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ORIGINAL RESEARCH

Comparison of postcontrast acute kidney injury based on previous and current diagnostic criteria following cerebral angiography in patients with acute ischemic stroke: a comparative case-control study

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Abstract

Background: Physicians often face challenges in deciding whether to perform imaging for patients with acute ischemic stroke(AIS) in the emergency department due to concerns about postcontrast acute kidney injury (PC-AKI) risk. The conventional PC-AKI definition has been criticized for overestimating AKI incidence, leading to the introduction of a revised diagnostic criterion. However, There is limited research on how well this new definition reflects PC-AKI, particularly regarding diagnostic rate changes in acute ischemic stroke patients undergoing cerebral angiography. This study aimed to assess the impact of updated diagnostic criteria on PC-AKI incidence in patients with AIS undergoing cerebral angiography in emergency departments. **Methods**: We hypothesized that the new criteria would result in lower PC-AKI diagnosis rates compared to the previous criteria. Data of 381 patients aged $\geq$18 years with AIS who visited the emergency department at a tertiary university hospital in Seoul, South Korea, and who underwent cerebral angiography between October 2018 and June 2023 were retrospectively analyzed. After applying selection criteria, 361 patients were included in the analysis. The primary outcome measure was the PC-AKI incidence based on previous and updated diagnostic criteria. Secondary outcomes included subgroup PC-AKI incidence analyses based on baseline estimated glomerular filtration rate (eGFR) intervals and prognostic outcome comparisons using area under the curve (AUC) values with 95% confidence intervals. **Results**: The incidence of PC-AKI was significantly lower under the updated criteria compared with the previous criteria ($p = 0.048$). Using the relative criterion resulted in nearly a three-fold lower PC-AKI incidence ($p = 0.002$). Patients with baseline eGFRs $\geq$90 mL/min/1.73 m^2 also had a significantly lower PC-AKI incidence under the updated criteria ($p = 0.03$). **Conclusions**: This study demonstrates that the updated PC-AKI diagnostic criteria result in a lower reported incidence than the previous criteria, which may influence clinical decision-making in patients with AIS.

Keywords

Acute kidney injury; Ischemic stroke; Cerebral angiography

1. Introduction

Post-contrast acute kidney injury (PC-AKI) is a critical complication associated with contrast-enhanced imaging, particularly following cerebral angiography in patients with acute ischemic stroke (AIS) [1, 2]. Its occurrence can lead to prolonged hospitalization, increased healthcare costs and adverse outcomes [3–6]. Previously used diagnostic criteria for PC-AKI were primarily based on small increases in serum creatinine levels after contrast exposure [7]. However, these criteria have been criticized for their lack of specificity, as small changes in creatinine levels may not always reflect true kidney injury, especially in patients with pre-existing renal conditions or those requiring intensive care [8].

The updated diagnostic criteria for PC-AKI address these limitations by incorporating more stringent definitions and thresholds to distinguish between true kidney injury and transient or unrelated changes in creatinine levels [9, 10]. These revisions aim to reduce the overdiagnosis of PC-AKI and improve the accuracy of incidence reporting [11]. By providing a more reliable diagnostic framework, the new criteria has the potential to positively impact patient outcomes by enabling clinicians to focus on cases with true clinical significance, optimizing treatment strategies and minimizing unnecessary

interventions [12].

According to the conventional criteria for PC-AKI, the definition was based on an absolute criterion or a relative criterion [13]. Some studies have suggested that existing definitions overestimate the incidence of PC-AKI [14, 15]. Particularly, the relative criterion in the conventional definition, although the most sensitive indicator for diagnosis, tends to overdiagnose PC-AKI, thus leading to a preference for the absolute criterion [16]. However, other studies have suggested that the relative criterion may have greater prognostic relevance than the absolute criterion in coronary angiography [17]. As the incidence of PC-AKI is significantly influenced by the diagnostic criteria used [18, 19], the European Society of Urogenital Radiology (ESUR) responded by introducing new diagnostic criteria for PC-AKI in 2018. Although some studies have reported a decrease in the incidence of PC-AKI after the use of the new diagnostic criteria, there is a lack of research on how the diagnosis rate of PC-AKI has changed and whether the revised definition effectively reflects PC-AKI in patients undergoing cerebral angiography for AIS [20, 21]. Therefore, we aimed to compare the previous and current diagnostic criteria for PC-AKI in patients with AIS who underwent cerebral angiography in the emergency department (ED), confirm the changes in the diagnostic rate of PC-AKI, and determine whether the revised criteria accurately reflected PC-AKI, with the goal of providing physicians with evidence to make decisions regarding proactive intervention and treatment in the ED.

