Original Article

Current status of nutritional provision and effects of nutritional support on the clinical outcomes of acute kidney injury requiring continuous renal replacement therapy in the surgical intensive care unit

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Background and Objectives: Patients with acute kidney injury requiring continuous renal replacement therapy are at high risk of malnutrition. Nutritional support is an important part of treatment for patients with critical illness admitted to the intensive care unit. We aimed to investigate the status of nutritional provision and the effects of nutritional support on clinical outcomes. **Methods and Study Design:** Our institution's medical records (from January 1, 2020, to December 31, 2021) were analyzed in this retrospective cohort study. We included 43 patients aged >18 years who received continuous renal replacement therapy for acute kidney injury in the surgical intensive care unit. **Results:** The demographic characteristics were similar between the survivor and non-survivor groups. The protein supply per body weight (0.88 ± 0.37 g/kg vs. 0.47 ± 0.53 g/kg, $p = 0.029$) and the proportion of patients who met the target protein level (58.9 ± 24.9% vs. 30.8 ± 34.9%, $p = 0.022$) were significantly higher in the survivor group. Approximately 79.1% of the patients had a high malnutrition risk with a modified Nutrition Risk in the Critically Ill score of ≥5. The lengths of hospital and intensive care unit stays were longer in the high nutritional risk group compared with that in the low nutritional risk group, but the result was not significant. **Conclusions:** The nutritional amount provided in patients with critical illness is significantly lesser than the recommended amount. Ensuring proper nutritional support can improve the clinical outcomes.

Key Words: acute kidney injury, continuous renal replacement therapy, intensive care unit, nutritional support

INTRODUCTION

Malnutrition is prevalent in a large proportion of patients with critical illnesses, with a particularly high incidence among patients with acute kidney injury (AKI).[1, 2] It is associated with an increased risk of morbidity and mortality, and the long-term lack of nutritional support increases the infection rate, worsens wound healing, and lengthens the hospital stays.[1, 2] Most patients in the intensive care unit (ICU) are at high risk of malnutrition.[3, 4] Inadequate nutritional support can significantly delay recovery, decrease function and quality of life, extend the length of hospital stay, and increase the medical costs.[4] Meanwhile, proper nutritional support is an important part of their treatment regimen and improves the clinical outcomes.[5]

Hypermetabolism, protein catabolism, muscle loss, electrolyte imbalance, and metabolic acidosis are observed in patients with AKI.[6-8] Continuous renal replacement therapy (CRRT) is used to treat AKI in patients with critical illness and enables steady volume control in patients with hemodynamic instability. In addition, CRRT is used in the removal of circulating fluid, correction of electrolyte imbalance, and elimination of toxins. In this process, a large amount of amino acids, electrolytes, and trace elements is lost through the dialysis solution.[6, 9] Hence, patients with AKI may experience malnutrition, and an appropriate nutritional supply of the lost nutrients due to CRRT can have a positive effect on renal function recovery.[7, 10, 11]

Despite recognizing the importance of nutritional intervention for enhancing the clinical outcomes and prognoses in patients with critical illness, it is not frequently implemented in clinical practice. The amalgamation of factors, such as fasting due to various tests and surgeries, unwarranted concerns of healthcare professionals, and inadequate awareness regarding nutritional support, further impedes its proper implementation. A considerable number of patients with critical illness receive suboptimal nutritional support, failing to meet their requisite demands.[12, 13]

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Although awareness regarding the significance of nutritional support in patients receiving CRRT exists, studies elucidating the precise status of nutritional provision in this patient population are limited. Hence, this study aimed to investigate the current state of calorie and protein provision and assess the effects of nutritional support adequacy on the clinical outcomes, aiming to shed light on the importance of providing optimized nutritional support to patients with AKI requiring CRRT.

METHODS

Ethical considerations

The present study was conducted in compliance with the ethical standards, protecting the privacy rights of the participants, and was approved by the Institutional Review Board of Keimyung University Hospital (approval number: DSMC 2022-08-059). Owing to the non-interventional and observational nature of this study, the requirement for obtaining informed consent was waived. The data were collected and analyzed in accordance with the ethical guidelines.

