 30 day mortality rate.[4]

Studies have found that 1–28% of patients undergoing elective open abdominal aortic aneurysm (AAA) repair experience worsening of renal function,[2 5–9] which is independently associated with mortality and prolongation of hospital and intensive care unit (ICU) stay.[10] Although several studies have investigated acute deterioration of renal function after AAA surgery, it is difficult to compare these studies because varying definitions of AKI have been used.

The two most commonly used definitions of AKI are derived from risk, injury, failure, loss, and end-stage (RIFLE) kidney disease criteria and from Acute Kidney Injury Network (AKIN) criteria.[11 12] The major difference between these two criteria is that AKIN criteria use a smaller change in sCr (26.2 μmol litre^{-1}) over a shorter time window (within 48 h) than RIFLE criteria in defining AKI. Furthermore, the AKIN criteria do not include baseline sCr; rather they define kidney injury at any acute increase in sCr that meets the criteria.[12]

While the incidence and prognostic values of both criteria have been investigated in many groups of patients, including in critically ill patients and those undergoing cardiac surgery or major abdominal surgery,[13–15] few reports have observed the AKI incidence and the prediction of mortality by both AKIN and RIFLE criteria in patients who have undergone infrarenal AAA surgery. This study therefore compared the ability of AKIN and RIFLE criteria to predict mortality in patients undergoing infrarenal AAA surgery, and compared the prevalence of, and perioperative risk factors for, AKI, evaluating the relationships between AKI and short- and long-term mortality using both the AKIN and RIFLE criteria.

Methods

Patient population

This study was a retrospective evaluation of the records of all patients who underwent open surgery or endovascular aneurysm repair (EVAR) of infrarenal AAA between January 1999 and December 2011. A total of 594 consecutive adult patients who had undergone abdominal aortic repair were identified through our electrical medical recording system. Of these 594 patients, 150 were excluded, including 62 patients with ruptured AAA or emergent surgery, 75 with AAA other than infrarenal AAA, eight with insufficient laboratory data, one under 18 yr of age, one who died during the operation, two who required conversion from EVAR to open repair, and one who underwent an unknown operative method. Thus, a total of 444 patients were included in the final analysis. The study protocol was approved by the Institutional Review Board of our institution (2012-0132), which waived the requirement for informed consent because of the retrospective non-interventional design of the study.

Clinical data

The computerized patient record system of our institution (Asan Medical Center Information System Electrical Medical Records) was retrospectively reviewed to obtain baseline characteristics, laboratory, surgical, and anaesthetic data on all patients, and also their postoperative outcomes. Patient characteristic data included patient age, sex, weight, height, BMI, smoking history, comorbidities [hypertension (HTN), diabetes mellitus (DM), heart failure (HF), ischaemic heart disease (IHD), chronic obstructive pulmonary disease (COPD), stroke, chronic kidney disease (CKD), and hypercholesterolaemia], and the use of prescribed medications [calcium channel blockers (CCBs), angiotensin-converting enzyme inhibitors (ACEIs)/ angiotensin receptor blockers, β-blockers, aspirin, antiplatelet agents, and oral hypoglycaemic agents]. HTN was defined as the use of any antihypertensive medications or arterial pressure >130/80 mm Hg at admission; DM as the use of any hypoglycaemic agents; HF as New York Heart Association Functional Class III or IV; IHD as positive coronary angiography or compatible electrocardiographic or perfusion scan findings; stroke as positive magnetic resonance imaging findings or neurological sequelae; CKD as a baseline estimated glomerular filtration rate (eGFR) <60 ml min^{-1} 1.73 m^{-2}; and hypercholesterolaemia as treatment with statins. COPD was documented by certified pulmonologists.