2. Materials and methods

2.1 Study design and population

This retrospective study used data from patients registered in the Brain Salvage through Emergent Stroke Therapy (BEST) protocol at a tertiary university hospital in Seoul, South Korea. All data were collected from electronic medical records. The study focused on adult patients aged ≥18 years who presented to the ED and underwent cerebral angiography after activating the BEST protocol from October 2018 to June 2023. This study targeted patients who underwent cerebral angiography after BEST protocol activation and were subsequently diagnosed with PC-AKI.

2.2 BEST protocol

The BEST protocol was designed for prompt diagnosis and rapid thrombolysis in patients suspected of having AIS in the ED. Neurological symptoms that are indicative of AIS include unilateral weakness, speech impairment, walking difficulties, altered consciousness, visual disturbances, sudden headaches and dizziness. When the ED physician initially examines a patient and activates the BEST protocol, the neurologist immediately performs a neurological examination, followed by a Computed Tomography Angiography (CTA). Subsequently, cerebral angiography is performed, followed by thrombolysis as needed.

2.3 CTA

All imaging procedures were performed using a high-resolution computed tomography scanner (Siemens SOMATOM Force; Siemens Healthcare, Erlangen, BY, Germany). For CTA, isotonic contrast material (iopamidol 755 mg/mL, Iopamiro 370; Bracco, Milan, Italy) was injected at a rate of 4 mL/s. The upper limit of the contrast medium volume was 100 mL.

2.4 Cerebral angiography

Cerebral angiography was performed using angiography systems (Allura Clarity FD 20/20 and Allura Xper FD 20/20; Philips Healthcare, Best, Netherlands). Isotonic contrast material (iodixanol 652 mg/mL, Visipaque 320; GE Healthcare, Chicago, IL, USA) was injected at a rate of 3–4 mL/s.

2.5 Comparison of the previous and current PC-AKI diagnostic criteria

The estimated glomerular filtration rate (eGFR) was calculated using the Chronic Kidney Disease Epidemiology Collaboration equation (https://www.kidney.org/content/ckd-epi-creatinine-equation-2009). Patients were categorized into four groups on the basis of their eGFR values: <30, 30 to <45, 45 to <60, 60 to <90 and ≥90 mL/min/1.73 m^2.

Definitions vary slightly according to guidelines. Estimates of disease prevalence and mortality differ because of the lack of consensus on the definition of acute renal failure. More recently, the Kidney Disease/Improving Global Outcomes (KDIGO) group revised the definition of AKI, classifying patients on the basis of changes in serum creatinine (SCr) levels and urine output. As the criteria for AKI defined by the KDIGO group and the SCr levels are the same as the new PC-AKI criteria from the ESUR, the 2018 ESUR guidelines were followed in this study.

According to the previous diagnostic criteria, PC-AKI was defined as an absolute increase in SCr levels ≥0.5 mg/dL within 72 h after contrast agent administration or a relative increase ≥1.25 times [13]. According to the current definition of PC-AKI, the absolute criterion for PC-AKI was defined as an increase in SCr level of 0.3 mg/dL within 72 h after exposure to the contrast agent. The relative criterion defined PC-AKI as an increase exceeding 1.5 times the baseline within 72 h after exposure to the contrast agent [10] (Table 1).

2.6 Data analysis and clinical outcomes

To examine the differences in the incidence of PC-AKI between the previous and current diagnostic criteria, subgroup analyses were conducted for each criterion (satisfying the absolute diagnostic criteria, the relative diagnostic criteria and both the absolute and relative criteria). Additionally, the differences in PC-AKI incidence were compared on the basis of baseline eGFR intervals. The analysis was divided into absolute and relative diagnostic criteria to explore how each criterion was more sensitively applied on the basis of the baseline eGFR. Lastly, the prognosis of patients diagnosed with PC-AKI was compared using the previous and current diagnostic criteria, and the differences in outcomes between the two sets of criteria

TABLE 1. Comparison of previous and latest diagnostic criteria for PC-AKI.

