Original Paper

Comparison of Serum Phosphate Levels in Critically Ill Patients with Acute Kidney Injury Undergoing Continuous Renal Replacement Therapy Using Different Dialysates

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Keywords. Acute kidney injury; Continuous renal replacement therapy; Hypophosphatemia

Introduction. Continuous renal replacement therapy (CRRT) is a recommended dialysis modality for hemodynamically unstable and critically ill patients with kidney failure. This study aimed to evaluate the effect of variations in serum phosphate levels based on the dialysate used during CRRT and to determine the impact of prognosis and mortality of patients with using dialysate solutions with diverse electrolyte compositions.
Methods. We retrospectively analyzed 117 patients' records, treated with intensive CRRT, comprising 70 patients treated with Phoxilium®, and 47 patients treated with MultiBic®.
Results. After 72 hours of CRRT, the Phoxilium and non-Phoxilium groups exhibited significantly different serum calcium, bicarbonate, and phosphate levels, as determined by an independent-samples t-test. ($P < .05$). The Kaplan–Meier analysis revealed no significant difference in survival rates between the two groups, demonstrating that the variation in serum phosphate level after 72h of CRRT did not significantly influence survival outcomes. ($P = .581$). The difference in serum phosphate levels after 72h of CRRT might affect respiratory muscles; however, although cumulative survival exhibited a stepwise decrease with longer mechanical ventilation duration, the two groups did not show significant difference in survival ($P = .819$). The incidence of hypophosphatemia was significantly lower in the group where CRRT was performed with Phoxilium dialysate containing phosphate compared to the group where CRRT was performed with non-Phoxilium dialysate, and severe hypophosphatemia did not occur. There were no significant associations between hypophosphatemia, mortality, and duration of mechanical ventilation.
Conclusion. Selecting Phoxilium as a dialysate for CRRT should be considered to correct severe hypophosphatemia, prevent complications, and improve prognosis.

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INTRODUCTION

Acute kidney injury (AKI) is often associated with critical illness, increased mortality, longer hospital stays, and increased need for resources in patients in the intensive care unit (ICU). Depending on the definition, the incidence of AKI among patients in ICU varies between 6% and 70%.[1,2] The reported incidence of renal replacement therapy

(RRT)-treated AKI in the general population varies between 8 and 30 per 100,000 persons/year,[3-6] whereas the incidence of RRT-treated AKI among patients in the ICU ranges between 4% and 8%.[1,7-9] In critically ill patients with AKI and unstable hemodynamics, hemodialysis is necessary in cases when electrolyte and fluid imbalances, and acid-base disorders are not well-controlled.[10] Continuous RRT (CRRT) has emerged as a recommended dialysis modality for critically ill patients with kidney failure and hemodynamic instability. Compared to standard intermittent hemodialysis, CRRT can be performed in hemodynamically unstable patients and provides greater overall solute clearance and fluid balance.[11]

Critically ill patients admitted in ICU may experience hypophosphatemia due to malnutrition, refeeding syndrome, severe sepsis, or insulin or parenteral nutrition use.[12] After calcium, phosphate is the second most abundant electrolyte in the body, with 80%–90% of phosphate located in bones and teeth in the form of calcium phosphate and the remaining exist in soft tissues. Phosphate is an important electrolyte that generates energy, is essential for nerve and muscle function as well as bone and acts as a buffer to maintain acid-base balance. Hypophosphatemia is an independent predictor of mortality in patients suffering from sepsis.[13-15] Hypophosphatemia is generally manageable in chronically ill patients; however, it can cause muscle weakness, especially affecting respiratory muscles and diaphragm. It can impact the prognosis of patients in ICU, even leading to coma and death.[16,17] Dialysates appropriate for the condition of the patient are selected to maintain CRRT in patients with hypophosphatemia. Since the electrolyte content of each dialysis solution is different, the patient's electrolyte status may be impacted by the specific dialysis solution used for that patient.[18] Several studies in critically ill patients have linked CRRT-related hypophosphatemia to adverse outcomes, including prolonged need for mechanical ventilation, longer hospital stay, and mortality.[19,20] In some studies, approaches to prevent hypophosphatemia, adding phosphate to the dialysate and replacement solution were found to be effective.[21-23] The reported incidence of hypophosphatemia during CRRT ranges from 27% to 78% across studies.[19,20,24,25] The present study aimed to evaluate changes in serum phosphate levels according to the dialysis solutions with different electrolyte contents used during CRRT and to determine whether the choice of the dialysate affected prognosis or mortality.

MATERIALS AND METHODS

Study design and participants

In this retrospective study, the medical records of 568 patients who underwent CRRT in the ICU between January 1, 2017, and June 30, 2020, in National University Hospital were reviewed. Patients aged ≥18 diagnosed with AKI according to the diagnostic criteria of the 2012 Kidney Disease: Improving Global Outcomes guidelines[26] and who underwent CRRT for more than 72 hrs were considered eligible. Following the exclusion of 279 patients who underwent CRRT for less than 72 hrs and 172 patients who did not meet the definition of AKI at the time of CRRT initiation, the final cohort included 117 patients (Figure 1).

