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ORIGINAL ARTICLE

RenalGuard system to prevent contrast-induced acute kidney injury in Japanese patients with renal dysfunction; RESPECT KIDNEY study

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Abstract

Increasing the urine flow rate (UFR) reduces the toxic effect of contrast media. Use of the RenalGuard system enables the achievement of a high UFR by maintaining intravascular volume and prevents the development of contrast-induced acute kidney injury (CI-AKI). However, the efficacy and safety of RenalGuard system have not yet been evaluated in Japan. This multicenter prospective study evaluated the efficacy and safety of the RenalGuard therapy in preventing CI-AKI development in 60 Japanese patients with renal dysfunction [estimated glomerular filtration rate (eGFR) < 45 mL/min/1.73 m^2] undergoing catheter procedures. Baseline eGFR and Mehran's CIN (contrast-induced nephropathy) risk score were 35.1 ± 8.5 mL/min/1.73 m^2 and 11.7 ± 4.3, respectively. Regardless of this high-risk profile, the incidence of CI-AKI was 8.6% (5/58) compared with the 26.1% incidence estimated by the CIN risk score. Moreover, two-sided 95% (Fisher's) exact confidence interval was 2.9–19.0 and its upper limit (i.e., 19.0) was less than the prespecified threshold incidence of 25.0. Univariate logistic regression analysis demonstrated that the UFR during catheter procedure was one of the most important factor associated with CI-AKI (odds ratio 0.99, confidence interval 0.98–1.00, $p = 0.03$). In conclusion, RenalGuard therapy may prevent CI-AKI development in Japanese patients with renal dysfunction. Further large-scale prospective multicenter studies are necessary to confirm our findings.

Keywords Contrast-induced acute kidney injury · RenalGuard therapy · Urine flow rate

Introduction

Contrast-induced acute kidney injury (CI-AKI), a serious complication of catheter procedures, is frequently associated with significant in-hospital and long-term morbidity and mortality, as well as a prolonged hospital stay [1–5], especially in patients with chronic kidney disease (CKD) [6]. Moreover, the clinical outcomes of patients who require emergency dialysis after percutaneous coronary intervention (PCI) are very poor, with an in-hospital mortality rate as high as 62% [7, 8]. CKD and reduced effective circulating volume are well-recognized risk factors for CI-AKI [1–3]. Thus, it is important to examine the useful method for prevention of CI-AKI in patients with CKD.

Although various strategies such as the use of acetylcysteine [9], carperitide [10], sodium bicarbonate [11], or other renoprotective drugs have been evaluated, hydration with 0.9% saline is the most useful strategy for preventing the onset of CI-AKI [12]. Data from the Prevention of Radiocontrast Induced Nephropathy Clinical Evaluation (PRINCE) study indicate that increasing the urine flow rate (UFR) (≥ 150 mL/h) reduces the toxic effect of contrast media [13]. Use of the RenalGuard system (PLC Medical Systems, Inc, Franklin, MA, USA) enables safe achievement of high urine output by maintaining the intravascular volume and minimizing the risk of over- or under-hydration. RenalGuard therapy (hydration with saline plus furosemide controlled by the RenalGuard system) is superior to conventional hydration regimens for preventing CI-AKI in high-risk patients [14, 15]. Therefore, we evaluated the efficacy

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and safety of RenalGuard therapy for preventing CI-AKI in Japanese patients with severe renal dysfunction who are undergoing catheter procedures.

Materials and methods

Study population

We recruited 60 patients with CKD who were scheduled to undergo catheter procedures at Yokohama Sakae Kyosai Hospital and Sendai Kosei Hospital between December 2013 and August 2016. Inclusion criteria were age ≥ 20 years but ≤ 85 years and estimated glomerular filtration rate (eGFR) ≤ 45 mL/min/1.73 m^2, calculated using the new Japanese equation for eGFR [16]: eGFR (mL/min/1.73 m^2) = 194 × serum Cr (mg/dL)$^{-1.094}$ × age (years)$^{-0.287}$ (× 0.739 for female subjects). Exclusion criteria were as follows: left ventricular ejection fraction (LVEF) < 30%, cardiogenic shock, uncompensated heart failure, chronic dialysis, pregnancy, intravascular administration of contrast medium within the previous 7 days, history of cerebrovascular accident within the previous 60 days, and history of allergy to the contrast medium.

