

Renal function-adjusted contrast medium volume is a major risk factor in the occurrence of acute kidney injury after endovascular aneurysm repair

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Abstract

Acute kidney injury (AKI) is a complication that can occur during endovascular aneurysm repair (EVAR), increasing postoperative mortality and disease-related death. We therefore evaluated the incidence of AKI after elective EVAR, as well as related factors affecting AKI occurrence, investigating the volume of contrast medium (CV)/estimated glomerular filtration rate (eGFR) ratio as a predictive factor.

We retrospectively reviewed the data of patients who underwent EVAR for infrarenal abdominal aorta aneurysm at a single center between April 2011 and December 2018. AKI was defined according to the Kidney Disease: Improving Global Outcomes criteria. We evaluated the occurrence of AKI within the first 7 days postoperatively, comparing serum creatinine levels, eGFR, CV, CV/eGFR ratio, fluid input and output, and morbidity between the AKI and no-AKI groups.

The data of 147 patients were analyzed, of which 131 (89.1%) were males (mean age: 72.10±7.40 years); the incidence of AKI was 4.1% (6/147 patients). The mean dose of contrast agents used was greater in the AKI group than in the no-AKI group (249.17±83.21 mL vs 179.43±84.32 mL, respectively; $P=.05$). The baseline eGFR was 42.69±22.08 mL/kg/1.73 m² in the AKI group and 77.96±18.92 mL/kg/1.73 m² in the no-AKI group ($P=.001$). The CV/eGFR ratio was significantly higher in the AKI group (8.21±6.13 vs 2.46±1.44; $P=0.003$). Baseline eGFR (odds ratio [OR]=0.922, $P=.001$) and the CV/eGFR ratio (OR=2.049, $P=.008$) were observed to be factors related to the occurrence of AKI in the logistic regression analysis for patients' characteristics, operation-related factors, and renal outcomes. In the receiver operating characteristic curve analysis, the area under the curve of the CV/eGFR ratio was 0.856, indicating the greatest influence. A CV/eGFR ratio cutoff value of 3.84 was considered the most appropriate, with an 83.3% sensitivity and 83.0% specificity.

The CV/eGFR ratio, rather than the absolute amount of contrast agents, was associated with the development of AKI after EVAR. The CV/eGFR ratio could be used as a possible indicator to limit the amount of contrast media required for the procedure.

Abbreviations: AAA = abdominal aorta aneurysm, AKI = acute kidney injury, CA-AKI = contrast-associated AKI, CV = volume of contrast medium, eGFR = estimated glomerular filtration rate, EVAR = endovascular aneurysm repair, KDIGO = Kidney Disease: Improving Global Outcomes, OR = open repair.

Keywords: abdominal, acute kidney injury, aortic aneurysm, contrast media, endovascular procedures, glomerular filtration rate

1. Introduction

Endovascular aneurysm repair (EVAR) has been reported as a less invasive treatment for abdominal aorta aneurysm (AAA)

than open repair (OR). With the advantage of lower 30-day mortality and morbidity, as well as shorter hospital stays,^{1,2} EVAR has been considered a first-line therapy for the treatment

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The authors report no conflicts of interest.

Data availability: The datasets generated during and/or analyzed during the current study are available in the Google Drive repository, <https://drive.google.com/file/d/1VVdaYvPQAe0Yzbbazg-cx4LywFBI478/view?usp=sharing>.

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The datasets generated during and/or analyzed during the current study are publicly available.

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of AAA. However, EVAR procedures have the disadvantages of a high rate of postoperative complications, including both device-related and systemic complications, as well as secondary reintervention.^[3]

Acute kidney injury (AKI) is a complication that may occur during both OR and EVAR. Postoperative AKI can result in additional complications, potentially increasing the length of hospital stay. This often results in an increase in both postoperative mortality and disease-related death.^[4] The incidence of AKI was lower for EVAR (range: 2.9%–18.8%) than for OR (range: 3.5%–26.3%).^[2,4–9] Although EVAR reduces the risk of ischemic insult due to aortic cross-clamping and perioperative blood loss during open surgical AAA repair,^[4] the procedure is associated with the risk of inducing AKI via the use of contrast medium during the procedure, as well as the device itself.