Dialysate and replacement solutions for CRRT were determined according to serum potassium levels. The selection protocol for CRRT prescription is described in Supplementary Table 1. Among the 117 eligible patients, 47 patients underwent CRRT with a non-Phoxilium solution (MultiBic®), and 70 patients underwent CRRT with Phoxilium® (Gambro Lundia AB, Lund, Sweden). The components of the CRRT solution according to the protocol are listed in Supplementary Table 2. Phoxilium contains less calcium and bicarbonate than MultiBic, and has 3.75 mg/dL of phosphate, which is not present in MultiBic. Conversely, MultiBic does not contain potassium, whereas Phoxilium contains 4 mmol/L of potassium. The concentrations of other components such as sodium, chloride, and magnesium are comparable between the two dialysates.

Medical records were used to collect information on patient characteristics, including age, sex, height, body weight, underlying disease (hypertension, diabetes mellitus, cardiovascular disease, peripheral vascular disease, cirrhosis, and malignancy), reasons for ICU admission, start and end times of CRRT, dialysate/replacement flow rate and blood flow rate (BFR) during CRRT, CRRT type, mechanical ventilation, start and end times of mechanical ventilation, hospitalization and discharge dates, death status, and laboratory tests (hemoglobin, platelet count, blood urea nitrogen, creatinine, calcium, albumin, phosphate, sodium, potassium,

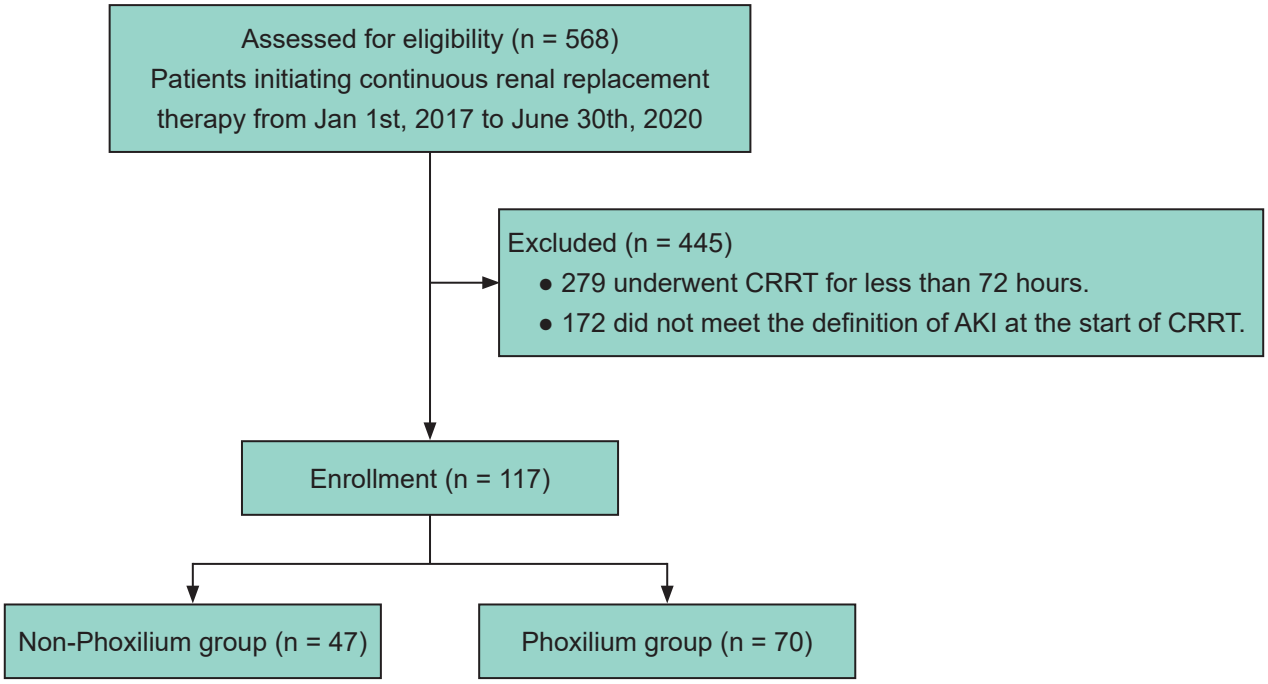

Figure 1. Study design. AKI, acute kidney injury; CRRT, continuous renal replacement therapy