Each patient was admitted to one of our hospitals 1 day before the scheduled catheter procedure, at which time serum and urinary marker levels were measured and echocardiography was performed. LVEF was calculated using the modified Simpson method. A nonionic low-osmolality contrast medium was used in all patients. Serum and urinary markers were measured at baseline, 24, 48, and 72 h after RenalGuard therapy. Additional measurements of serum markers were performed at 1 week and 1 month. We calculated the contrast-induced nephropathy (CIN) risk score [17] of all patients after the coronary procedures. Anemia was defined using World Health Organization criteria: baseline hematocrit value < 39% for men and < 36% for women [18].

CI-AKI was defined as an absolute increase in serum creatinine (Cr) level of at least 0.5 mg/dL or a relative increase in serum Cr level more than 25% from the baseline value within 72 h after administration of the contrast medium [19].

The ethics committees of Yokohama Sakae Kyosai Hospital and Sendai Kosei Hospital approved the protocol, and written informed consent was obtained from each patient. This study was registered in the UMIN protocol registration system under identification number UMIN000007308.

RenalGuard therapy

The RenalGuard system includes a closed-loop fluid management system, high-volume fluid pump, high-accuracy dual weight measuring system, motion-detection artifact reduction, single-use intravenous set and urine collection system that interfaces with a standard Foley catheter, real-time display of urine and replacement fluid volumes, timely alerts to drain the urine bag or replace the hydration fluid bag, and safety features such as automatic air and occlusion detection (Fig. 1a). An initial bolus (priming) of 250 mL of 0.9% saline was infused over 30 min [Pre-CM (contrast media) phase]. In the presence of left ventricular dysfunction (LVEF ≤ 40%, as assessed by two-dimensional echocardiography), priming was reduced to 150 mL. Furosemide (0.25 mg/kg) was administered intravenously in cases in which we could not achieve the target value (UFR ≥ 300 mL/h) after the priming. If the UFR could not reach the target value, additional furosemide (0.25 mg/kg) was administered. As soon as the UFR reached the target value, the catheter procedure was started (CM phase). Controlled hydration by the RenalGuard system continued during the procedure and for 4 h thereafter (Post-CM phase). UFR was monitored and maintained at the target value (≥ 300 mL/h) during and 2 h after the procedure (Fig. 1b). Additional furosemide administrations were allowed in