The occurrence of the condition after EVAR is considered postcontrast AKI; in situations wherein we cannot exclude other potential etiologies, contrast-associated AKI (CA-AKI), caused by the contrast material, is considered. The most important factor in the occurrence of CA-AKI is the amount of contrast medium used during procedures, that is, a higher volume of contrast medium (CV) increases the odds of CA-AKI development. In patients with chronic renal failure, however, CA-AKI may be induced with lower doses, often <100 cc of contrast medium.^[10]

During the EVAR procedure, >100 cc of contrast media is typically used.^[4,6,8] To prevent AKI after EVAR, determining the required dosage of contrast medium with due consideration of and adjustment to the risk factors of each patient is important. Several reports evaluated the CV adjusted to the estimated glomerular filtration rate (eGFR) as a predictive factor for AKI after percutaneous coronary intervention^[11–13]; however, the CV/eGFR ratio has rarely been used during EVAR.

Our study, therefore, evaluated the incidence of AKI after elective EVAR and related factors affecting AKI occurrence while investigating the CV/eGFR ratio as a predictive factor.

2. Methods

2.1. Patients and data collection

We retrospectively reviewed the data of patients who underwent EVAR at a single center between April 2011 and December 2018 after acquiring ethical approval from the Institutional Review Board of Pusan National University Yangsan Hospital (IRB no: 05–2020-071). Informed consent was waived because of the retrospective study design. A total of 171 patients underwent EVAR for infrarenal AAA. We excluded 16 patients who had ruptured or symptomatic AAA, 4 patients with end-stage renal disease who had already undergone dialysis before the operation, and 4 patients who needed continuous renal replacement therapy due to postoperative complications caused by limb ischemia or myocardial infarction. Finally, 147 patients were enrolled in the study.

We collected clinical data from patients' electronic medical records. Data regarding demographics, perioperative renal function, CV used during the EVAR procedure, postoperative urine output, operation-related factors and postoperative complications in 30 days, and length of intensive care unit stay were collected and analyzed. Serum creatinine levels and urine output were collected postoperatively, as well as on postoperative

days 1 and 2 after EVAR. Intraoperative input and output data were recorded by an anesthesiologist.

The primary endpoint was the occurrence of AKI within the first 7 days postoperatively. The secondary endpoint was the comparison of serum creatinine levels, eGFR, the CV/eGFR ratio, fluid input and output, and morbidity between the AKI and no-AKI groups.

2.2. Definition of acute kidney injury

We used the Chronic Kidney Disease Epidemiology Collaboration equation to calculate the eGFR.^[14] The serum creatinine value at the time of admission was used as the preoperative value; AKI was diagnosed according to the Kidney Disease: Improving Global Outcomes (KDIGO) criteria,^[15] which defined it as an increase of more than 0.3 mg/dL in serum creatinine over 48 hours, a urine output <0.5 mL/kg/hour for 6 hours after operation, or a serum creatinine increase of 1.5 times the baseline or more within 7 days postoperatively. The severity of AKI was also based on the KDIGO criteria.^[15]

2.3. Perioperative management

Each patient was hospitalized 2 days before surgery and maintained on a dose of 1000 cc of isotonic, crystalloid, normal saline mixed with 600 mg of N-acetylcysteine administered at a rate of 40 cc per hour for 24 to 48 hours until the procedure.^[16] After surgery, we administered hydration using the same method; intraoperative fluid management was performed by an anesthesiologist. Of the 17 patients with diabetes, 10 were taking metformin; they were asked to discontinue the medication 2 days before the operation. Computed tomography angiography was evaluated at least 3 days before surgery.

2.4. Surgical procedure

Surgery was performed under general anesthesia. EVAR was performed on a portable fluoroscopic unit (C-arm) until September 2016 with undiluted contrast; thereafter, the procedure was performed in a hybrid room with diluted contrast. Contrast medium was injected using a different method between different periods and was used without dilution when EVAR was performed under a C-arm. Since September 2016, a contrast medium to normal saline ratio of 6:4 was used. We used iodixanol, with an osmolarity of 290 mOsm/kg and viscosity of 11.8 cP (at 37°C). After dilution, the osmolarity and viscosity were 292 mOsm/kg and 7.5 cP (at 37 °C), respectively. Each contrast media injection was administered at specific time intervals. In general, it was injected by first identifying the proximal neck of the AAA; we used a diluted contrast agent at a rate of 10 cc/second for 2 seconds (actual contrast medium usage: 12 cc). Second, to measure both distal limbs' size, we used contrast media at a rate of 6 cc/second for 2 seconds (actual contrast medium usage: 14.4 cc). For the final angiogram, we used contrast media at a rate of 10 cc/second for 3 seconds (actual contrast medium usage: 18 cc). No endoleak was identified on the final angiogram, and there was no obstruction to the renal artery orifice. When required, an additional amount of a diluted contrast agent was used between each process to confirm the anatomical morphology. About 5 to 6 days after the surgery, we performed computed tomography angiography to reconfirm the