Supplementary Table 1. CRRT prescription protocol

1. CRRT protocol when using Phoxilium solution
   i. Dialysate
      1. If potassium < 5.0 mEq/L: Phoxilium
      2. If potassium > 5.0 mEq/L: Hemosol B0
   ii. Replacement
      1. If potassium < 3.3 mEq/L: Phoxilium + potassium 5mEq/L mix
      2. If potassium 3.3-4.3 mEq/L: Phoxilium
      3. If potassium 4.3-4.7 mEq/L: Prismasol 2 + potassium 10mEq/L mix
      4. If potassium > 4.7 mEq/L: Hemosol B0
2. CRRT protocol without using Phoxilium solution
   i. Dialysate
      1. If potassium < 5.0 mEq/L: Multibic 5L + potassium 20mEq/L mix
      2. If potassium > 5.0 mEq/L: Multibic 5L
   ii. Replacement
      1. If potassium < 3.3 mEq/L: Multibic 5L + potassium 25mEq/L mix
      2. If potassium 3.3-4.3 mEq/L: Multibic 5L + potassium 20mEq/L mix
      3. If potassium 4.3-4.7 mEq/L: Multibic 5L + potassium 10mEq/L mix
      4. If potassium > 4.7 mEq/L: Multibic 5L

Supplementary Table 2. Components of CRRT solution

Compotonents (mmol/L)	MultiBic	Hemosol B0	Phoxilium	Prismasol 2
Sodium	140	140	140	140
Potassium	0	0	4	2
Chloride	109	109.5	116	111.5
Calcium	1.5 (6mg/dl)	1.75 (7mg/dl)	1.25 (5mg/dl)	1.75 (7mg/dl)
Bicarbonate	35	32	30	32
Lactate	0	3	0	3
Phosphate	0	0	1.2 (3.75mg/dl)	0
Magnesium	0.5 (1.2mg/dl)	0.5 (1.2mg/dl)	0.6 (1.5mg/dl)	0.5 (1.2mg/dl)
Glucose	5.55 (1.0g)	0	0	6.1 (1.1g)
Serum Osmolality	292	287	293	297

and bicarbonate) at the time of CRRT initiation and 24 hrs after CRRT. A MultiFiltrate CRRT device (Fresenius Medical Care, Germany) was used in the ICU.

Statistical analysis

The IBM SPSS Statistics software (version 26; IBM, Armonk, NY, USA) was used for all analyses, and a *P* value of < 0.05 was set to indicate statistical significance. Independent-samples t-test was used to confirm if the biochemistry profile of patients had a significant impact on the duration of CRRT. In addition, independent-samples *t* test was used to compare the duration of mechanical ventilation, and the duration of ICU stay between patients categorized according to the dialysate type used for CRRT. Subsequently, receiver operating characteristic (ROC) curve analysis was conducted to determine the best cutoff for serum phosphate level based on area under the ROC curve (AUC), and the Kaplan–Meier analysis was performed to compare survival rate in relation to the duration of CRRT and the duration of mechanical ventilation between subgroups of patients categorized on the basis of the cutoff serum phosphate level.

The primary endpoint was the change in electrolytes at 24 and 72 hrs of CRRT. The secondary endpoints were differences in the duration of ICU stay, mortality rate, and duration of mechanical ventilation in patients undergoing mechanical ventilation comparing the non-Phoxilium and Phoxilium groups.

RESULTS

Table 1 summarizes participant characteristics at baseline. The study population included 66 males (56.4%) and 51 females (43.6%). The non-Phoxilium and Phoxilium groups included 47 and 70 patients, respectively. The mean age was 69 years in the non-Phoxilium group and 67 years in the Phoxilium group. The number of patients who underwent mechanical ventilation was 41 (87.2%) and 52 (74.3%) in the non-Phoxilium and Phoxilium groups, respectively. The durations of

Table 1. Baseline study participant characteristics at the time of continuous renal replacement therapy initiation

Characteristic	Overall (N = 117)	CRRT Group		*P*
		Non-Phoxilium (N = 47)	Phoxilium (N = 70)	
Age, mean (range), years	68.0 (19–93)	69.0 (27–87)	67 (19–93)	.495
Sex, n (%)				
Male	66 (56.4)	26 (55.3)	40 (57.1)	.847
Female	51 (43.6)	21 (44.7)	30 (42.9)	
Number of patients on mechanical ventilation	93 (79.5)	41 (87.2)	52 (74.3)	.091
Duration of mechanical ventilation, days (range)	11 (1–118)	9 (3–118)	11 (1–91)	.974
Duration of ICU stay, days	14 (3–160)	19 (4–118)	13 (3–160)	.455
Duration of hospitalization, days	57.2 (3–610)	37 (4–217)	38.5 (3–610)	.400
APACHE II score	22 (5–43)	21 (8–43)	22 (5–40)	.438
Duration of CRRT (days)	5 (3–31)	5 (3–31)	6 (3–31)	.805
Duration of CRRT (h)	129 (72–751)	127 (72–751)	132 (72–751)	.687
CRRT mode (CVVHDF)				
BFR (ml/min)	150 (120–150)	150 (120–150)	150 (120–150)	.788
Dialysate flow rate (mL/h)	1000 (700–1500)	1000 (700–1500)	1000 (700–1500)	.427
Replacement fluid flow rate (mL/h)	1000 (700–1500)	1000 (700–1500)	1000 (700–1500)	.455
Dialysate flow rate/body weight (mL/kg/h)	19.0 (11.4–29.4)	19.0 (13.3–23.8)	19.1 (11.4–29.4)	.641
Replacement flow rate/body weight (mL/kg/h)	19.0 (11.4–29.4)	19.0 (13.3–23.8)	19.1 (11.4–29.4)	.641
Comorbidities, n (%)				
Diabetes mellitus	45 (38.5)	15 (61.7)	30 (42.9)	.237
Hypertension	52 (44.4)	18 (38.3)	34 (48.6)	.277
Heart failure	28 (23.9)	10 (21.3)	18 (25.7)	.585
Ischemic heart disease	14 (12.0)	5 (10.6)	9 (12.9)	.720
Cirrhosis	19 (16.2)	4 (8.5)	15 (21.4)	.064
Cancer	24 (15.4)	5 (10.6)	19 (27.1)	.030