Study description and definitions

The medical records of the patients admitted to Keimyung University Hospital between January 1, 2020 and December 31, 2021 were analyzed in this retrospective cohort study. The patients' information and scores were determined using the data obtained within the first 24 h after admission to the ICU. For patients with no known organ dysfunction, the baseline Sequential Organ Failure Assessment (SOFA) score of each organ was assumed to be 0, and organ dysfunction was defined as a SOFA score of >2 at the time of the event.[14, 15] The modified Nutrition Risk in the Critically Ill (mNUTRIC) scores (without the interleukin-6 values) were used to identify patients at nutritional risk based on five variables: age, number of days from hospital to ICU admission, number of comorbidities, and SOFA and Acute Physiology and Chronic Health Evaluation (APACHE) II scores. Patients with mNUTRIC scores of ≥5 and <4 were considered to have high and low risks of malnutrition, respectively.[16] The target amounts of calories and proteins to be supplied during CRRT were 25 kcal/kg and 1.5 g/day/kg, respectively, according to the latest guidelines.[7, 10, 17]

Patients

Patients aged >18 years and who received CRRT for more than 48 hrs after ICU admission were eligible for analysis. Our study enrolled 292 patients who received CRRT in our institution for 2 years. The researchers are surgical intensivists and primarily treat critically ill patients with intra-abdominal infections and severe multiple traumas, as well as patients who underwent abdominal surgery. Providing appropriate enteral nutrition (EN) and parenteral nutrition (PN) to these patients was more challenging than providing them to medical ICU or neurological ICU patients. Moreover, studies investigating the nutritional support for surgical ICU patients who underwent CRRT are limited. Therefore, this study focused on examining surgical ICU patients and excluded 243 medical ICU and neurological ICU patients. Patients with chronic kidney disease undergoing hemodialysis treatment, patients who were brain dead and scheduled for organ donation, and patients with coronavirus disease 2019 who received CRRT in a non-ICU setting were excluded from this study. This study ultimately included 43 surgical patients who were admitted to the surgical ICU and required CRRT for AKI (Figure 1).

Data collection

Our institution's surgical ICU has two dedicated surgical intensivists who managed all patient care. Each morning, all patients in the surgical ICU received individualized reevaluation of their nutritional needs, and adjustments were made to the EN and PN doses based on their current condition and daily nutritional requirements. Patients with sepsis, severe multiple trauma, postoperative care, and liver and kidney transplantation were admitted to the surgical ICU. Medical alert responses for surgical patients also called for an admission to the surgical ICU.

A prospectively maintained database was searched to

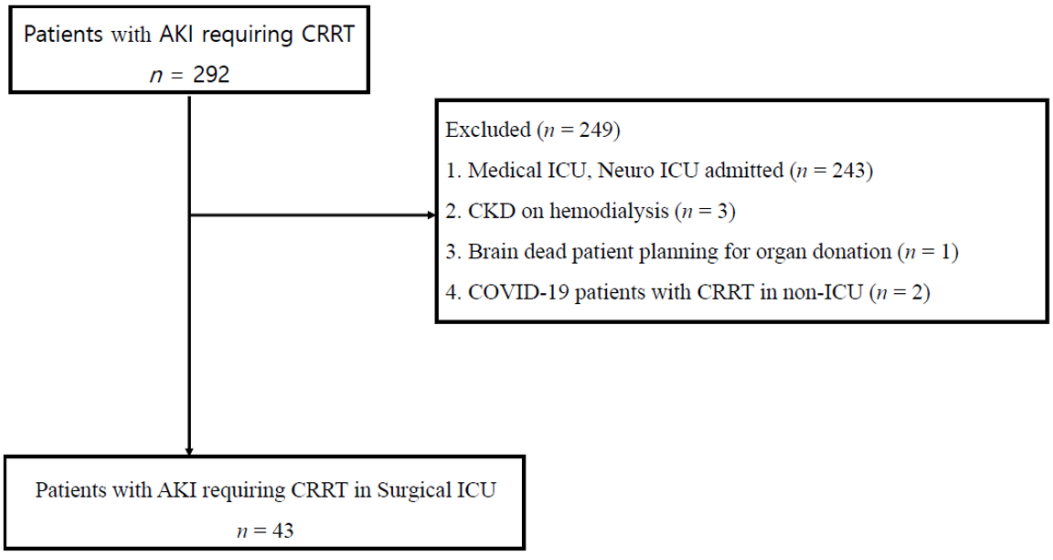

Figure 1. Flow chart of the patient selection process. AKI, acute kidney injury; CRRT, continuous renal replacement therapy; CKD, chronic kidney disease; ICU, intensive care unit