Criteria	Previous diagnostic criteria	Latest diagnostic criteria
Definition	Increase in serum creatinine levels ≥0.5 mg/dL or ≥25% from baseline within 48–72 h after contrast administration.	Increase in serum creatinine levels ≥0.3 mg/dL or ≥50% from baseline within 48 h after contrast administration.

were examined.

To ensure the accuracy of survival and 30-day mortality analysis, we thoroughly reviewed the patients' medical records and excluded cases where mortality was attributed to causes unrelated to PC-AKI. Specifically, one patient who died due to sepsis after being transferred to the internal medicine department and three who died from cerebral hemorrhage following interventional procedures were excluded from the survival and mortality evaluation.

2.7 Statistical analyses

Categorical variables are presented as counts (%), and continuous variables are expressed as means ± standard deviations or means (95% confidence intervals (CIs)). The *Z*-test was used to examine the difference in the incidence of PC-AKI between the two criteria. For the prognostic analysis of patients diagnosed with PC-AKI, the area under the curve values were calculated with 95% CIs and compared using DeLong's method. All statistical analyses were performed using SAS version 9.4 (SAS Institute Inc., Cary, NC, USA), and *p*-values < 0.05 were considered statistically significant.

3. Results

3.1 Study population

Between October 2018 and June 2023, 381 patients who presented with AISs in our center's ED and underwent cerebral angiography were identified. After excluding 20 patients (Fig. 1), 361 were finally included in this analysis. Among them, 34 were diagnosed with PC-AKI based on previous diagnostic criteria, and 20 were diagnosed with PC-AKI based on the current diagnostic criteria (Fig. 1). The clinical characteristics of the patients are summarized in Table 2.

3.2 Incidence of PC-AKI (previous versus current diagnostic criteria)

The incidence of PC-AKI was significantly lower based on the current diagnostic criteria than based on the previous criteria