APACHE, Acute Physiologic and Chronic Health Evaluation; BFR, blood flow rate; CRRT, continuous renal replacement therapy; CVVHDF,; ICU, intensive care unit

ICU stay, hospitalization, mechanical ventilation, and CRRT and Acute Physiologic and Chronic Health Evaluation II score[27] were not significantly different between the non-Phoxilium and Phoxilium groups (independent-samples *t* test). All patients received CRRT in the CVVHDF mode, and there was no significant difference in BFR between the two groups.

As shown in Table 2, the most common indication for CRRT was AKI due to sepsis, followed by AKI due to cardiogenic shock.

Table 2. Indications of continuous renal replacement therapy (CRRT)

Indications	CRRT Group	
	Non-Phoxilium (N = 47)	Phoxilium (N = 70)
AKI due to nephrotoxic agents	1	5
AKI with sepsis	33	48
Pneumonia	16	32
Urinary tract infection	2	5
Colitis	2	1
Biliary sepsis	1	6
Peritonitis	3	1
Others	9	3
AKI with cardiogenic shock	10	9
AKI with hypovolemic shock	3	8

AKI, Acute kidney injury

As shown in Table 3, the biochemistry profiles of patients before CRRT initiation did not significantly differ between the non-Phoxilium and Phoxilium groups.

Table 4 shows the biochemistry profiles of patients 24 hrs after CRRT. By independent-samples *t* test, serum levels of calcium, corrected calcium, and bicarbonate were significantly different between the non-Phoxilium and Phoxilium groups whereas serum phosphate levels did not significantly differ between the two groups. Mean serum calcium level was significantly lower in the Phoxilium group than in the non-Phoxilium group 24 hrs after CRRT ($P < .001$), whereas mean albumin-corrected calcium level was within the normal range in both groups. Mean serum bicarbonate level was significantly lower in the Phoxilium group than in the non-Phoxilium group 24 hrs after CRRT ($P = .039$) although it was within the normal range in both groups. Mean serum phosphate level was not significantly different between the two groups ($P = .275$).

Table 3. Biochemistry profiles prior to continuous renal replacement therapy

Characteristic (mean ± standard deviation)	Overall (N = 117)	CRRT Group		*P*
		Non-Phoxilium (N = 47)	Phoxilium (N = 70)	
Hemoglobin (g/dL)	9.8 ± 2.1	9.9 ± 2.2	9.7 ± 2.0	.576
Platelet (×1000^3/μL)	118.9 ± 78.8	119.6 ± 76.1	118.4 ± 81.1	.934
Blood urea nitrogen (mg/dL)	56.5 ± 27.0	58.4 ± 25.2	55.3 ± 28.2	.544
Creatinine (mg/dL)	2.8 ± 1.7	2.8 ± 1.2	2.9 ± 1.9	.686
Phosphate (mg/dL)	4.3 ± 1.6	4.7 ± 1.8	4.1 ± 1.5	.066
Albumin (g/dL)	2.7 ± 0.4	2.8 ± 0.5	2.7 ± 0.4	.144
Calcium (mg/dL)	7.9 ± 0.8	8.0 ± 0.9	7.9 ± 0.6	.377
Corrected calcium (mg/dL)	8.9 ± 0.7	8.9 ± 0.8	8.9 ± 0.6	.826
Sodium (mEq/L)	138.8 ± 7.2	138.8 ± 5.4	138.9 ± 8.3	.943
Potassium (mEq/L)	4.1 ± 0.8	4.1 ± 0.8	4.1 ± 0.8	.993
Bicarbonate (mEq/L)	18.1 ± 5.7	17.7 ± 6.0	18.4 ± 5.6	.495

Table 4. Patient biochemistry profiles 24 h after continuous renal replacement therapy (CRRT) Initiation