Table 1**General characteristics of patients.**

Value	Total (N = 147)	No-AKI (N = 141)	AKI (N = 6)	P
Age, y, mean \pm SD	72.10 \pm 7.39	71.96 \pm 7.40	75.33 \pm 6.95	.27
Male (%)	131 (89.1)	126 (89.4)	5 (83.3)	.50
BMI, kg/m ²	23.58 \pm 3.07	23.56 \pm 3.05	24.08 \pm 3.80	.68
Smoking	67 (45.6)	65 (46.1)	2 (33.3)	.68
Comorbidity				
HTN	94 (63.9)	89 (63.1)	1 (83.3)	.41
DM	25 (17.0)	23 (16.3)	2 (33.3)	.27
Hyperlipidemia	43 (29.3)	42 (29.8)	1 (16.7)	.67
CVD	33 (22.4)	31 (22.0)	2 (33.3)	.61
COPD	6 (4.1)	6 (4.3)	0 (0.0)	1.00
Baseline eGFR (mL/kg/1.73 m ²)	76.53 \pm 20.22	77.97 \pm 18.92	42.69 \pm 22.08	.001
\geq 60 mL/kg/1.73 m ²	117	116 (82.3)	1 (16.7)	.001
<60 mL/kg/1.73 m ²	30	25 (17.7)	5 (83.3)	.001

Values are presented as mean \pm standard deviation or number (%).

AKI = acute kidney disease, BMI = body mass index, COPD = chronic obstructive pulmonary disease, CVD = coronary vascular disease, DM = diabetes mellitus, eGFR = estimated glomerular filtration rate, HTN = hypertension, SD = standard deviation.

stent graft position and rule out any other complications, including any obstruction to the renal artery orifice.

2.5. Statistical analysis

Continuous variables are expressed as mean \pm SD and were compared using the Mann-Whitney *U* test. Categorical variables were compared using χ^2 or Fisher exact tests as appropriate; a *P* value of $<.05$ was considered statistically significant. Logistic regression analysis was conducted to evaluate the independent predictors of AKI occurrence. To examine the factor with the greatest influence on AKI occurrence, we used the likelihood-ratio test. An evaluation of an additional cutoff value was performed using receiver operating characteristic curve analysis. IBM SPSS Statistics version 26.0 for Windows (IBM Co., Armonk, NY) was used for all statistical analyses.

3. Results

We compared the AKI group and the no-AKI group according to the patient demographics and comorbidities. The mean age was

72.10 years, and 89.1% of patients were male. AKI occurred in 6 of 147 patients. There were no statistical differences with regard to age, sex, body mass index, smoking, or comorbidities. Baseline eGFR was lower in the AKI group, and the only characteristic that showed a statistical difference between the two groups (Table 1). When classified according to preoperative eGFR results, 83.3% of patients with eGFRs of >60 mL/kg/1.73 m² were in the no-AKI group and 17.7% were in the AKI group. According to the KDIGO AKI staging,^[15] 5 of 6 patients were categorized into stage 1 (serum creatinine ≥ 1.5 –1.9 times the baseline); the remaining patient was classified into stage 2 (serum creatinine ≥ 2.0 –2.9 times the baseline). No patient required postoperative renal replacement therapy. In terms of operation-related factors (Table 2), 5 of 6 patients underwent EVAR using a C-arm. In the AKI group, the mean doses of contrast agents used were statistically higher than those in the no-AKI group (249.17 \pm 83.21 mL vs 179.43 \pm 84.32 mL, respectively; *P* = .05). Even though it was not statistically significant, the AKI group showed a longer operation time (180.00 \pm 87.06 minutes vs 146.75 \pm 45.69 minutes, respectively; *P* = .25), more intraoperative blood loss