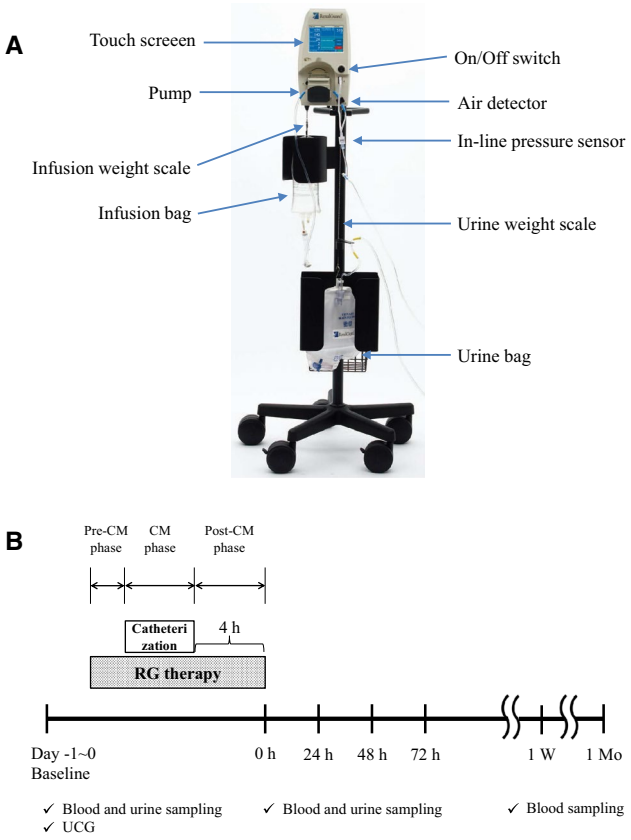

Fig. 1 **a** Scheme of the RenalGuard system. **b** Protocol diagram of the RESPECT KIDNEY Study. *RG* RenalGuard, *UCG* ultrasound echocardiography, *pre-CM phase* pre-contrast medium exposure or pre-procedural time, *CM phase* contrast medium exposure or intra-procedural time, *post-CM phase* post-contrast medium or post-procedural time

instances in which the UFR decreased to below the target value.

Laboratory determinations

Serum cystatin C (CysC) was measured by particle-enhanced immunonephelometry on a Behring nephelometer system (Dade Behring Co., Tokyo) [20]. Urinary liver-type fatty acid-binding protein (L-FABP) was measured by a specific enzyme-linked immunosorbent assay [21] and collected as urinary Cr value.

Sample size calculation

We have enough information about CI-AKI in the global population and no methods are more useful than the RenalGuard system for preventing CI-AKI. Moreover, the RenalGuard system has not been approved yet in Japan. Therefore, we considered that a single-arm trial consisting of the RanalGuard therapy group was suitable to obtain as much information on the RanalGuard system as possible. The sample size was set as 60 cases to reflect the number of patients who met the study eligibility criteria at our hospitals. Since the clinically acceptable incidence of CI-AKI is 25% and the estimated incidence of CI-AKI in the RenalGuard group was 10% in previous reports [1–5, 14, 15], the statistical power that the upper limit of two-sided 95 percent (Fisher's) exact confidence interval (CI) is less than 25% (threshold incidence rate) is approximately 86%.

Statistical analysis

We compared the patients' background between the 2 groups with and without CI-AKI to identify the predictor of CI-AKI under RenalGuard therapy. Continuous variables were summarized as means and standard deviations (SD) and categorical variables were summarized as counts and percentages. Intergroup differences in continuous variables were compared by *t* test. Categorical variables between the 2 groups were compared using Fisher's exact test. Univariate logistic regression analyses were performed to evaluate significant factors associated with the occurrence of CI-AKI. The receiver operating characteristic (ROC) curve was analyzed to determine the cut-off value of UFR during the CM phase for predicting CI-AKI. All *p* values were two-sided and those < 0.05 were considered statistically significant. All statistical analyses were performed using StatView 5.0 for Windows (SAS Institute, Cary, NC, USA) and Statistical Package for the Social Sciences version 19.0 (SPSS Inc., Chicago, IL, USA).

Results

Usefulness of RenalGuard therapy for preventing CI-AKI

Although 60 patients were recruited in this study, two were excluded because they underwent cerebral angiography performed by a neurosurgeon and their laboratory data during hospitalization were not obtained. The remaining 58 patients (51 men; mean age, 76 years) with CKD (mean serum Cr, 1.6 ± 0.5 mg/dL; mean eGFR, 35.1 ± 8.5 mL/min/1.73 m^2) were included in the analysis (Table 1). Among them, CI-AKI developed in five (8.6%), and its incidence increased as the CIN risk score increased (Fig. 2).

Comparison of CI-AKI and non-CI-AKI groups

In the CI-AKI group, the CIN risk score was higher (15.6 ± 4.8 vs. 11.3 ± 4.1, $p = 0.03$) and contrast media volume to eGFR ratio tended to be higher (5.0 ± 3.2 vs. 3.3 ± 1.8, $p = 0.06$) than those in the non-CI-AKI group (Table 1). On the other hand, there were no significant differences in several known risk factors for CI-AKI, such as age, left ventricular ejection fraction, renal function, diabetes mellitus, and anemia between the two groups. Changes in serum and urinary marker levels are shown in Table 2. All baseline markers in the CI-AKI group tended to be higher than those in the non-CI-AKI group. Even in the CI-AKI group, serum Cr and CysC levels returned to their baseline values at 1 month and none of the patients who developed CI-AKI required emergency or continuous dialysis. Moreover, urinary L-FABP did not increase after the application of RenalGuard therapy in either group.