Characteristic (mean ± standard deviation)	Overall (N = 117)	CRRT Group		*P*
		Non-Phoxilium (N = 47)	Phoxilium (N = 70)	
Phosphate (mEq/L)	3.3 ± 1.0	3.2 ± 1.1	3.4 ± 0.8	.275
Albumin (g/dL)	2.8 ± 0.4	2.8 ± 0.4	2.8 ± 0.4	.593
Calcium (mg/dL)	8.3 ± 0.8	8.7 ± 0.7	8.0 ± 0.7	< .001
Corrected calcium (mg/dL)	9.2 ± 0.7	9.6 ± 0.7	9.0 ± 0.7	< .001
Sodium (mEq/L)	137.8 ± 3.4	138.5 ± 2.6	137.4 ± 3.8	.105
Potassium (mEq/L)	3.8 ± 0.4	3.8 ± 0.5	3.9 ± 0.4	.100
Bicarbonate (mEq/L)	23.5 ± 3.1	24.2 ± 3.5	23.0 ± 2.8	.039

Table 5. Patient biochemistry profiles 72 h after continuous renal replacement therapy (CRRT) initiation

Characteristic (mean ± standard deviation)	Overall (N = 117)	CRRT Group		*P*
		Non-Phoxilium (N = 47)	Phoxilium (N = 70)	
Phosphate (mEq/L)	3.0 ± 1.0	2.2 ± 0.7	3.5 ± 0.7	< .001
Albumin (g/dL)	2.8 ± 0.4	2.9 ± 0.3	2.8 ± 0.5	.659
Calcium (mg/dL)	8.5 ± 0.9	9.2 ± 0.6	8.0 ± 0.8	< .001
Corrected calcium (mg/dL)	9.4 ± 0.9	10.1 ± 0.6	8.9 ± 0.7	< .001
Sodium (mEq/L)	137.5 ± 2.8	137.0 ± 2.2	137.9 ± 3.0	.083
Potassium (mEq/L)	3.9 ± 0.4	3.7 ± 0.3	4.0 ± 0.4	< .001
Bicarbonate (mEq/L)	24.0 ± 3.4	25.7 ± 2.8	22.8 ± 3.2	< .001

Table 5 shows the biochemistry profiles of patients 72 hrs after CRRT. By independent-samples t- test, not only mean serum calcium, corrected calcium, and bicarbonate levels but also mean phosphate and potassium levels were significantly different between the two groups. Specifically, mean serum calcium was significantly lower in the Phoxilium group than in the non-Phoxilium group at this time point ($P < .001$) although mean albumin-corrected calcium level was within the normal range in both groups. Additionally, mean serum levels of bicarbonate and potassium were lower in the Phoxilium group than in the non-Phoxilium group 72 hrs after CRRT ($P < .001$ for both) although mean bicarbonate and potassium levels were within the normal range in both groups. Mean serum phosphate level was significantly higher in the Phoxilium group than in the non-Phoxilium group at 72 hrs ($P < .001$), and hypophosphatemia was present in the non-Phoxilium group. Changes in serum phosphate levels at different timepoints in relation to CRRT are presented in Figure 2, which shows a trend of correction in serum phosphate levels over time in both groups and reveals that serum phosphate levels were significantly lower in the non-Phoxilium group than in the Phoxilium group 72 hrs after CRRT.

Given the significant difference in serum phosphate levels between the two groups at 72 hrs after CRRT initiation, we calculated the AUC to further evaluate the association of serum phosphate level at 72 hrs after CRRT initiation with study outcomes. As shown in Figure 3, the AUC was 0.914 based on the cutoff serum phosphate value of 2.9 mEq/L at 72 hrs after CRRT initiation. The patients were categorized into those with low and high serum phosphate levels using this cutoff value and the study outcomes were evaluated. The Kaplan–Meier analysis (Figure 4) did not reveal a significant difference in survival during 240 hrs. of CRRT between these two groups ($P = .581$; log-rank). In both groups, cumulative survival gradually decreased with longer duration of CRRT, with a sharp decline in survival approximately 70 hrs after CRRT initiation. These results demonstrated that the difference in serum phosphate level 72 hrs after CRRT initiation did not have a significant impact on survival rate in patients receiving CRRT in the ICU.

Given that serum phosphate levels can impact respiratory muscles and the survival of patients undergoing mechanical ventilation, we also conducted Kaplan–Meier analysis to compare survival in relation to the duration of mechanical ventilation between the patients with high and low serum phosphate levels at 72 hrs after CRRT initiation. As shown in Figure 5, in both groups, cumulative survival exhibited a stepwise decrease with longer mechanical ventilation duration, with no significant difference between the two groups ($P = .819$; log-rank).