Table 2**Operation-related factors.**

	Total (N = 147)	No-AKI (N = 141)	AKI (N = 6)	P
Duration between pre-Op. CT and Op., day	14.64 \pm 18.62	14.83 \pm 18.94	10.17 \pm 7.25	.86
C-arm	87 (59.2)	82 (58.2)	5 (83.3)	.40
Hybrid operation room	60 (40.8)	59 (41.8)	1 (16.7)	.40
Operation time, min	148.11 \pm 48.01	146.75 \pm 45.69	180.00 \pm 87.06	.25
Contrast volume, mL	182.28 \pm 85.13	179.43 \pm 84.32	249.17 \pm 83.21	.05
I/O balance during operation				
Input, mL	1790.68 \pm 909.02	1782.84 \pm 903.13	1975.00 \pm 1117.03	.68
Urine amount, mL	636.19 \pm 496.10	640.92 \pm 499.69	525.00 \pm 423.97	.59
Blood loss, mL	255.24 \pm 286.67	248.37 \pm 283.43	416.67 \pm 343.03	.14
Total I/O, mL	899.25 \pm 724.45	893.55 \pm 724.86	1033.33 \pm 768.55	.68
Mortality (30 days)	1 (0.7)	1 (0.7)	0 (0.0)	1.00
Morbidity (30 days)	6 (4.1)	5 (3.5)	1 (16.7)	.22
Pulmonary edema	42 (28.6)	39 (27.7)	3 (50.0)	.35
ICU stay, days	0.88 \pm 0.43	0.87 \pm 0.43	1.17 \pm 0.41	.08
Hospital stay, days	10.56 \pm 30.84	10.33 \pm 31.21	16.00 \pm 21.73	.33

Values are presented as mean \pm standard deviation or number (%).

AKI = acute kidney injury, CT = computed tomography, I/O = input and output, ICU = intensive care unit, Op. = operation.

Table 3
Renal outcomes.

Value	Total (N=147)	No-AKI (N=141)	AKI (N=6)	P
Baseline				
S _{Cr} , mg/dL	0.99±0.38	0.96±0.29	1.84±0.94	.001
eGFR (mL/kg/1.73 m ²)	76.53±20.22	77.96±18.92	42.69±22.08	.001
Post-op				
S _{Cr} , mg/dL	0.86±0.38	0.82±0.28	1.89±0.89	<.001
eGFR (mL/kg/1.73 m ²)	85.48±20.19	87.35±17.80	41.65±25.14	<.001
24 h				
S _{Cr} , mg/dL	0.91±0.44	0.86±0.30	2.19±0.99	<.001
eGFR (mL/kg/1.73 m ²)	83.04±21.98	85.06±19.61	35.34±22.41	<.001
Urine output, cc/kg/h	1.63±0.74	1.64±0.75	1.43±0.48	.50
Input, cc/kg/h	1.62±0.70	1.60±0.70	2.06±0.52	.08
I/O, cc	84.31±934.81	43.89±924.06	966.83±768.59	.01
48 h*	(N=102)	(N=96)	(N=6)	
S _{Cr} , mg/dL	1.03±0.60	0.92±0.31	2.85±1.16	<.001
eGFR (mL/kg/1.73 m ²)	77.23±24.25	80.55±20.63	24.03±13.55	<.001
Discharge				
S _{Cr} , mg/dL	0.92±0.51	0.86±0.33	2.46±1.22	<.001
eGFR (mL/kg/1.73 m ²)	83.24±22.68	85.37±20.03	33.06±25.24	<.001
CV/eGFR ratio	2.72±2.13	2.46±1.44	8.21±6.13	.003
CV/eGFR ratio >3.84, n (%)	29 (19.7)	24 (17.0)	5 (83.3)	.001

Values are presented as mean±standard deviation or number (%).

AKI=acute kidney injury, CV=volume of contrast media, eGFR=estimated glomerular filtration rate, Post-op=postoperative, S_{Cr}=serum creatinine.

*Data of 45 patients were missing after 48 hours of surgery.

(416.67±343.03 mL vs 248.37±283.43 mL, respectively; $P = .14$), and longer intensive care unit stays (1.17 ± 0.41 days vs 0.87 ± 0.43 days, respectively; $P = .08$) and hospital stay (16.00 ± 21.73 days vs 10.33 ± 31.21 days, respectively; $P = .33$) (Table 2).

Renal outcomes were compared between the 2 groups. The eGFR was statistically lower in the AKI group than in the no-AKI group at baseline, postoperatively, 24 hours postoperatively, 48 hours postoperatively, and at discharge. The baseline eGFR was 42.69 ± 22.08 mL/kg/1.73 m² in the AKI group and 77.96 ± 18.92 mL/kg/1.73 m² in the no-AKI group ($P = .001$). Postoperative eGFR results after 24 hours and 48 hours showed opposite results in the 2 groups. In the AKI group, postoperative eGFR decreased from 42.69 ± 22.08 mL/kg/1.73 m² (baseline) to 24.03 ± 13.55 mL/kg/1.73 m² after 48 hours. On the contrary, postoperative eGFR in the no-AKI group slightly increased from 77.96 ± 18.92 mL/kg/1.73 m² (baseline) to 80.55 ± 20.63 mL/kg/1.73 m² after 48 hours. In the AKI group, the reduced eGFR was improved at the time of discharge (Table 3).