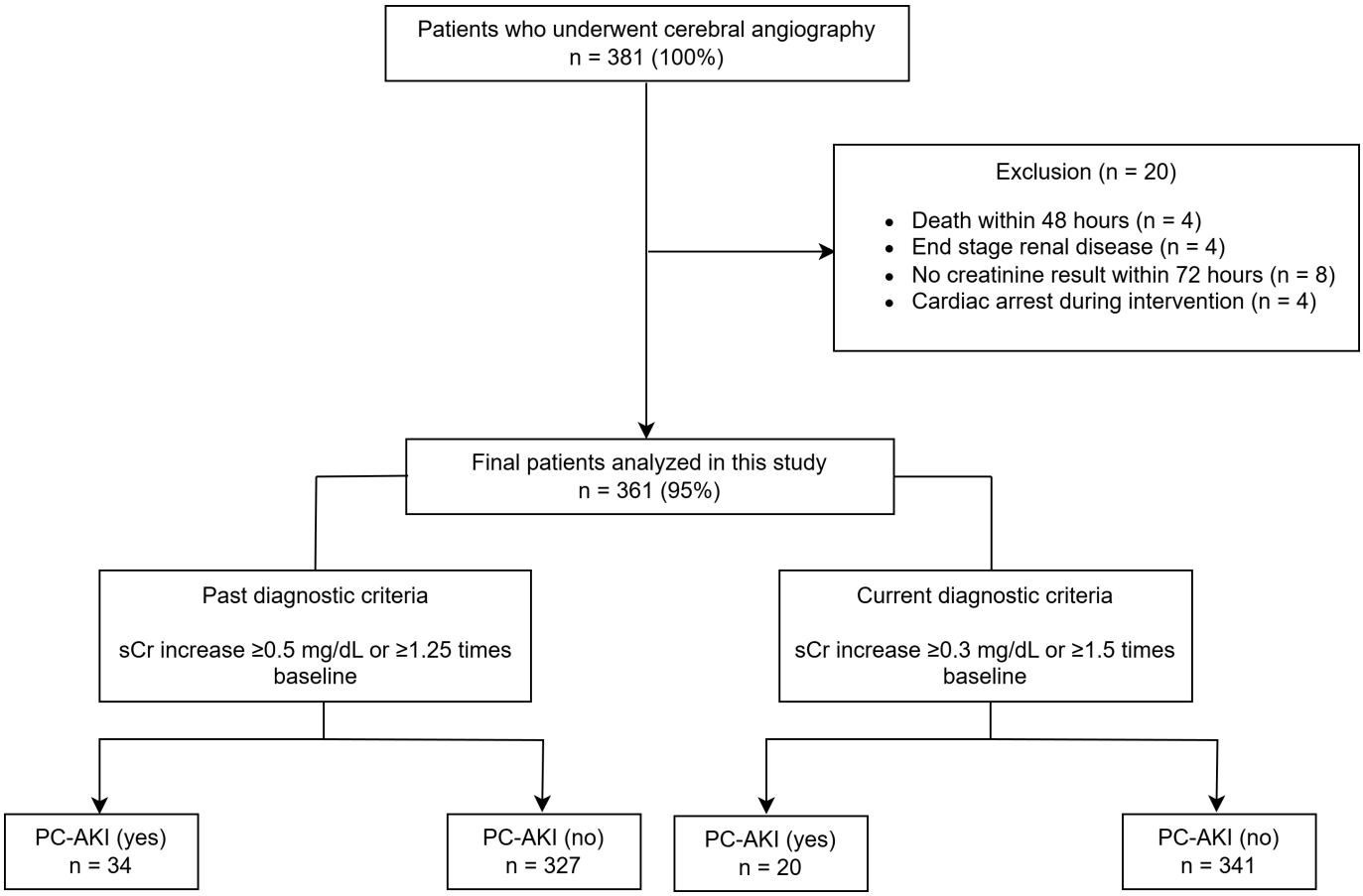

FIGURE 1. Patient inclusion flowchart. SCr, serum creatinine; PC-AKI, postcontrast acute kidney injury.

TABLE 2. Clinical characteristics of patients.

Variables	Previous PC-AKI (n = 34)	Current PC-AKI (n = 20)	*p*-value
Vital sign			
Systolic blood pressure (mmHg)	166.15 ± 29.33	168.50 ± 31.08	0.784
Diastolic blood pressure (mmHg)	83.70 ± 14.78	88.05 ± 14.86	0.359
Pulse rate (b/min)	82.97 ± 21.45	82.30 ± 16.20	0.905
Respiratory rate (b/min)	18.03 ± 2.27	17.70 ± 2.45	0.621
Age (yr)	76.65 ± 12.42	77.70 ± 12.75	0.767
Sex, male	15 (44.1%)	9 (45%)	0.999
Medical history			
Hypertension	30 (88.23%)	18 (90%)	0.999
Diabetes mellitus	11 (32.35%)	8 (40%)	0.769
Chronic kidney disease	2 (5.89%)	2 (10%)	0.622
Atrial fibrillation	12 (20.59%)	7 (35%)	0.999
Dyslipidemia	6 (17.65%)	4 (20%)	0.999
Previous Stroke	6 (17.65%)	4 (20%)	0.999
Heart failure	2 (5.89%)	2 (10%)	0.622
Obstructive coronary artery disease	3 (8.82%)	2 (10%)	0.999
Malignancy	7 (20.59%)	5 (25%)	0.744
Use of nephrotoxic medication			
Before ACEI/ARB	14 (41.18%)	9 (45%)	0.999
Before beta blocker	7 (20.59%)	6 (30%)	0.517
Before statin	15 (44.12%)	10 (50%)	0.780
Before insulin	4 (11.76%)	2 (10%)	0.999
Before oral anti-diabetic drug	10 (29.41%)	8 (40%)	0.552
Before NSAID	5 (14.71%)	2 (10%)	0.999
After ACEI/ARB	10 (29.41%)	6 (30%)	0.999
After beta blocker	9 (26.47%)	6 (30%)	0.999
After statin	34 (100%)	20 (100%)	0.999
After insulin	16 (47.06%)	12 (60%)	0.408
After oral anti-diabetic drug	6 (17.65%)	5 (25%)	0.728
After NSAID	8 (23.53%)	3 (15%)	0.510

Data are presented as means ± SDs for continuous variables and numbers (%) for categorical variables.
PC-AKI, postcontrast acute kidney injury; ACEI, angiotensin-converting enzyme inhibitor; ARB, angiotensin receptor blocker; NSAID, nonsteroidal anti-inflammatory drug; SD, standard deviation.