Application of RenalGuard therapy and its safety

Details of RenalGuard therapy are described in Table 3. Priming, infusion, and urine volume in the pre-CM phase did not differ between the two groups. In the CI-AKI group, UFR in the CM and post-CM phases were significantly lower (469 ± 211 vs. 727 ± 246, $p = 0.03$ and 237 ± 29 vs. 385 ± 123 mL/h, $p = 0.01$, respectively) and CM phase duration was significantly longer (100.0 ± 47.1 vs. 45.0 ± 28.9 min, $p < 0.001$) than those in the non-CI-AKI group. Infusion and urine volume during the CM phase did not differ between the two groups, whereas those in the post-CM phase of patients with CI-AKI were significantly lower than those with non-CI-AKI (935 ± 469 vs. 1511 ± 516, $p = 0.02$ and 978 ± 437 vs. 1479 ± 532 mL, $p = 0.047$, respectively).

Table 1 Baseline clinical characteristics of patients with and without CI-AKI

Variable	All patients ($n=58$)	CI-AKI ($n=5$)	Non-CI-AKI ($n=53$)	p value
Age (years)	76 ± 6	75 ± 8	76 ± 6	0.62
Gender (male/female)	51/7	4/1	47/6	0.49
BMI (kg/m^2)	24.1 ± 4.0	22.9 ± 7.0	24.3 ± 3.6	0.45
LVEF (%)	59 ± 12	65 ± 3	59 ± 12	0.25
BNP (pg/mL)	86 ± 86	114 ± 89	83 ± 86	0.55
Hematocrit (%)	37.0 ± 4.7	33.8 ± 3.0	37.3 ± 4.8	0.11
BUN (mg/dL)	25.7 ± 8.9	33.3 ± 10.3	25.0 ± 8.5	0.045
Serum Cr (mg/dL)	1.6 ± 0.5	1.9 ± 0.9	1.6 ± 0.4	0.12
eGFR (mL/min/1.73 m^2)	35.1 ± 8.5	30.2 ± 9.9	35.6 ± 8.3	0.17
CKD stage (stage 3/4)	44/14	3/2	41/12	0.59
CIN risk score[a]	11.7 ± 4.3	15.6 ± 4.8	11.3 ± 4.1	0.03
Volume of contrast media (mL)	111 ± 38	132 ± 30	109 ± 39	0.21
Contrast media volume/eGFR ratio	3.4 ± 2.0	5.0 ± 3.2	3.3 ± 1.8	0.06
Procedure type (CAG/PCI/EVT)	15/33/10	1/2/2	14/31/8	0.44
Diabetes mellitus, *n* (%)	37 (64)	4 (80)	33 (62)	0.64
Hypertension, *n* (%)	53 (91)	5 (100)	48 (91)	1
Anemia, *n* (%)	42 (72)	5 (100)	37 (70)	0.31
ACE inhibitors or ARBs, *n* (%)	40 (69)	5 (100)	35 (66)	0.31
β blocker, *n* (%)	28 (48)	2 (40)	26 (49)	1
Diuretics, *n* (%)	20 (34)	2 (40)	18 (34)	1
Statin, *n* (%)	38 (66)	3 (60)	35 (66)	1

Data are expressed as the mean ± SD or number (%)

CI-AKI contrast-induced acute kidney injury, *BMI* body mass index, *LVEF* left ventricular ejection fraction, *BNP* brain natriuretic peptide, *Cr* creatinine, *eGFR* estimated glomerular filtration rate, *CIN* contrast-induced nephropathy, *ACE* angiotensin-converting enzyme, *ARB* angiotensin-receptor blocker, *CAG* coronary angiography, *PCI* percutaneous coronary intervention, *EVT* endovascular therapy

[a]Reference number [17]