Laboratory data included haemoglobin, sCr, albumin, troponin I, cholesterol concentrations, and eGFR. Serum albumin concentrations at baseline and on postoperative days 1–7 were measured using the bromocresol green-dye binding method.[16] eGFR was estimated from preoperative sCr concentration using the Modification of Diet in Renal Disease study equation for adult patients and adjusted for each 1.73 m^2 of body surface area.[17] Left ventricle ejection fraction (LVEF) and the incidence of atrial fibrillation were recorded. Surgical and anaesthetic data included type of surgical procedure (open repair or EVAR), maximum diameter of AAA, aortic clamping time, anaesthetic methods (general, regional, or local infiltration), duration of surgery, volume and type of fluids (colloid and crystalloid), and volume of blood components [packed red blood cells (RBCs) and fresh-frozen plasma (FFP)], lowest intraoperative mean arterial pressure, total volume of radiocontrast agent, and the type of diuretics used intraoperatively (mannitol or furosemide). Colloid agents used during surgery included 10% hydroxyl ethyl starch (HES) 260/0.45 (Pentaspan™; Bristol-Myers Squibb, Montreal, Canada), 6% HES 130/0.4 (Voluven®; Fresinus Kabi, Bad Homburg, Germany), or albumin. EVAR in all patients was performed using iso-osmolar (iodixanol, Visiopaque™, GE Healthcare AS, Oslo, Norway) contrast media.

The type of surgical procedure was based on the site and extension of the aneurysm. Aneurysms restricted to the aorta were treated with tube graft stents. Aneurysms extending into the iliac arteries were treated with Y graft stents, composed of a main body for anastomosis of the aorta and common iliac artery and a limb for the contralateral common iliac artery. Devices used for EVAR included Zenith (Cook, Bloomington, IN, USA), Excluder® (W.L. Gore and Associates, Flagstaff, AZ, USA), Seal (S&G Biotech, Seongnam, Korea), AneuRx AAAdvantage stent graft® (Medtronic, Minneapolis, MN, USA), Talent™ or Endurant™ (Medtronic) stent grafts, depending on the anatomy of each aneurysm.

Definition of outcomes

Postoperative AKI was diagnosed by the AKIN and RIFLE criteria by the alteration of sCr concentration on postoperative 1–7 days compared with the baseline sCr concentration, defined as the last concentration measured before surgery.[12] If sCr was measured more than once per day on postoperative days 1–7, the highest reading of that day was used.

The associations between clinical, laboratory, surgical, and anaesthesia data and the development of AKI were assessed, as were the associations of 30 day mortality and overall survival with postoperative AKI. Mortality rates were evaluated within 30 days of surgery and during the entire study period.

Statistical analysis

Continuous variables are reported as mean (SD) or median and inter-quartile range (IQR). Patient age, height, weight, BMI, MD, EF, laboratory data, amounts of administered blood products and fluids, times of anaesthesia and cross-clamping, and lowest mean arterial pressure were compared using one-way analysis of variance with multiple comparison followed by Dunn's multiple comparison test. Categorical variables are expressed as frequencies and percentages, and analysed with the χ^2 test or Fisher exact test, as appropriate. Multiple logistic regression analysis was performed to identify independent predictors of AKI. All variables with $P<0.1$ on univariate analysis were included in the multivariable analysis. Multivariate Cox's proportional hazard regression analyses were utilized to assess adjusted hazard ratios (HRs) of the relationships between AKI and outcome variables.

Weighted logistic regression and the Cox proportional hazards regression models were used to reduce the influence of possible confounding variables on the association between AKI and mortality, adjusting for major differences between patients with and without AKI using the inverse probability of treatment weighting (IPTW) method.[18] IPTW is a method that uses propensity score to deal with confounders by indication and calculates the probability of individual exposure (or treatment), based on observed and time-dependent covariates. Weights for patients with AKI were the inverse of 1-propensity score, and weights for patients without AKI were the inverse of the propensity scores. All propensity scores for IPTW matching were estimated with all variables (including amount of radiocontrast medium and time period) shown in Tables 1 and 2 without regard to outcomes, using multiple logistic regression analysis to obtain the odds ratio (OR) or HR, as appropriate. Therefore, it was desirable to have as many independent variables as possible for accurate outcomes. The distribution of propensity score in each group is depicted in Supplementary Figure S1. Discrimination of the model was assessed by *C*-statistics, and calibration was evaluated with the Hosmer–Lemeshow statistics. Cumulative survival rates were calculated by the Kaplan–Meier method, and differences between curves were evaluated using the log-rank test.