DISCUSSION

CRRT is highly effective in urea clearance and facilitates gradual fluid removal compared to intermittent hemodialysis, resulting in better hemodynamic stability and improved fluid balance management with a more gradual control of solute concentration. All these contribute to the prevention of large fluctuations and fluid shifts and provide greater flexibility, allowing the adaptation of treatment to the patient's need at any time.[28] However, CRRT commonly causes hypophosphatemia due to the simultaneous clearance of phosphate. In particular, higher effluent flow rate and prolonged CRRT are

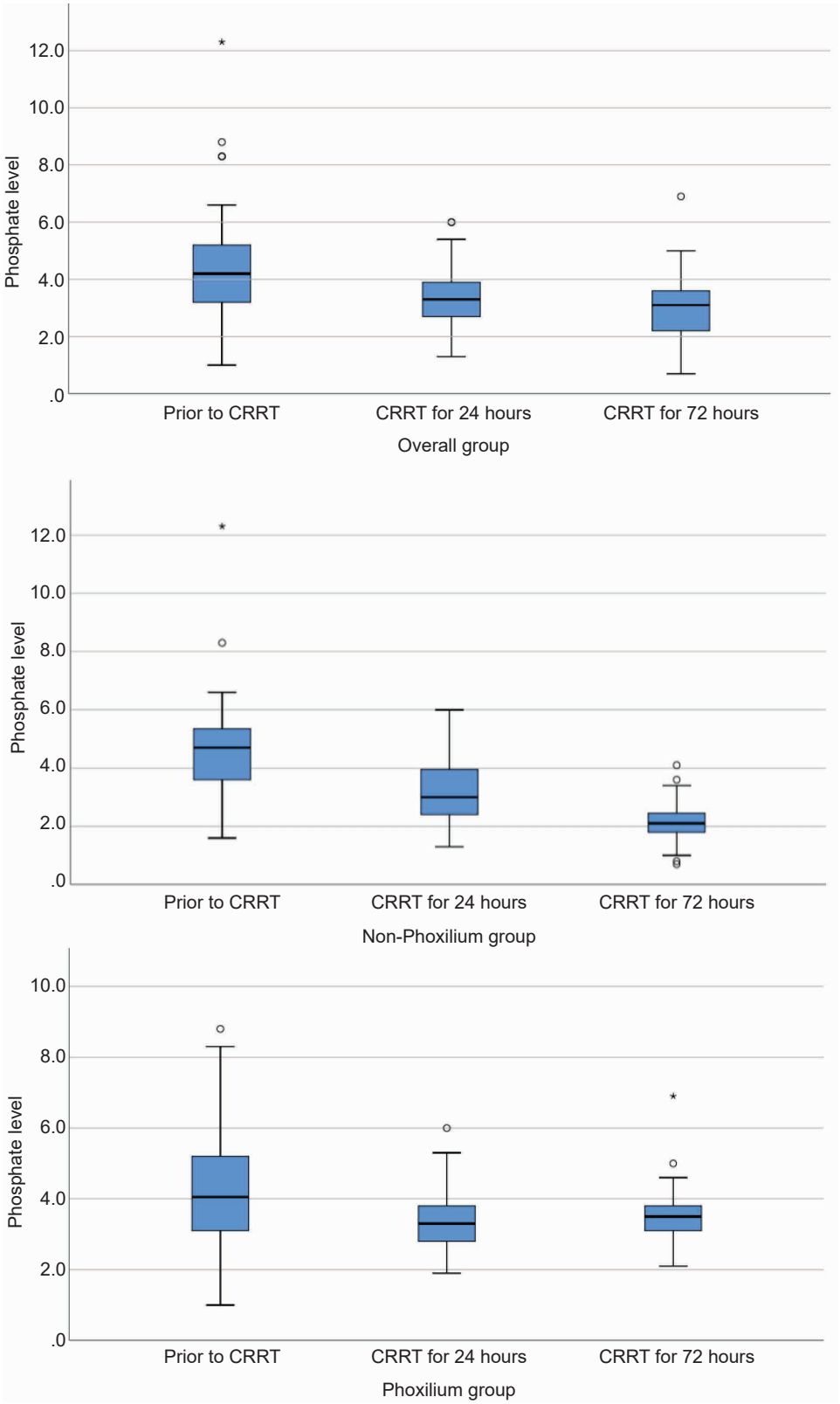

Figure 2. Box plot of changes in serum phosphate levels in patients who underwent CRRT with and without Phoxilium dialysate. CRRT, continuous renal replacement therapy