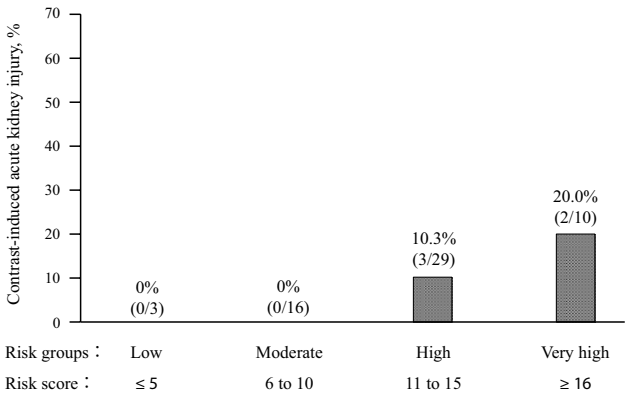

Fig. 2 Incidence of CI-AKI in RenalGuard therapy. CI-AKI developed in five patients (8.6%), and its incidence gradually increased as the CIN risk score increased. *CI-AKI* contrast-induced acute kidney injury, *CIN* contrast-induced nephropathy

No patients developed any electrolyte abnormalities associated with RenalGuard therapy during follow-up period (Fig. 3). Although three patients developed hypotension during the CM or post-CM phase, they were recovered with fluid replacement consisting of normal saline. Although only 1 (baseline serum Cr was 3.32 mg/dL and CIN risk score was 23) out of these 3 patients developed CI-AKI, his serum Cr level improved to the baseline value within 1 week and prolonged renal injury was not observed. The hemodynamics of the remaining patients did not change throughout the procedure, and no serious complications associated with RenalGuard therapy occurred.

Predictor of CI-AKI under RenalGuard therapy

Univariate logistic regression analyses showed that CIN risk score (odds ratio 1.29, confidence interval 1.00–1.65, $p=0.05$) and UFR during the CM phase (odds ratio 0.99, confidence interval 0.98–1.00, $p=0.03$) were significant factors associated with the development of CI-AKI (Table 4). The ROC analysis showed that the area under the curve of UFR during the CM phase was 0.80 ($p=0.02$). At a cut-off value of 494.8 mL/h, it exhibited 80.0% sensitivity and 82.7% specificity for predicting CI-AKI (Fig. 4).

Table 2 Changes in serum and urinary marker levels

Variable	CI-AKI ($n=5$)	Non-CI-AKI ($n=53$)	p value
Serum Cr (mg/dL)			
Baseline	1.90 ± 0.88	1.56 ± 0.42	0.12
After 24 h	2.34 ± 1.20*	1.54 ± 0.44	0.002
After 48 h	2.45 ± 1.21*	1.52 ± 0.44	< 0.001
After 72 h	2.40 ± 1.14*	1.52 ± 0.41	< 0.001
After 1 week	2.28 ± 0.83	1.61 ± 0.42	0.003
After 1 month	1.78 ± 0.81	1.53 ± 0.41	0.23
Serum CysC (mg/L)			
Baseline	2.07 ± 0.43	1.72 ± 0.46	0.11
After 24 h	2.34 ± 0.66	1.61 ± 0.40§	< 0.001
After 48 h	2.25 ± 0.50	1.61 ± 0.39§	0.001
After 72 h	2.25 ± 0.59	1.62 ± 0.40‡	0.002
After 1 week	2.21 ± 0.56	1.73 ± 0.39	0.02
After 1 month	2.09 ± 0.51	1.68 ± 0.41	0.047
Urinary L-FABP (μg/gCr)			
Baseline	28.9 ± 45.2	11.4 ± 32.9	0.28
After 24 h	14.4 ± 8.5	14.1 ± 21.1	0.97
After 48 h	19.1 ± 15.9	8.4 ± 16.7	0.17
After 72 h	17.5 ± 14.6	7.1 ± 15.2	0.15

Data are expressed as the mean ± SD

CI-AKI contrast-induced acute kidney injury, *Cr* creatinine, *CysC* cystatin C, *L-FABP* liver-type fatty acid-binding protein

*$p < 0.05$, ‡$p < 0.001$, §$p < 0.0001$ compared with baseline value

Discussion

The present study demonstrated that RenalGuard therapy (hydration with saline plus furosemide controlled by the RenalGuard system) is useful for preventing the development of CI-AKI in Japanese patients with renal dysfunction undergoing catheter procedures, and no serious complications associated with its use occurred. In addition, UFR during the catheter procedure was one of the useful predictors of CI-AKI on logistic regression analysis.