We conducted logistic regression analysis for patients' characteristics, operation-related factors, and renal outcomes. Chronic obstructive pulmonary disease was excluded due to the number of occurrences. Baseline eGFR and the CV/eGFR ratio were observed to be factors related to the occurrence of AKI. Other factors did not show statistically significant results in the odds ratio (Table 4). Additionally, we performed ROC curve analysis. The area under the curve of the CV/eGFR ratio was 0.856 (Figure 1). When the cutoff value of the CV/eGFR ratio was 3.84, it was observed to be the most appropriate, with 83.3% sensitivity and 83.0% specificity. Furthermore, 19.9% of patients had a CV/eGFR ratio of >3.84. In 83.3% of patients in the AKI group, the CV/eGFR ratio was higher than the cutoff value (Table 3).

Complications occurred in 1 (16.7%) and 5 (3.5%) patients in the AKI and non-AKI groups, respectively, and 1 mortality was reported due to ischemic colitis in the AKI group. Five of the 6

complications occurred in the no-AKI group. Complications included 1 case of cerebral infarction, 2 cases of distal limb embolization, and 2 cases of ischemic colitis, which led to death in 1 case. The other case of ischemic colitis was caused by AKI due to bleeding after surgery.

4. Discussion

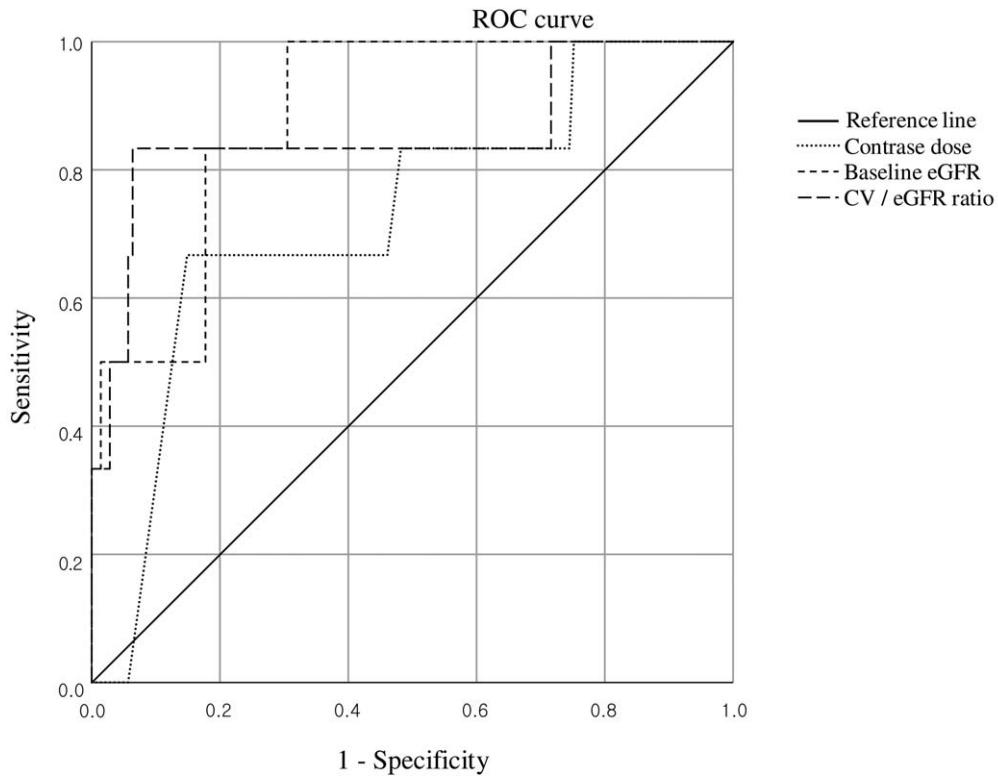
In our study, the overall incidence of AKI was 4.1%, which was compared with those of other studies (Table 5).^[4,6-9] In particular, the rate of AKI occurrences had decreased from 6.1% to 1.7% since the introduction of the hybrid system in September 2016 (Table 6).