The ability of AKIN and RIFLE criteria to predict overall mortality was assessed using the net reclassification improvement (NRI) method.[19] Increases and decreases in the estimated risk of an event when a given variable is taken into account are described as up and down movements, respectively. NRI is calculated by computing the difference between the proportions of individuals whose estimated risk moves up and down in those who do (cases) and do not (controls) develop events. 'Upward and downward movement' in risk categories for cases indicated improved and worsened classification, respectively, whereas upward and downward movements in risk categories for controls indicated worsened and improved classifications, respectively. NRI is therefore calculated as the percentage of patients with correct change in

Table 1 Patient characteristics. Values are expressed median (IQR) or *n* (%). The non-AKI group consisted of patients not diagnosed with AKI by either AKIN or RIFLE criteria. AKI, acute kidney injury; AKIN, Acute Kidney Injury Network; RIFLE, risk, injury, failure, loss, and end-stage; LVEF, left ventricle ejection fraction; COPD, chronic obstructive pulmonary disease; eGFR, preoperative estimated glomerular filtration rate; CCB, calcium channel blocker; ACEIs, angiotensin converting enzyme inhibitors. **P*<0.01 compared with the non-AKI group

	Non-AKI (*n*=354)	AKI by AKIN (*n*=82)	AKI by RIFLE (*n*=55)	*P*-value
Patient characteristics				
Age (yr)	69 (64–74)	72 (66–76.3)	72 (66–77)*	<0.01
Sex, male [*n* (%)]	307 (86.7)	74 (90.2)	47 (85.5)	0.64
Body mass index (kg m^{-2})	23.8 (21.5–25.9)	23.6 (21.9–25.2)	23.1 (20.9–25.2)	0.30
LVEF (%)	61 (58–64.3)	59.5 (55.8–64)*	59 (55–64)*	0.01
Comorbidity				
Ischaemic heart disease [*n* (%)]	101 (28.5)	28 (34.1)	20 (36.4)	0.36
Diabetes [*n* (%)]	56 (15.8)	16 (19.5)	10 (18.2)	0.69
HTN [*n* (%)]	243 (68.6)	66 (80.5)	42 (76.4)	0.07
Cerebrovascular disease [*n* (%)]	33 (9.3)	14 (17.1)	8 (14.5)	0.10
COPD [*n* (%)]	97 (27.4)	22 (26.8)	17 (30.9)	0.85
CKD [*n* (%)]	16 (4.5)	19 (23.2)*	14 (25.5)*	<0.01
Preoperative laboratory data				
Creatinine (μmol litre^{-1})	88 (70.4–96.8)	96.8 (79.2–123.2)*	88.0 (70.4–123.2)	<0.01
Albumin (g dl^{-1})	3.7 (3.4–4.0)	3.6 (3.2–3.8)*	3.5 (3.1–3.8)*	<0.01
Haemoglobin (g dl^{-1})	13.3 (12.1–14.2)	12.4 (10.8–14.0)*	12.1 (10.7–13.5)*	<0.01
eGFR (ml kg^{-1} min^{-1})	71 (60.0–88.0)	62.5 (49.5–76.3)*	60 (48.0–86.0)*	<0.01
Preoperative medications				
CCB [*n* (%)]	142 (40.1)	39 (47.6)	25 (45.5)	0.40
ACEIs [*n* (%)]	117 (33.1)	31 (37.8)	21 (38.2)	0.59
β-Blocker [*n* (%)]	108 (30.5)	29 (35.4)	17 (30.9)	0.69
Aspirin [*n* (%)]	143 (40.4)	33 (40.2)	25 (45.5)	0.77
Antiplatelet agent [*n* (%)]	48 (13.6)	19 (23.2)*	13 (23.6)	0.03
Oral hypoglycaemic agent [*n* (%)]	44 (12.4)	14 (17.1)	9 (16.4)	0.45

Table 2 Intraoperative patient characteristics. Values are expressed as median (IQR) or *n* (%). The non-AKI group consisted of patients not diagnosed with AKI by either AKIN or RIFLE criteria. AKI, acute kidney injury; AKIN, Acute Kidney Injury Network; RIFLE, risk, injury, failure, loss, and end-stage; EVAR, endovascular aneurysm repair; RBCs, red blood cells; FFPs, fresh-frozen plasma. *$P<0.01$ compared with the non-AKI group