Pre-existing renal dysfunction and reduced effective circulating volume are well-recognized risk factors of CI-AKI [1]. Hydration with normal saline is one of the most effective methods for preventing the development of CI-AKI. It produces expansion of plasma volume with concomitant suppression of the renin–angiotensin–aldosterone system (RAAS) and sympathetic nervous system (SNS), down-regulation of tubuloglomerular feedback, dilution of contrast media, and consequent prevention of renal vasoconstriction and tubular obstruction [12, 22, 23]. By contrast, an increase in urine output might be expected to dilute the concentration of contrast within the renal tubule lumen and decrease its contact time with renal tubule cells [23, 24]. However, attempts to force diuresis using mannitol or furosemide have generally resulted in a higher incidence of kidney injury induced by contrast media [25–27]. This is likely a result of failure in maintaining euvolemia, resulting in SNS and RAAS activation. The

Table 3 Details of RenalGuard therapy

Variable	CI-AKI ($n=5$)	Non-CI-AKI ($n=53$)	p value
Total infusion volume (mL)	2165 ± 533	2785 ± 732	0.07
Total urine volume (mL)	1927 ± 549	2522 ± 728	0.08
Total furosemide dose (mg)	27.1 ± 14.9	22.1 ± 11.3	0.36
Total time of RG therapy (min)	404.6 ± 26.5	347.7 ± 34.4	< 0.001
Pre-CM phase			
Priming volume (mL)	250 ± 0	244 ± 23	0.59
Infusion volume (mL)	585 ± 306	681 ± 220	0.37
Urine volume (mL)	331 ± 305	451 ± 219	0.26
Duration (min)	64.6 ± 30.1	62.7 ± 19.4	0.84
CM phase			
Infusion volume (mL)	645 ± 410	594 ± 352	0.76
Urine volume (mL)	618 ± 381	591 ± 334	0.87
UFR (mL/h)	469 ± 211	727 ± 246	0.03
Duration (min)	100.0 ± 47.1	45.0 ± 28.9	< 0.001
Post-CM phase			
Infusion volume (mL)	935 ± 469	1511 ± 516	0.02
Urine volume (mL)	978 ± 437	1479 ± 532	0.047
UFR (mL/h)	237 ± 29	385 ± 123	0.01
Duration (min)	240 ± 0	240 ± 0	–

Data are expressed as the mean ± SD or number (%)

CI-AKI contrast-induced acute kidney injury, *RG* RenalGuard, *UFR* urine flow rate, *pre-CM phase* pre-contrast medium exposure or pre-procedural time, *CM phase* contrast medium exposure or intra-procedural time, *post-CM phase* post-contrast medium or post-procedural time