(mean (95% CI): 0.0554 (0.0342–0.0843) *vs.* 0.0942 (0.0661–0.1291), $p = 0.048$) (Table 3). Furthermore, when using the relative criteria based on the creatinine ratio for diagnosis, the incidence was nearly threefold lower than with the previous criteria (0.0360 (0.0193–0.0608) *vs.* 0.0942 (0.0661–0.1291), $p = 0.002$) (Table 3).

3.3 PC-AKI incidence based on baseline eGFR

Among patients with eGFRs of ≥90 mL/min/1.73 m^2, the incidence of PC-AKI was significantly lower based on the current diagnostic criteria than based on the previous criteria (0.0114 (0.0003–0.0617) *vs.* 0.0795 (0.0326–0.1570), $p = 0.030$) (Table 4). No significant differences in PC-AKI incidence were observed between the previous and current diagnostic criteria for the other eGFR intervals.

3.4 PC-AKI incidence based on baseline eGFR for both absolute and relative criteria

Upon application of the absolute criteria, there was no significant difference in the PC-AKI diagnostic rates between the previous and current diagnostic criteria in all intervals (Table 5). However, for the relative criteria, the PC-AKI diagnostic rate based on the previous criteria was significantly higher than that based on the current criteria in the groups with baseline eGFRs of 60 to <90 mL/min/1.73 m^2 and ≥90 mL/min/1.73 m^2 (0.1070 (0.0666–0.1603) *vs.* 0.0374 (0.0152–0.0756), *p*

TABLE 3. Incidence of PC-AKI comparing the previous and current diagnostic criteria.

	Incidence of PC-AKI (95% CI)	*p*-value
Previous diagnostic criteria	0.0942 (0.0661–0.1291)	0.048
Current diagnostic criteria	0.0554 (0.0342–0.0843)	
Absolute criteria		
Cr ≥0.5 mg/dL (past)	0.0332 (0.0173–0.0573)	0.199
Cr >0.3 mg/dL (current)	0.0526 (0.0320–0.0810)	
Relative criteria		
Cr ratio ≥1.25 times (past)	0.0942 (0.0661–0.1291)	0.002
Cr ratio >1.5 times (current)	0.0360 (0.0193–0.0608)	
Absolute and relative criteria		
Cr ≥0.5 mg/dL and Cr ratio ≥1.25 times (past)	0.0332 (0.0173–0.0573)	>0.999
Cr >0.3 mg/dL and Cr ratio >1.5 times (current)	0.0332 (0.0173–0.0573)	

PC-AKI, postcontrast acute kidney injury; Cr, creatinine level; CI, confidence interval.

TABLE 4. PC-AKI incidence based on baseline eGFR.

eGFR	Incidence of PC-AKI (95% CI)	*p*-value
<30 mL/min/1.73 m^2		
Previous	0 (0–0)	NA
Current	0 (0–0)	
30–<45 mL/min/1.73 m^2		
Previous	0.2105 (0.0605–0.4557)	>0.999
Current	0.2105 (0.0605–0.4557)	
45–<60 mL/min/1.73 m^2		
Previous	0.0469 (0.0098–0.1309)	>0.999
Current	0.0469 (0.0098–0.1309)	
60–<90 mL/min/1.73 m^2		
Previous	0.1070 (0.0666–0.1603)	0.139
Current	0.0642 (0.0336–0.1094)	
≥90 mL/min/1.73 m^2		
Previous	0.0795 (0.0326–0.1570)	0.030
Current	0.0114 (0.0003–0.0617)	

eGFR, estimated glomerular filtration rate; PC-AKI, postcontrast acute kidney injury; NA, not applicable; Previous, previous diagnostic criteria; Current, current diagnostic criteria; CI, confidence interval.