	Non-AKI (n=354)	AKI by AKIN (n=82)	AKI by RIFLE (n=55)	*P*-value
Treatment				0.04
Open (n=254)	194 (54.8)	57 (69.5)*	35 (63.6)	
EVAR (n=190)	160 (45.2)	25 (30.5)*	20 (36.4)	
Maximal diameter (cm)	5.7 (5.0–6.5)	6 (5.1–7.0)	5.7 (5.1–6.7)	0.10
Intraoperative use of diuretics				<0.01
None [*n* (%)]	246 (69.5)	44 (53.7)*	31 (56.4)	
Furosemide [*n* (%)]	34 (9.6)	15 (18.3)*	10 (18.2)	
Mannitol [*n* (%)]	54 (15.3)	11 (13.4)	5 (9.1)	
Both [*n* (%)]	20 (5.7)	12 (14.6)*	9 (16.4)*	
Anaesthesia type				0.63
General [*n* (%)]	291 (82.2)	72 (87.8)	44 (80)	
Regional [*n* (%)]	35 (9.9)	7 (8.5)	7 (12.7)	
Local [*n* (%)]	28 (7.9)	3 (3.7)	4 (7.3)	
Radiocontrast (mg)	320 (320–640)	640 (320–960)	640 (400–960)*	<0.01
RBCs (units)	2 (0–3)	3 (2–5)*	3 (2–5)*	<0.01
FFPs (units)	0 (0–0)	0 (0–0)*	0 (0–2)*	<0.01
Normal saline (litre)	1.2 (0.7–2.1)	1.2 (0.6–2.9)	1.2 (0.8–2.7)	0.94
Hartman solution (litre)	2.6 (1.7–3.6)	3.0 (2.0–4.0)	2.5 (2.1–3.7)	0.31
Pentastarch (litre)	0.5 (0.5–0.5)	0.5 (0.5–0.6)	0.5 (0.5–0.8)	0.96
Hydroxyethyl starch (litre)	1.0 (0.5–1.0)	1.0 (0.6–1.0)	1.0 (0.8–1.0)	0.17
Intraoperative urine output (litre)	0.7 (0.4–1.0)	0.7 (0.4–1.1)	0.7 (0.3–1.1)	0.64
Anaesthesia time (min)	269.5 (210–335)	305.5 (244–390)*	292 (205–385)	<0.01
Aortic clamp time (min)	50 (0–93)	77.5 (0–100)*	60 (0–97)	0.02
Lowest mean arterial pressure (mm Hg)	65.3 (60.7–72.3)	65 (59.7–71)	65 (58.3–70.7)	0.44

risk category (an increase for cases or a decrease for controls).

$$\text{NRI} = \{\text{Proportion (up/cases)} - \text{Proportion (down/cases)}\} - \{\text{Proportion (up/controls)} - \text{Proportion (down/controls)}\}$$

NRI has been shown to be a sensitive measure for comparing the discriminatory power of prediction models.[20]

All values of $P<0.05$ were considered statistically significant. Data manipulation and statistical analyses were performed using SAS® Version 9.1 (SAS Institute Inc., Cary, NC, USA).

Results

The median follow-up for the overall patient population was 3.2 yr (IQR 1.5–5.1 yr). As this study involved patients who underwent surgery over a 10 yr period, patients were divided into those who underwent surgery in 1999–2006, 2007–9, and 2010–2011. All patients had an infrarenal AAA. Overall, AKI based on AKIN and RIFLE criteria occurred in 82 (18.5%) and 55 (12.4%) patients, respectively. Of the 444 patients, 254 (57.2%) underwent open repair of AAA and 190 (42.8%) were treated by EVAR (Tables 1 and 2, Fig. 1).

Patients diagnosed with AKI were older, had lower preoperative LVEF, lower albumin, haemoglobin concentrations, and eGFR concentrations, and were more likely to have CKD than those without AKI. Moreover, preoperative sCr was higher in patients with AKI diagnosed by the AKIN than the RIFLE criteria, than in those without AKI. Anaesthetic method (general, regional, or local) was similar in patients with and without AKI. Postoperative AKI was more frequent in patients who did use diuretics than those who did not. Renal placement was required by 13.4% of patients diagnosed with AKI by AKIN criteria and by 20% of patients diagnosed with AKI by RIFLE criteria ($P<0.01$ each), whereas none of the patients without AKI by either set of criteria required renal replacement therapy. According to AKIN criteria, AKI was more frequent in patients who underwent open repair (n=57, 69.5%) than EVAR (n=25, 30.5%) (P=0.04), whereas, according to RIFLE criteria, AKI incidence was similar in patients undergoing open repair and EVAR.