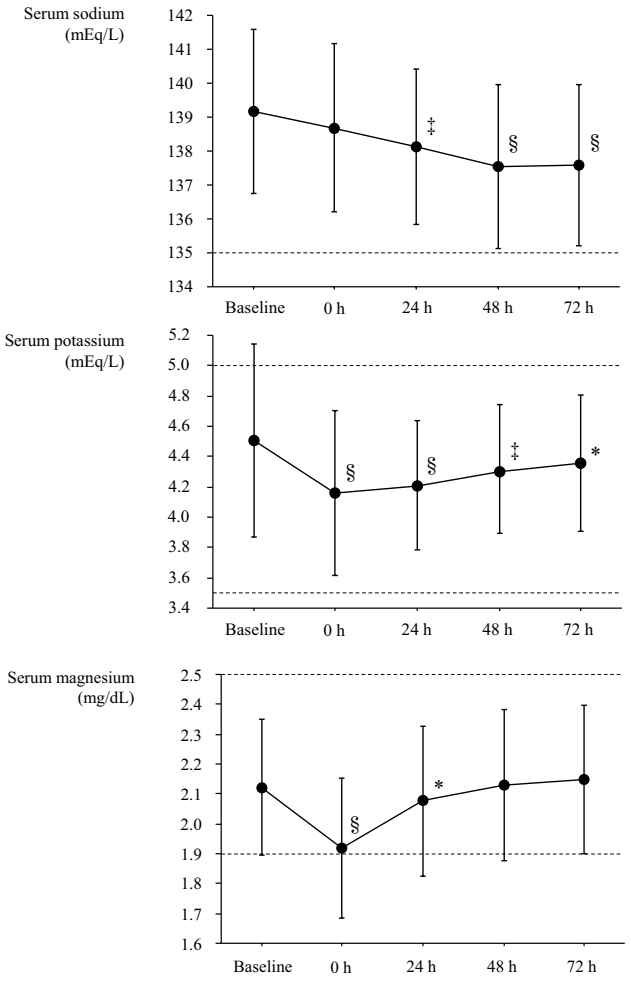

Fig. 3 Serial changes in serum electrolyte levels. No patients developed any electrolyte abnormalities associated with RenalGuard therapy during the follow-up period. The dashed lines show the normal range of each electrolyte. Data are expressed as mean ± SD. $^{*}p < 0.05$, $^{‡}p < 0.001$, $^{§}p < 0.0001$ compared with baseline values

Table 4 Factors associated with the occurrence of CI-AKI

Variables	OR	CI (95%)	*p* value
Age (years)	0.96	0.83–1.12	0.62
LVEF (%)	1.06	0.96–1.15	0.25
eGFR (mL/min/1.73 m^2)	0.93	0.84–1.03	0.18
Serum CysC (mg/L)	3.93	0.67–22.93	0.13
Urinary L-FABP (μg/gCr)	1.01	0.99–1.03	0.32
CIN risk score	1.29	1.00–1.65	0.05
Contrast media volume/eGFR ratio	1.32	0.95–1.83	0.1
Total furosemide dose (mg)	1.04	0.96–1.12	0.36
UFR during CM phase (mL/h)	0.99	0.98–1.00	0.03

For other abbreviations, please refer to Tables 1, 2, and 3

OR odds ratio, *CI* confidence interval

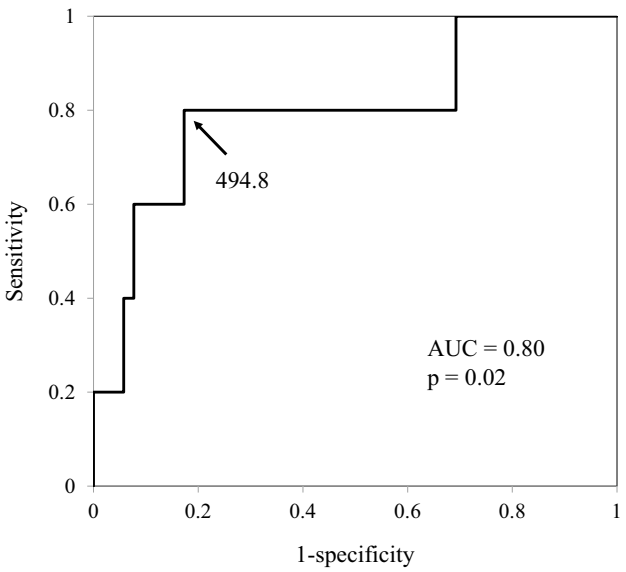

Fig. 4 Receiver operating characteristic curve analysis. At a cut-off value of 494.8 mL/h, the urine flow rate during the catheter procedure exhibited 80.0% sensitivity and 82.7% specificity for predicting contrast-induced acute kidney injury