The contrast agent usage under hybrid-based EVAR compared to that in C-arm-based EVAR was significantly reduced by

Table 4
Logistic regression analyses of risk factors for acute kidney injury.

Variable	OR	P	95% CI
Age	1.066	.27	0.950–1.197
Sex	1.680	.64	0.184–15.357
Smoking	1.711	.54	0.303–9.642
BMI	1.055	.68	0.916–1.365
HTN	2.921	.33	0.332–25.692
DM	2.565	.29	0.443–14.839
Hyperlipidemia	0.471	.49	0.053–4.159
CVD	1.774	.51	0.310–10.144
Operation time	1.010	.11	0.998–1.023
Blood loss	1.001	.17	0.999–1.004
Contrast dose	1.010	.06	1.000–1.020
Baseline eGFR	0.922	.001	0.878–0.967
CV/eGFR ratio	2.049	.008	1.209–3.471

BMI=body mass index, CI=confidence interval, CV=volume of contrast media, CVD=coronary vascular disease, DM=diabetes mellitus, eGFR=estimated glomerular filtration rate, HTN=hypertension, OR=odds ratio.



	Area under the curve	Standard error	P-value	Confidence interval
Contrast dose	0.728	0.106	0.059	0.520-0.936
Baseline eGFR	0.888	0.051	0.001	0.789-0.987
CV/eGFR ratio	0.856	0.106	0.003	0.649-1.000

Figure 1. ROC curve. ROC analysis on contrast dose, baseline eGFR, and the contrast medium (CV)/eGFR ratio. CV/eGFR was considered statistically significant ($P = .003$). CV=volume of contrast media, eGFR=estimated glomerular filtration rate, ROC=receiver-operating characteristic

approximately 50% (Table 6). After using the hybrid system, the patients' baseline eGFR was not significantly different; however, the CV/eGFR had decreased. Therefore, the dose of contrast agent was determined to be an important factor in the occurrence of AKI.

Contrast media is known to cause renal vasoconstriction and hypoxic injury, leading to acute tubular necrosis.^[17,18] In addition to the contrast agent volume, the properties of the contrast agent have also been noted to be associated with a

Table 5
Comparison of the incidence of acute kidney injury.

	PNUYH (N = 147)	Castagno et al ^[7] (N = 136)	Cheng et al ^[8] (N = 216)	Saratzis et al ^[6] (N = 149)	Lee et al ^[9] (N = 78)	Nonaka et al ^[4] (N = 189)
Age	72.10 ± 7.40	76.7 ± 6.9	73 (33–92)	70 ± 8.0	72.75 ± 9.5	77.5 ± 7.6
Male (%)	131 (89.1)	93 (68.4)	188 (87)	133 (89)	61 (78)	159 (84.1)
HTN	94 (63.9)	112 (77)	183 (84)	114 (76)	60 (78)	150 (79.4)
DM	25 (17.0)	22 (15)	40 (19)	25 (17)	31 (40)	22 (11.6)
CVD	33 (22.4)	40 (27)	20 (9)	11 (7)	10 (13)	32 (16.9)
Contrast dose	182.28 ± 85.13		140 (30–370)	121 ± 15	91.19 ± 82.9	134.2 ± 51.0
Hydration	NS 1 L/day			NS 1.5 L/day	NS 1 L/day	
NAC	600 mg/day				600 mg 3 times/day	
Contrast	Iodixanol		Iopromide or ioxilan	Iopromide	–	
AKI	6 (4.1)	8 (5.5)	25 (12)	28 (18.8)	11 (14.1)	7 (3.7)

Values are presented as mean ± standard deviation or number (%).

AKI=acute kidney injury, CVD=coronary vascular disease, DM=diabetes mellitus, HTN=hypertension, NAC=N-acetylcysteine, PNUYH=Pusan National University Yangsan Hospital.

Table 6
Comparisons according to the x-ray source.

	Total (N = 147)	C-arm (N = 82)	Hybrid system (N = 59)	P
AKI (%)	6 (4.1)	5 (6.1)	1 (1.7)	
Operation time, min	148.11 ± 48.01	158.01 ± 50.83	133.75 ± 39.80	.002
Contrast dose, mL	182.28 ± 85.13	229.49 ± 68.32	113.82 ± 55.45	<.001
eGFR (mL/kg/1.73 m ²)				
Baseline	76.53 ± 20.22	74.56 ± 20.15	79.38 ± 20.15	.15
Post-op	85.48 ± 20.19	84.98 ± 20.88	86.21 ± 19.30	.71
24 h	83.04 ± 21.98	81.50 ± 22.31	85.26 ± 21.49	.30
CV/eGFR ratio	2.72 ± 2.13	3.54 ± 2.36	1.52 ± 0.82	<.001

Values are presented as mean ± standard deviation or number (%).