HES (10%, 260/0.45) was used as the main colloid agent until 2006, after which it was replaced by 6% HES 130/0.4. However, there was no relationship between AKI incidence and type of colloid agent. Radiocontrast was administered only in patients who underwent EVAR both by AKIN [742.4 (430.5) *vs* 552.7 (374.6) mg, $P<0.05$] and RIFLE [768.0

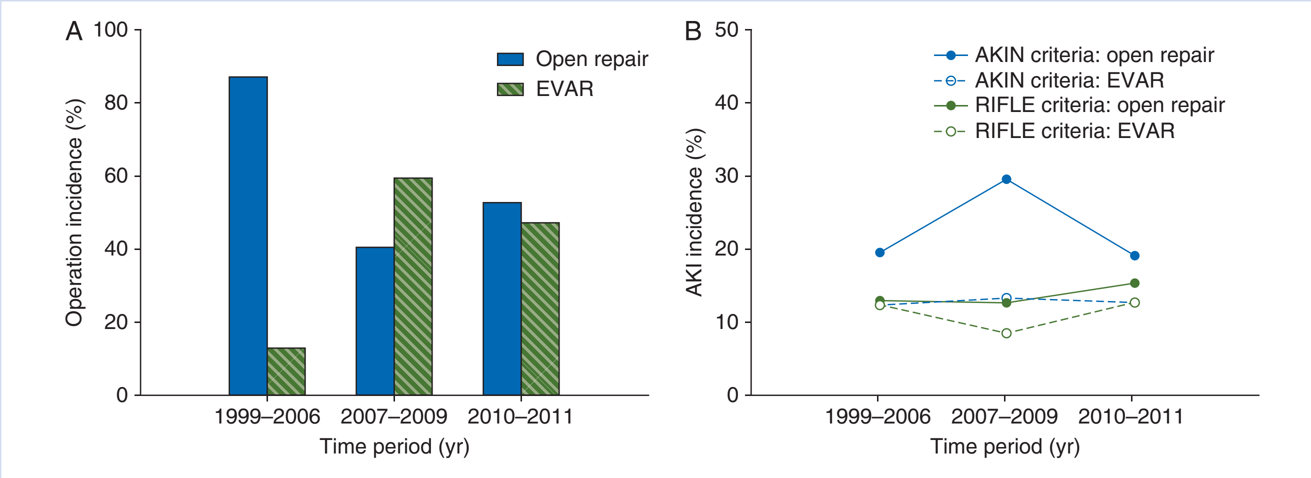

Fig 1 Incidences of AKI by AKIN and RIFLE criteria according to the operation method and period. In (A), the proportions of open repair and EVAR in each period were depicted. In (B), the incidences of AKI according to the operative method were displayed with blue colored line (AKIN criteria) and green colored line (RIFLE criteria). Full line means open repair and dashed line means EVAR.

Table 3 Clinical outcome variables associated with AKI by AKIN and RIFLE criteria. AKI, acute kidney injury; IPTW, inverse probability of treatment weighting; MACE, major adverse cardiac events; OR, odds ratio; HR, hazard ratio; CI, confidence interval; AKIN, Acute Kidney Injury Network; RIFLE, risk, injury, failure, loss, and end-stage. *All variables (including amount of radiocontrast and time) are showed in Tables 1 and 2

	Unadjusted			**Multivariable adjusted**			**IPTW adjusted***		
		95% CI	***P*-value**		**95% CI**	***P*-value**		**95% CI**	***P*-value**
AKIN criteria	**OR**			**OR**			**OR**		
30 day mortality	8.8	2.9–27.0	0.01	8.1	2.2–30.1	<0.01	10.1	4.3–23.8	<0.01
	HR			**HR**			**HR**		
Overall mortality	3.4	2.0–5.7	<0.01	2.1	1.2–3.8	0.01	3.6	1.2–5.9	<0.01
RIFLE criteria	**OR**			**OR**			**OR**		
30 day mortality	21.4	6.4–71.0	<0.01	21.7	5.5–85.3	<0.01	48.3	21.0–111.2	<0.01
	HR			**HR**			**HR**		
Overall mortality	3.9	2.2–6.8	<0.01	2.4	1.2–4.6	0.01	6.1	3.5–10.7	<0.01

(380.1) *vs* 555.3 (382.2) mg, $P<0.05$] criteria, with the amount higher in patients with AKI than without AKI.