PRINCE study showed that forced diuresis achieved with a single dose of diuretic in combination with intravenous fluid replacement matched to urine output prevented dehydration and had a modest protective effect against CIN [13]. Moreover, this study demonstrated that CIN requiring dialysis did not develop in any patient who could achieve a UFR ≥ 150 mL/h. Thus, furosemide-induced high-volume diuresis with concurrent maintenance of the intravascular volume through matched hydration is associated with enhanced resistance to CIN in high-risk patients. RenalGuard therapy enables safe achievement of high urine output by maintaining the intravascular volume and minimizing the risk of over- or underhydration; two randomized trials demonstrated the efficacy of RenalGuard therapy for preventing CI-AKI in patients with severe renal dysfunction [14, 15]. We also demonstrated its usefulness and safety for prevention of CI-AKI in high-risk Japanese patients without developing any complications such as congestive heart failure or electrolyte disorders. Sato et al. [28] demonstrated that Mehran's CIN risk score was adapted in Japanese patients and might provide useful information for prediction of CI-AKI. Moreover, the incidence of CI-AKI gradually increases with increasing in CIN risk score [28]. The incidence of CI-AKI in the present study was less than the previous study in any risk groups. Therefore, RenalGuard therapy may provide a protective effect against the CI-AKI for patients with any risk profiles. We previously reported that a baseline urinary L-FABP ≥ 19.0 μg/gCr was an independent predictor of CI-AKI [29], and some reports suggested that the urinary excretion of L-FABP might reflect various kinds of stresses that cause tubulointerstitial damage and may be a useful clinical

marker of CKD progression [30, 31]. In the present study, urinary L-FABP levels did not increase after exposure to contrast media by introduction of RenalGuard therapy in both the CI-AKI and the non-CI-AKI group. This phenomenon would represent the effectiveness of RenalGuard therapy against contrast media.

Another important result of the present study was that maintaining a high UFR during the catheter procedure (CM phase) was one of the useful factors affecting the development of CI-AKI. A recent study also demonstrated that the best threshold for CI-AKI prevention was a mean UFR during the CM phase $\geq$ 450 mL/h (area under the curve, 0.62; $p = 0.009$; sensitivity, 80%; specificity, 46%), and a UFR during the CM phase < 450 mL/h was one of the independent predictors of CI-AKI [32]. This cut-off value was consistent with that of 494.8 mL/h in our study. A strong time dependence of contrast-induced renal cell cytotoxicity has been reported [33]. In an experimental model, the percentage of apoptotic cells had significantly increased within 15 min of exposure to contrast medium and continued to increase progressively up to the maximum studied period of 3 h. This time dependency highlights the importance of strategies limiting the kidneys' exposure to contrast medium by generating a high UFR in patients at risk, especially when the contrast media is injected.

Study limitations

The present study has several limitations. First, it involved a small number of patients at two centers and did not include a control group because there are no methods more useful than the RenalGuard system for preventing CI-AKI. However, two-sided 95 percent (Fisher's) exact CI was 2.9–19.0 and its upper limit (i.e., 19.0) was less than the prespecified threshold incidence of 25.0%. Moreover, because the mean value of CI-AKI incidence calculated from Mehran's CIN risk score and baseline clinical characteristics of our study patients [17] was 26.3%, the prespecified threshold incidence of 25% was considered reasonable and proper. Thus, the usefulness of RenalGuard therapy for preventing CI-AKI was statistically significant with sufficient accuracy. Second, catheter procedures were not unified, including coronary angiography, PCI, and endovascular therapy. Third, the amount of contrast media used in this study was relatively smaller than that used in previous trials. Finally, the etiologies of renal dysfunction differed among the patients.

Conclusions

The present study demonstrates that RenalGuard therapy may prevent the development of CI-AKI safely in Japanese patients with renal dysfunction undergoing a catheter procedure. We also suggest that a high urine flow rate during a catheter procedure is one of the useful factors protecting against CI-AKI. Further large-scale prospective multicenter control trials are necessary to confirm our conclusions.

Compliance with ethical standards

Conflict of interest The authors disclose no conflicts of interest.

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