AKI = acute kidney injury, CV = volume of contrast media, eGFR = estimated glomerular filtration rate, Post-op = postoperative.

difference in the incidence of AKI.^[17] The osmolality of the contrast media solution increases linearly with the molar concentration, whereas the viscosity increases exponentially. The frequency of adverse reactions to contrast media ranges between 5% and 12% for high-osmolar contrast media and between 1% and 3% for low-osmolar contrast media.^[17,19] We used iodixanol, a low-osmolar contrast agent, and we were able to further reduce viscosity by using a 6:4 diluted solution using a high-resolution hybrid-based EVAR.

In our study, baseline eGFR was the factor related to AKI after EVAR. In the AKI group, the mean baseline eGFR was significantly lower than that of the no-AKI group. In 83.3% of AKI patients, baseline eGFR was <60 mL/kg/1.73 m². Therefore, it is important to confirm the patient's renal function before surgery; renal protection methods should thus be considered, especially in the lower eGFR groups.

To protect renal function, 1000 cc of normal saline for hydration, mixed with 600 mg of N-acetylcysteine was administered at a rate of 40 cc per hour for 24 to 48 hours until the procedure. Sufficient hydration could help protect the kidneys,^[20] but may result in side effects such as pulmonary effusion or edema. After EVAR, we checked for pulmonary edema or effusion via chest x-rays. The incidence of pulmonary edema or effusion was 28.6%; however, most cases involved only a small amount, and no cases required intervention (Table 2).

Aside from renal function, CV was observed to be a significantly different factor between the two groups in our study. In the AKI group, a contrast media volume of almost 70 cc higher than the no-AKI group was used. Considering the difference in eGFR between the two groups, renal function-adjusted CV, or the CV/eGFR ratio, was investigated as both a risk factor and a predictive model. Although several studies have used this ratio as a predictor for CA-AKI after percutaneous coronary interventions,^[11–13,21] it has not been used during the EVAR procedure for AAA; however, one study had previously reported the CV/eGFR ratio as a useful predictor for CA-AKI occurrence after EVAR.^[22]

In this study, the mean CV/eGFR ratio of the AKI group was more than two times higher than that of the no-AKI group. The CV/eGFR ratio was determined to be statistically significant as a risk factor and predictive value for AKI occurrence (Table 4). We were able to determine an optimal cutoff value of 3.84, which exhibited >80% sensitivity and specificity. In 5 of 6 patients in the AKI group, this ratio was higher than the cutoff value. Kawatani et al.^[22] suggested that the appropriate cutoff value of the CV/eGFR ratio was >1.62. Although the 2 values were different, the usefulness of the CV/eGFR ratio as a predictive value was clearly demonstrated.

In addition, the study in which coronary intervention was performed showed cutoff results in the range of 2.5 to 3.0.^[11–13,21] Further research is needed to obtain a standard cutoff value and to estimate the optimal dose of contrast agent.

This study has several limitations, including the small sample size, which was a major limitation, and the retrospective and single-center study design. Among other reasons contributing to the occurrence of AKI after EVAR, the difficulty of the procedure as well as the complications that occur during surgery may also play a role. Nonetheless, we did not mention the complexity of procedure; these factors can be reflected in the operation time or blood loss, but our study did not yield meaningful results.

4.1. Conclusions

We demonstrated that the CV/eGFR ratio is a useful factor for predicting AKI occurrence. Furthermore, this ratio is a possible indicator that could be used to limit the amount of contrast media. Based on these preliminary results, further studies are warranted to test this hypothesis.

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References

- [1] Dua A, Kuy S, Lee CJ, et al. Epidemiology of aortic aneurysm repair in the United States from 2000 to 2010. *J Vasc Surg* 2014;59:1512–7.
- [2] Revuelta Suero S, Martinez Lopez I, Hernandez Mateo M, et al. Outcomes of the repair of 1000 abdominal aortic aneurysms in the endovascular era. *Ann Vasc Surg* 2019;59:63–72.
- [3] Daye D, Walker TG. Complications of endovascular aneurysm repair of the thoracic and abdominal aorta: evaluation and management. *Cardiovasc Diagn Ther* 2018;8(suppl 1):S138–56.