Multivariate logistic analysis showed that intraoperative RBC transfusion [OR: 1.20; 95% confidence interval (CI) 1.1–1.3. $P<0.01$], CKD (OR: 5.26; 95% CI 2.45–11.33, $P<0.01$), and preoperative use of antiplatelet agent (OR: 1.92; 95% CI 1.01–3.64, $P=0.05$) were significantly associated with AKI by AKIN criteria. For RIFLE criteria, age (OR: 1.04; 95% CI 1.003–1.09, $P=0.03$), intraoperative RBC transfusion (OR: 1.18; 95% CI 1.07–1.29, $P<0.01$), and CKD (OR: 4.29; 95% CI 1.87–9.80, $P<0.001$) were significantly associated with AKI.

The associations between AKI and postoperative outcome are shown in Table 3. AKI by AKIN (OR: 8.1; 95% CI 2.2–30.1, $P<0.01$) and RIFLE (OR: 21.7; 95% CI 5.5–85.3, $P<0.01$) criteria was associated with increased 30 day mortality. The multivariable Cox proportional hazard analysis showed that AKI, both by AKIN (HR: 2.1; 95% CI 1.2–3.8, $P<0.01$) and RIFLE (HR: 2.4; 95% CI 1.2–4.6, $P<0.001$) criteria, was independently related to overall mortality. After IPTW adjustment, AKI remained significantly associated with 30 day and overall mortality. The survival rate of patients with AKI, as assessed by both AKIN and RIFLE criteria, was significantly lower than those without AKI (log-rank test, $P<0.001$, Fig. 2).

The NRI method showed that the ability of AKIN criteria to predict overall mortality was improved by 15.2% ($P=0.04$) compared with RIFLE criteria (Table 4).

We also compared patient characteristic and intraoperative variables and outcomes in the open repair and EVAR groups (Supplementary material). The patient characteristics and clinical characteristics are summarized separately in Supplementary Table S1. Patients who underwent EVAR were significantly older and had more comorbidities than those who underwent open repair. Other baseline characteristics were similar in two groups. The patients in the open repair group

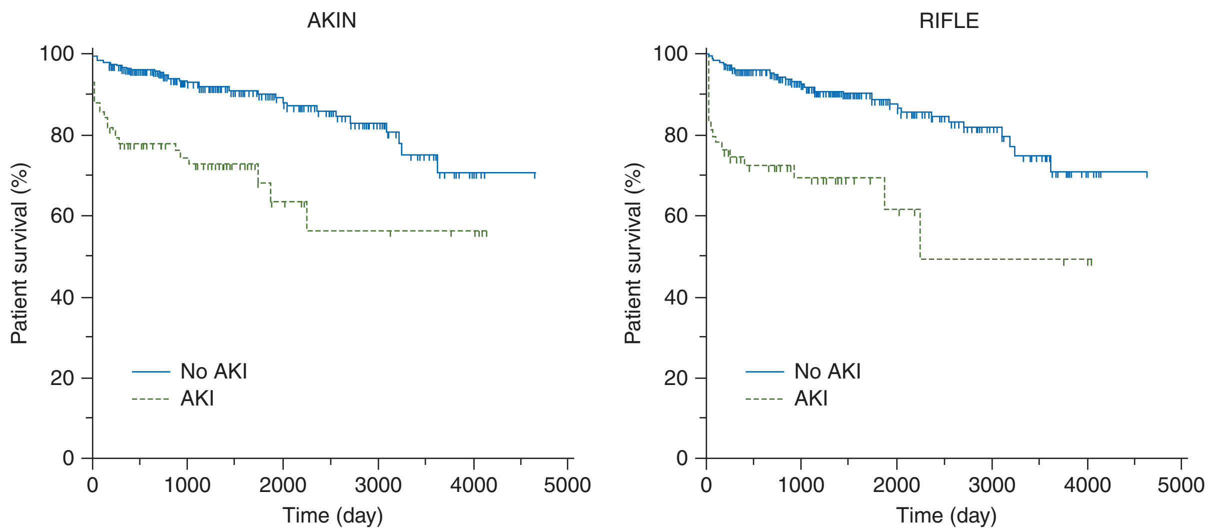

Fig 2 Kaplan–Meier curves for overall survival in patients with AAA surgery. The tickmarks indicate censored data.