= 0.009 and 0.0795 (0.0326–0.1570) *vs.* 0.0114 (0.0003–0.0617), $p = 0.030$, respectively) (Table 5).

3.5 Prognosis of patients with PC-AKI

Patients diagnosed with PC-AKI based on the previous criteria were more likely to have complete recovery of SCr levels to normal at discharge than those diagnosed based on the current criteria (0.984 (0.974–0.993) *vs.* 0.703 (0.599–0.807), $p < 0.001$) (Table 6). However, there were no significant differences between the two groups in terms of survival or 30-day mortality. Additionally, it was observed that one patient in each group required hemodialysis.

4. Discussion

Among the 361 patients with AISs who presented to the ED and underwent cerebral angiography, 20 (5.5%) developed PC-AKI, demonstrating a lower incidence than that observed based on the previous diagnostic criteria. Patients with eGFRs ≥90 mL/min/1.73 m^2 had a significantly lower incidence of PC-AKI based on the current diagnostic criteria than based on the previous criteria. When analyzed based on absolute and relative criteria, the incidence of PC-AKI was lower in patients with baseline eGFRs ≥60 mL/min/1.73 m^2 when applying the relative criteria. Patients diagnosed with PC-AKI based on the previous criteria were more likely to have a complete recovery of SCr levels at discharge.

The rate of PC-AKI diagnosis varies widely, ranging be-

TABLE 5. PC-AKI incidence based on baseline eGFR for the absolute and relative criteria.

eGFR	Absolute criteria		Relative criteria	
	Incidence of PC-AKI (95% CI)	*p*-value	Incidence of PC-AKI (95% CI)	*p*-value
<30 mL/min/1.73 m^2				
Previous	0 (0–0)	NA	0 (0–0)	NA
Current	0 (0–0)		0 (0–0)	
30–<45 mL/min/1.73 m^2				
Previous	0.2105 (0.0605–0.4557)	>0.999	0.2105 (0.0605–0.4557)	>0.999
Current	0.2105 (0.0605–0.4557)		0.2105 (0.0605–0.4557)	
45–<60 mL/min/1.73 m^2				
Previous	0.0313 (0.0038–0.1084)	0.648	0.0469 (0.0098–0.1309)	0.310
Current	0.0469 (0.0098–0.1309)		0.0156 (0.0004–0.0840)	
60–<90 mL/min/1.73 m^2				
Previous	0.0321 (0.0119–0.0685)	0.147	0.1070 (0.0666–0.1603)	0.009
Current	0.0642 (0.0336–0.1094)		0.0374 (0.0152–0.0756)	
≥90 mL/min/1.73 m^2				
Previous	0 (0–0)	NA	0.0795 (0.0326–0.1570)	0.030
Current	0 (0–0)		0.0114 (0.0003–0.0617)	

eGFR, estimated glomerular filtration rate; PC-AKI, postcontrast acute kidney injury; NA, not applicable; Previous, previous diagnostic criteria; Current, current diagnostic criteria; CI, confidence interval.

TABLE 6. Prognosis of patients with PC-AKI.

	Previous	Current	*p*-value
Patients whose SCr levels returned to normal at the time of discharge	0.984 (0.974–0.993)	0.703 (0.599–0.807)	<0.001
Survival discharge	0.648 (0.568–0.729)	0.608 (0.536–0.681)	0.137
30-day mortality	0.630 (0.555–0.705)	0.595 (0.529–0.662)	0.160

SCr, serum creatinine; PC-AKI, postcontrast acute kidney injury; Previous, previous diagnostic criteria; Current, current diagnostic criteria.

tween approximately 3% and 10%, depending on factors such as the type of diagnostic tool used, age and underlying health conditions [22–24]. However, the question arises as to whether the diagnosis of PC-AKI accurately reflects the actual renal damage. Studies indicated that the rate of PC-AKI diagnosis varies depending on the definition and sensitivity to certain conditions based on absolute and relative diagnostic criteria [16–19]. In response to these concerns, the ESUR released guidelines in 2018 modifying the diagnostic criteria for PC-AKI to prevent overdiagnosis associated with the relative criteria [14, 15].