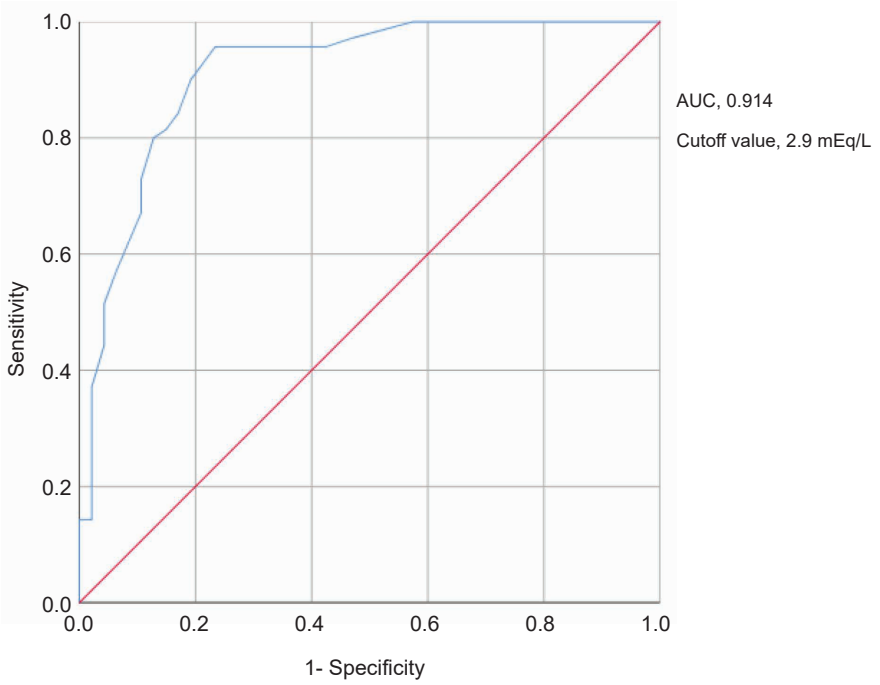

Figure 3. ROC curve analysis of serum phosphate level after 72 h of CRRT in the not-Phoxilium and Phoxilium groups
AUC, area under the receiver operating characteristic curve; CRRT, continuous renal replacement therapy; ROC, receiver operating characteristic

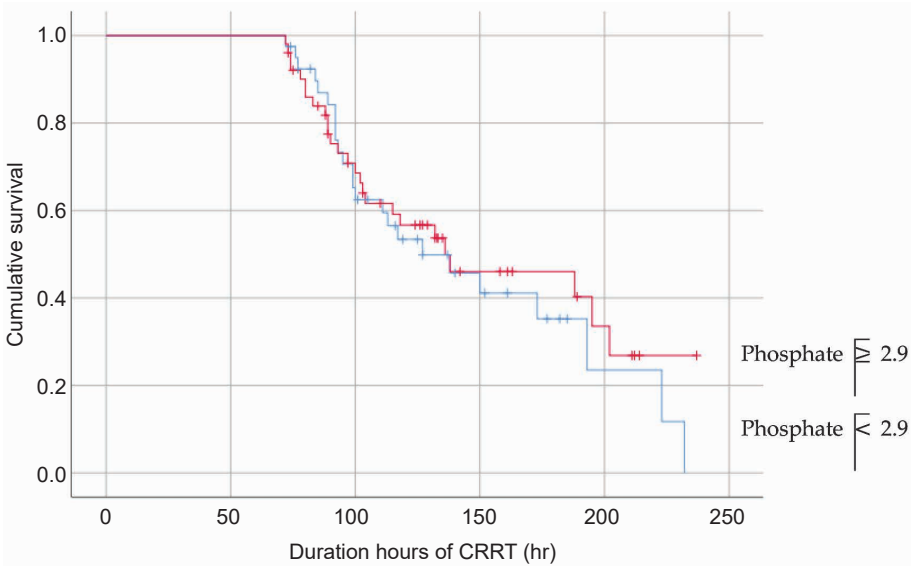

Figure 4. Kaplan–Meier analysis comparing CRRT duration in patients categorized according to the cutoff serum phosphate level of 2.9 mEq/L at 72 h of CRRT initiation
CRRT, continuous renal replacement therapy

associated with increased incidence of CRRT-induced hypophosphatemia. In addition, albeit the low incidence, other electrolyte imbalances such as dysnatremia and hypokalemia may occur even when CRRT is maintained.[29-33] Pesta *et al.* reported that muscle weakness could be explained by decreased muscle ATP synthetic flux caused by hypophosphatemia in a mouse model.[34] Additionally, in a study evaluating the effect of hypophosphatemia on muscle function in dogs, Fuller *et al.* reported that reversible changes in the skeletal muscle composition and transmembrane potential were caused by moderate phosphorus depletion.[35] In critically

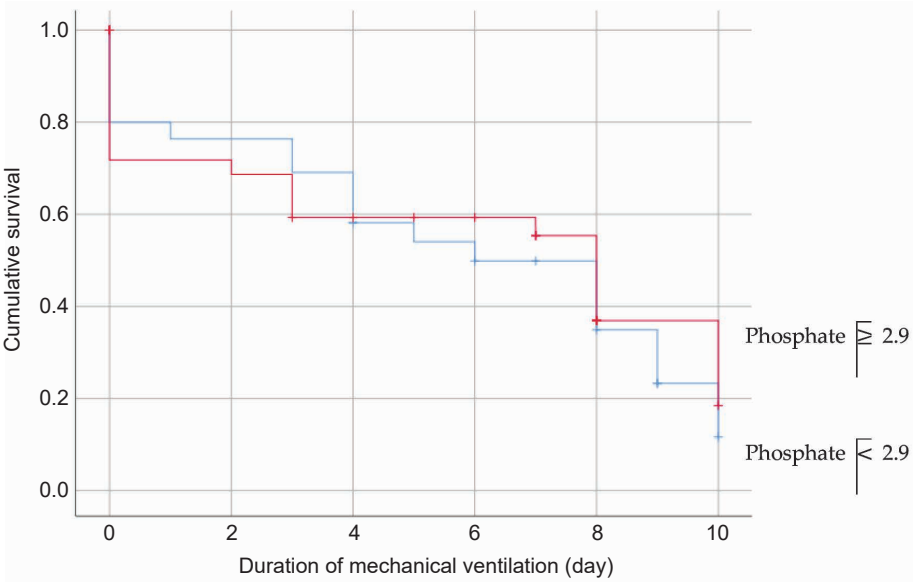

Figure 5. Kaplan–Meier analysis comparing mechanical ventilation duration in patients categorized according to the cutoff serum phosphate level of 2.9 mEq/L at 72 h of CRRT initiation