Table 4 Reclassification table comparing overall mortality risk strata for AKIN and RIFLE criteria. *Non-survivors were reassigned to higher risk categories and survivors were reassigned to lower risk categories. †Non-survivors were reassigned to lower risk categories and survivors were reassigned to higher risk categories. Reclassification improvement was 29.2%, whereas classification worsened by 14%, leading to an NRI of 15.2% (P=0.04). ‡Case indicates non-survivors and control indicates survivors at final follow-up date

RIFLE	AKIN				Row totals	Reclassified into AKIN category	
	0	1	2	3		Correctly reclassified (%)*	Incorrectly reclassified (%)†
0	354	36	0	3	393	19.7	7.0
Case‡	34	10	0	2	46		
Control	320	26	0	1	347		
1	6	29	0	3	38	2.6	3.8
Case	2	2	0	1	5		
Control	4	27	0	2	33		
2	2	0	2	4	8	6.9	1.6
Case	1	0	0	4	5		
Control	1	0	2	0	3		
3	0	0	1	4	5		1.6
Case	0	0	1	4	5		
Control	0	0	0	0			
Total, *n*	362	65	3	14	444	29.2	14
Case	37	12	1	11	61		
Control	325	53	2	3	383		

had larger aneurysms; required greater amounts of diuretics, transfused units, and fluid replacement; more commonly underwent general anaesthesia, and experienced more severe hypotension (Supplementary Table S2).

AKI was more frequently diagnosed in the open repair group by AKIN criteria, but the incidence of AKI according to RIFLE criteria, was comparable in patients undergoing open repair and EVAR (Supplementary Table S3). Overall hospital stay and ICU stay were shorter in the EVAR group, but 30 day and overall (P=0.18) mortality rates were similar. However, the survival rate of the patients with AKI diagnosed by AKIN and RIFLE criteria was lower than that of non-AKI patients in both groups (P<0.01).

Discussion

The major finding of our study was that AKI developed in 18.5% of patients undergoing AAA surgery according to AKIN criteria and in 12.4% according to RIFLE criteria. In addition, postoperative AKI according to both criteria was independently associated with increased 30 day and overall mortality rates, irrespective of other postoperative complications and comorbidities. Furthermore, the NRI method showed that the AKIN criteria were better able to predict overall mortality rate than the RIFLE criteria in patients undergoing AAA surgery.

As our study involved a 10 yr period, we divided this period into three parts and analysed changes in the type of operation, incidence of AKI, and use of colloid solution. During the first time period, open AAA surgery was more frequent than EVAR. Over time, however, EVAR became more frequent. AKI developed more frequently with open repair than with EVAR by AKIN, but not by RIFLE criteria. Interestingly, the incidence of AKI by AKIN criteria was higher from 2007 to 2009 than from 1999 to 2006 or 2010 to 2011, although the differences were not statistically significant. We found that the incidence of AKI in patients undergoing open repair was higher in 2007–9 (29.6%) than in 1999–2006 (19.6%) or 2010–2011 (19.2%); however, the proportion of patients undergoing open repair was lower in 2007–9 (40.6%) than in 1999–2006 (86.9%) or 2010–2011 (52.4%). Although the proportion of patients undergoing EVAR has increased over the 10 yr study period, the incidence of AKI has not decreased correspondingly. Even though we do not know the exact reason, EVAR may not protect against AKI as defined by AKIN criteria. The older age and increase in numbers of comorbidities in the EVAR group may have prevented the incidence of AKI from decreasing. Radiocontrast has also been associated with AKI in patients undergoing EVAR.[5 21] Consistent with previous reports, we found that the total amount of radiocontrast administered during EVAR was significantly higher in patients with AKI than without AKI, as assessed by both AKIN and RIFLE criteria.