In this study, the probability of diagnosing PC-AKI using the current criteria was approximately half of that observed when using the previous criteria. Myung *et al*. [2] investigated the incidence of PC-AKI using the previous criteria at the same hospital under similar conditions and reported a diagnosis rate of 9.5%, highlighting the fact that the changes in the diagnostic criteria significantly impacted the diagnostic rate of PC-AKI. Additionally, the finding that there is a difference in the diagnostic rate only in the segment corresponding to baseline eGFRs ≥90 mL/min/1.73 m^2, which corresponds with normal kidney function, raises doubts about whether the previous diagnostic criteria accurately identified patients with impaired renal function. Furthermore, the study revealed that changes in the relative criteria in the diagnostic criteria significantly influenced the diagnostic rate. Using the previous relative diagnostic criteria, PC-AKI's diagnosis was three times more sensitive in patients with baseline eGFRs between 60 and <90 mL/min/1.73 m^2 and the diagnostic rate was nearly seven times more sensitive in patients with baseline eGFRs ≥90 mL/min/1.73 m^2. These findings align with the reasons for the changes in the diagnostic guidelines, suggesting that PC-AKI may have been overdiagnosed. Good baseline renal function does not guarantee the absence of clinical PC-AKI. However, the higher diagnostic rate in patients with normal baseline renal function indicates a significant likelihood of PC-AKI being overdiagnosed. Additionally, from the perspective of the prognosis of patients diagnosed with PC-AKI, more patients diagnosed using the previous criteria achieved normalization of SCr levels at discharge. This result further supports the likelihood of the overdiagnosis of PC-AKI using the previous diagnostic criteria.

Previous studies presented contradicting results regarding the prognostic prediction of PC-AKI in patients with cardiovascular-related conditions based on the diagnostic criteria [25, 26]. These two studies reported contrasting

results regarding the prognostic prediction of PC-AKI in patients with cardiovascular-related conditions based on the diagnostic criteria. Our findings are consistent with those of Guillon *et al*. [25]. Although these studies focused on cardiovascular conditions and may not be directly comparable to the study on ischemic stroke, they collectively highlight the potential issues associated with the relative diagnostic criteria for PC-AKI. Additionally, considering the limited number of studies on changes in PC-AKI diagnostic criteria in patients with strokes, these studies could provide valuable insights and serve as a basis for further research on this specific population.

Flammia *et al*. [26] reported that the significance of proteinuria as a longstanding marker for renal function cannot be overstated. It has been entrenched in medical literature as a robust predictor of renal deterioration and prognosis. Moreover, Schmid *et al*. [27] explained the limitations of relying solely on SCr levels to identify subtle renal function changes. Their insights underscore the need for novel biomarkers, which, in combination with existing diagnostic tools, can significantly enhance the diagnostic accuracy of conditions such as AKI [27]. These seminal studies highlight the current knowledge and a critical juncture, prompting further exploration of the PC-AKI diagnostic criteria's efficacy proposed in our research, which presents an avenue for future investigations into renal pathophysiology and thereby refine our diagnostic and therapeutic approaches.

When reviewing previous studies on the occurrence and prognosis of PC-AKI, there appear to be some controversial aspects. While the occurrence of PC-AKI may lead to long hospital stays and mortality rates, studies have shown that it is not strongly or directly correlated [5, 6, 28]. For instance, Chomicka *et al.* [11] reported that the prognostic analysis of patients with PC-AKI shows no statistically significant direct impact on mortality rates. Therefore, stricter diagnostic criteria for PC-AKI are not expected to have a major effect on prognostic factors. However, further investigation of critical prognostic indicators, such as the need for renal replacement therapy and survival rates, should be conducted in studies with larger sample sizes in the future.

Finally, the current study highlights the sensitivity of changes in the relative diagnostic criteria for specific diagnoses and tests. By analyzing the sensitivity of these changes on the basis of baseline renal function, this study provides practical evidence for the modified diagnostic criteria. According to our findings, a PC-AKI diagnosis based on previous criteria often does not represent actual AKI. Therefore, it is advisable to adopt the newly revised PC-AKI diagnostic criteria and pursue a more proactive and aggressive approach towards conducting imaging tests and providing interventions, such as cerebral angiography.