- [4] Nonaka T, Kimura N, Hori D, et al. Predictors of acute kidney injury following elective open and endovascular aortic repair for abdominal aortic aneurysm. *Ann Vasc Dis* 2018;11:298–305.
- [5] Zarkowsky DS, Hicks CW, Bostock IC, et al. Renal dysfunction and the associated decrease in survival after elective endovascular aneurysm repair. *J Vasc Surg* 2016;64:1278–85. e1271.
- [6] Saratzis A, Melas N, Mahmood A, et al. Incidence of acute kidney injury (AKI) after endovascular abdominal aortic aneurysm repair (EVAR) and impact on outcome. *Eur J Vasc Endovasc Surg* 2015;49:534–40.
- [7] Castagno C, Varetto G, Quaglino S, et al. Acute kidney injury after open and endovascular elective repair for infrarenal abdominal aortic aneurysms. *J Vasc Surg* 2016;64:928–33. e921.
- [8] Cheng EL, Hong Q, Yong E, et al. Validating the use of contrast-induced nephropathy prediction models in endovascular aneurysm repairs. *J Vasc Surg* 2020;71:1546–53.
- [9] Lee J, Park KM, Jung S, et al. Occurrences and results of acute kidney injury after endovascular aortic abdominal repair? *Vasc Specialist Int* 2017;33:135–9.
- [10] Mehran R, Nikolsky E. Contrast-induced nephropathy: definition, epidemiology, and patients at risk. *Kidney Int Suppl* 2006;S11–5.
- [11] Ando G, de Gregorio C, Morabito G, et al. Renal function-adjusted contrast volume redefines the baseline estimation of contrast-induced acute kidney injury risk in patients undergoing primary percutaneous coronary intervention. *Circ Cardiovasc Interv* 2014;7:465–72.
- [12] Celik O, Ozturk D, Akin F, et al. Association between contrast media volume-glomerular filtration rate ratio and contrast-induced acute kidney injury after primary percutaneous coronary intervention. *Angiology* 2015;66:519–24.
- [13] Raposeiras-Roubin S, Abu-Assi E, Ocaranza-Sanchez R, et al. Dosing of iodinated contrast volume: a new simple algorithm to stratify the risk of contrast-induced nephropathy in patients with acute coronary syndrome. *Catheter Cardiovasc Interv* 2013;82:888–97.
- [14] Stevens LA, Claybon MA, Schmid CH, et al. Evaluation of the Chronic Kidney Disease Epidemiology Collaboration equation for estimating the glomerular filtration rate in multiple ethnicities. *Kidney Int* 2011;79:555–62.
- [15] Khwaja A. KDIGO clinical practice guidelines for acute kidney injury. *Nephron Clin Pract* 2012;120:c179–84.
- [16] Biernacka-Fialkowska B, Szuksztul M, Suslik W, et al. Intravenous N-acetylcysteine for the PREvention Of Contrast-induced nephropathy - a prospective, single-center, randomized, placebo-controlled trial. The INPROC trial. *Postepy Kardiol Interwencyjnej* 2018;14:59–66.
- [17] Andreucci M, Faga T, Pisani A, et al. The choice of the iodinated radiographic contrast media to prevent contrast-induced nephropathy. *Adv Nephrol* 2014;2014:1–1.
- [18] Yang JS, Peng YR, Tsai SC, et al. The molecular mechanism of contrast-induced nephropathy (CIN) and its link to in vitro studies on iodinated contrast media (CM). *Biomedicine (Taipei)* 2018;8:1.
- [19] Beckett KR, Moriarity AK, Langer JM. Safe use of contrast media: what the radiologist needs to know. *Radiographics* 2015;35:1738–50.
- [20] McCullough PA, Stacul F, Becker CR, et al. Contrast-Induced Nephropathy (CIN) Consensus Working Panel: executive summary. *Rev Cardiovasc Med* 2006;7:177–97.
- [21] Park HS, Kim CJ, Yi JE, et al. Contrast volume/Raw eGFR ratio for predicting contrast-induced acute kidney injury in patients undergoing percutaneous coronary intervention for myocardial infarction. *Cardiorenal Med* 2015;5:61–8.
- [22] Kawatani Y, Kurobe H, Nakamura Y, et al. The ratio of contrast medium volume to estimated glomerular filtration rate as a predictor of contrast-induced nephropathy after endovascular aortic repair. *J Med Invest* 2018;65:116–21.