ill patients, hypophosphatemia might exacerbate muscle weakness, especially in respiratory muscles and diaphragm, which might affect prognosis.[13] Therefore, correcting hypophosphatemia is crucial in critically ill patients with hemodynamic instability who are treated by CRRT. In the present study, we compared electrolyte alterations based on the dialysate used for CRRT in patients with AKI experiencing hemodynamic instability and assessed the influence of these electrolyte changes on prognosis and mortality. In patients undergoing CRRT with Phoxilium containing phosphate, prevention of hypophosphatemia was statistically more significant and severe hypophosphatemia did not occur. Lim *et al.* found no significant association between hypophosphatemia during RRT and mortality or the need for prolonged vasopressor support, confirming the results of other multivariate analyses.[18,19] In the present study, we did not find an association between hypophosphatemia and mortality or duration of mechanical ventilation. Suzuki *et al.* reported that hypophosphatemia (serum phosphate < 0.6 mmol/L) was associated with increased incidence and duration of mechanical ventilation.[36] In the present cohort study, the lowest initial serum phosphate level was 1 mg/dL, suggesting that none of the patients had severe hypophosphatemia, defined as serum phosphate levels of < 1 mg/dl,[37] which might partially explain the differences of our findings from those reported in other studies.

Broman *et al.* reported that hypophosphatemic episodes did not occur in patients undergoing CRRT with Phoxilium, which has a phosphate concentration of 1.2 mmol/L, as dialysate and replacement fluid.[24] Other studies also reported that phosphate-containing solutions such as Phoxilium effectively prevented hypophosphatemia in patients undergoing CRRT.[24,38,39] In the present study, significant hypophosphatemia was not present in patients undergoing CRRT using Phoxilium compared to non-Phoxilium dialysate.

THE STUDY LIMITATIONS

We acknowledge that our study has several limitations. First, this was a single-center retrospective study that relied on available patient information, which might be potentially incomplete or missing, introducing selection bias, and preventing the establishment of causal relationships. Therefore, it may not be possible to generalize our findings to other populations undergoing evaluation. Additionally, the single-center study design limited the sample size. Second, only South Korean individuals were included in the study, precluding our ability to evaluate potential racial or ethnic differences among the participants. Third, the criteria for weaning from mechanical ventilation have not

been clearly established. In the ICU, weaning from mechanical ventilation was performed by using O_2 saturation on arterial blood gas analysis and improvement of pulmonary edema or tachypnea as indicators; however, the decision was based on the attending clinician's judgment. During the retrospective review of medical records, we noted that mechanical ventilation was performed with re-intubation after extubation in some patients. Therefore, the duration of mechanical ventilation varied depending on the judgment of the attending clinician, which might have also introduced bias. Additionally, the average duration of CRRT (7.7 days [183.9 h] was short, compared to the average durations of mechanical ventilation (13.9 days), ICU stay (23.5 days), and hospitalization (57.2 days). The shorter duration of CRRT might have introduced a bias because the patients were not necessarily on CRRT during their ICU and hospital stays or while on mechanical ventilation. Finally, patient randomization was not possible due to the retrospective study design. Future studies in cohorts from other countries should observe objective standards for weaning from mechanical ventilation to further evaluate the impact of the dialysate fluid used during CRRT and serum phosphate levels on outcomes of patients with AKI in the ICU.

CONCLUSION

CRRT, recommended for critically ill patients including those with severe kidney failure who are hemodynamically unstable, can precipitate or worsen hypophosphatemia due to complications. Selection of appropriate dialysate solutions for CRRT is important in critically ill patients with hypophosphatemia. Our findings suggest that Phoxilium dialysate containing phosphate might be playing an important role in correcting severe hypophosphatemia and in preventing potential complications and poor prognosis.

ETHICAL APPROVAL

This study was conducted in accordance with the 1964 Declaration of Helsinki and its later amendments. Medical records were retrieved anonymously in accordance with data protection rules after obtaining approval from the hospital ethics committee. The institutional review board of Chungnam National University Sejong Hospital approved the study (approval no. CNUSH 2023-08-020).

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INFORMED CONSENT STATEMENT

Not applicable.

DATA AVAILABILITY STATEMENT

The data presented in this study are available on request from the corresponding author. The data are not publicly available owing to privacy and ethical reasons.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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