However, it is imperative to acknowledge the nuanced implications of such a proposal. While advocating for proactive measures, we must guard against the misconception that AKI is a trivial or easily manageable condition. Given that there is a risk that emphasizing the reduction in PC-AKI's incidence may inadvertently downplay its severity and effect on patient outcomes, our proposal should be interpreted without diminishing the importance of PC-AKI. Various studies have highlighted PC-AKI as a serious medical concern, reporting its potential to prolong treatment duration, increase mortality rates and sometimes lead to permanent kidney damage [4, 29].

The definitive treatment methods for PC-AKI are still evolving. However, standardized preventive measures outlined in various clinical guidelines have already been established and are being implemented in clinical practice [10]. These preventive measures contribute to mitigating the incidence and severity of PC-AKI. Therefore, alongside the introduction of new PC-AKI diagnostic criteria, the rigorous implementation of standardized preventive measures in clinical practice should continue to be the focal point of research. Necessary tests and treatments for patients suspected of having AISs should be promptly conducted without delay. Simultaneously, applying preventive strategies to mitigate the likelihood of PC-AKI's occurrence can minimize its negative effects. This comprehensive approach ensures that patients receive timely and appropriate testing and treatment for potentially life-threatening conditions while simultaneously preventing PC-AKI, thereby optimizing overall patient care and outcomes.

This study has some limitations. First, because this study was conducted at a single center, the generalizability of the results may be limited. Additionally, the relatively small sample size further restricts the ability to draw definitive conclusions and reduces the statistical power of the analysis. Second, this study was a retrospective analysis, and there could be selection bias owing to the exclusion of cases in which SCr levels after 72 h were unavailable or cases wherein patients died within 48 h after the evaluation. Third, to comprehensively evaluate the prognosis of patients with PC-AKI, we used measures such as complete recovery of SCr levels at discharge, survival to discharge, and 30-day mortality. However, considering these measures as perfect indicators may be challenging, and further research, including additional indicators such as 24-h urine analysis, may be necessary. Fourth, this study only included patients who underwent CTAs and cerebral angiography and excluded those who refused CTA examinations because of concerns about renal function deterioration. Fifth, preventive measures for PC-AKI, such as hydration therapy before and after procedures, were not consistently applied on the basis of clear criteria and were determined by the clinical judgment of the attending physicians. This tendency may have led to variations in the incidence of PC-AKI. Additionally, considering that the time from preventive measures to the actual procedure could vary among patients, the effectiveness of preprocedural preventive measures might differ; however, this aspect was not analyzed in this study. Lastly, the concern about PC-AKI overdiagnosis also implies the need for additional indicators that can accurately diagnose actual AKI beyond SCr levels. There is currently a lack of research directly examining the relationship between AKI diagnosis and its actual prevalence. Therefore, further studies are needed to address this gap, along with a large-scale investigation into new practical criteria for diagnosing PC-AKI, considering factors such as risk factors, contrast agent volume and injection rate and prevention methods.

5. Conclusions

The incidence of PC-AKI in patients with AIS undergoing cerebral angiography significantly decreased by nearly half in conjunction with changes in the diagnostic criteria. Particularly, patients with a baseline eGFR $\geq$90 mL/min/1.73 m^2 had a substantial reduction in PC-AKI incidence. When focusing solely on the relative criteria, a decrease in PC-AKI incidence was observed in patients with baseline eGFRs $\geq$60 mL/min/1.73 m^2. These results enhance the robustness of the current diagnostic criteria and may encourage more proactive interventions without hesitation about weighing the risks and benefits when patients with suspected AIS present to the ED.

AVAILABILITY OF DATA AND MATERIALS

All data used in the analysis in this study are available at any time from the corresponding author upon reasonable request.

AUTHOR CONTRIBUTIONS

CP and JHB—conceptualization; methodology; and software; supervision. SY and JHB—data curation and writing–original draft preparation. EH—visualization and investigation. SY—software and validation. EH, CP and JHB—Writing-reviewing and editing. All the authors have read and agreed to the published version of the manuscript. All the authors have made substantial contributions.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was conducted in accordance with the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board of Yonsei University College of Medicine, Severance Hospital (No. 4-2023-1217). The requirement for informed consent was waived by Yonsei University Ethics Committee.

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Not applicable.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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