The main colloid agent used until 2006 was 10% HES, after which it was replaced by 6% HES. Although the use of 10% HES has been associated with AKI,[22 23] we observed no relationship between AKI incidence and type of HES. It is unclear whether the type of anaesthetic used for EVAR affects renal impairment.[24] We found, however, that anaesthetic method (general, regional, or local) was similar in patients with and without AKI, perhaps because >80% of the operations were performed under general anaesthesia in our institution.

The incidence of AKI, as assessed by AKIN and RIFLE criteria, has been shown to be similar in critically ill patients and patients undergoing cardiac surgery.[13 24] In contrast, we found a discrepancy in the incidence of AKI based on AKIN and RIFLE criteria, perhaps because postoperative sCr may be increased more acutely after AAA surgery. The change in sCr is smaller and the time window shorter for AKI assessed by AKIN than by RIFLE criteria, suggesting that the inclusion of sCr concentration may result in a discrepancy in the incidence of AKI by AKIN and RIFLE criteria. Similarly, other studies have reported discrepancies in AKI incidence by these criteria in patients who underwent cardiac surgeries[25] and in critically ill patients.[26] Taken together, our results showed that the sensitivity of AKIN criteria in determining the incidence of AKI was higher than that of RIFLE criteria in patients who underwent AAA surgery.

Our findings also demonstrated that AKI was related to adverse outcome after infrarenal AAA surgery, irrespective of the criteria used. This finding is in agreement with results showing that AKI is an independent predictor of long- and short-term mortality rates.[15 27] Even after IPTW adjustment, AKI remained significantly associated with 30 day and overall mortality rates. In addition, the ORs and HR of these clinical outcome variables were increased after IPTW adjustment. Therefore, it might be useful to assess and modulate the variables that predict the development of AKI, and thereby improve the prognosis of patients who undergo AAA surgery.

This study investigated the ability of AKIN and RIFLE criteria to predict overall mortality in patients who underwent AAA surgery. Several methods have been utilized to assess the discriminatory power of two sets of criteria, with one of the most popular methods being area under the receiver-operating characteristic curve (AUC).[28] Recently, the NRI method was found useful for comparing the discriminatory abilities of predictive models or markers, quantifying the degree of improvement when a new marker is added to a previous system.[19 20] However, caution is needed in the interpretation of the NRI, because the summation of the proportion with correct upward and downward movement in risk category masks relative contributions of each component.[29] Therefore, we showed each component separately in Table 4. Based on the NRI method, AKIN criteria showed a 15.2% (P=0.04) improvement in the prediction of overall mortality compared with RIFLE criteria. Moreover, a previous study demonstrated that AKIN criteria might be more accurate and better predictive of mortality than the RIFLE criteria in burn patients.[24]

This study had several limitations. First, because it was a retrospective observational analysis, causality could not be determined. Although we performed propensity analyses in an attempt to control selection bias, we could not entirely remove the potential for residual confounding variables. However, in the absence of a prospective study, it may be reasonable to use statistical methodology to compensate for the results of retrospective analysis. Secondly, this study addressed the association between all-cause sCr increase and subsequent adverse events including mortality. The aetiology of AKI after surgery is generally multifactorial, with AKI strongly related to mortality irrespective of the cause of AKI. Further randomized controlled study will be needed to confirm this issue. Thirdly, because this study enrolled patients undergoing AAA surgery, the results cannot be generalized to other populations. Accordingly, these results should be interpreted cautiously.

In conclusion, we found that both AKIN and RIFLE criteria may be useful in assessing the development of AKI and short- and long-term mortality rates after AAA surgery. However, the AKIN criteria seemed more sensitive in determining the incidence of AKI and were more predictive of mortality in patients who underwent AAA surgery.

Supplementary material

Supplementary material is available at *British Journal of Anaesthesia* online.

Authors' contributions

J.-Y.B. and J.-G.S. took a major role in conception and design of this manuscript, analysis and interpretation of data and drafting of the manuscript. J.-B.L. conducted statistical analysis. Y.Y. and H.-S.S. conducted analysis and interpretation of data. G.-S.W. revised the manuscript critically for important intellectual content. Finally, J.-G.S. has approved the submission of this manuscript.

Declaration of interest

None declared.

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