collect the data on patients' demographic characteristics, clinical information, organ dysfunction status, and nutritional supply. The following data were collected retrospectively in our institution: (1) patients' characteristics, including age, sex, body mass index (BMI), Charlson Comorbidity Index (CCI) score, APACHE II score, initial SOFA score, diagnosis upon admission, mNUTRIC score, cancer history, and laboratory results prior to CRRT; (2) clinical data, including length of hospital stay, length of ICU stay, duration of admission to CRRT initiation, duration of CRRT, and duration of mechanical ventilator use; (3) organ dysfunction data, including type of organ dysfunction; and (4) nutritional supply data, including amounts of calories and proteins supplied per body weight, nutritional adequacy of supplied calories and proteins, satisfaction of target calorie and protein requirements, the first day of CRRT calorie and protein supply, the last day of CRRT calorie and protein supply, date of EN initiation, and date of PN initiation. The maximum CRRT application period was calculated as 7 days during the nutritional evaluation because the median number of days of the CRRT application period was 7 days.

Statistical analyses

The continuous data were expressed as the mean ± standard deviation or median (Q1–Q3). The categorical data were expressed as numbers and percentages. Data normality was assessed using the Kolmogorov-Smirnov test and confirmed by visual inspection of the histogram. To compare the clinical characteristics and outcomes of the survivor and non-survivor groups, the continuous variables were analyzed using Student's t-test or Mann-Whitney U test, while the categorical variables were analyzed using the chi-square or Fisher's exact test. For clinical data stratified by nutritional status, the continuous variables were compared using Student's t-test or Mann-Whitney U test, while the categorical variables were compared using the chi-square or Fisher's exact test. A logistic regression analysis was performed to determine the effect of organ dysfunction on the 28-day mortality rate, and results were presented as odds ratios (ORs). Univariable and multivariable logistic regression analyses were performed to identify the risk factors associated with 28-day mortality, with the degree of association presented as ORs and their corresponding 95% confidence intervals. Moreover, OR was used to present the effect of nutritional parameters on 28-day mortality in the logistic regression analysis with unadjusted and adjusted evaluations. The 28-day mortality was adjusted for age, sex, BMI, CCI score, and mNUTRIC score. The logistic regression performance was evaluated using C-statistics and Hosmer–Lemeshow tests. A p value of <0.05 was considered significant. IBM Corporation's Statistical Package for the Social Sciences software (version 26.0; Armonk, NY, USA) was used for performing all statistical analyses.

RESULTS

Patients' characteristics and clinical data

Patient characteristics at the time of CRRT initiation are summarized in Table 1. The mean age was 61.1 ± 17.4 years, and 60.5% were men. The mean BMI was 23.4 ± 3.7 kg/m^2, and no significant difference was observed between the survivor and non-survivor groups. The mean CCI score (p = 0.148) and APACHE II score (p = 0.466) were similar between the two groups. Moreover, the initial SOFA score was significantly higher in the non-survivor group than in the survivor group (13.8 ± 3.5 vs. 11.7 ± 2.8, p = 0.047). Patients admitted to the ICU included those who experienced sepsis (37.2%), hepatic failure (23.3%), trauma (14.0%), rhabdomyolysis (14.0%), postoperative bleeding (7.0%), and post-cardiopulmonary cerebral resuscitation (4.7%). However, no significant difference was observed between the two groups (p = 0.671).

No significant difference was observed in the median mNUTRIC score between the two groups (5.00 [5.00–6.50] vs. 5.00 [4.50–6.00], p = 0.779). Furthermore, no significant difference was found between the two groups in terms of malnutritional high risk (mNUTRIC score of ≥5) (80.6% vs. 75.0%, p = 0.692); however, the risk was relatively high (79.1%) in all patients.

According to the results of initial laboratory test carried out at the time of CRRT initiation, the white blood cell count (7.94 [5.21–10.2] vs. 10.7 [9.06–16.1], p = 0.026), platelet count (55.5 [27.5–107] vs. 100 [66.5–168], p = 0.021), albumin level (2.7 ± 0.5 vs. 3.1 ± 0.5, p = 0.018), and hydrogen ion concentration (7.27 [7.21–7.30] vs. 7.37 [7.30–7.42], p = 0.003) were lower in the non-survivor group than in the survivor group. The lactic acid level was significantly higher in the non-survivor group than in the survivor group (6.65 [3.40–10.2] vs. 1.90 [1.00–3.00], p < 0.001).

The 28-day mortality rate in the enrolled patients was 27.9% (n = 12/43). The median duration of ICU stay was significantly longer in the survivor group than in the non-survivor group (28.9 [7.34–52.3] days vs. 5.83 [1.68–12.9] days, p = 0.002), and a similar scenario was observed for the length of hospital stay (51.0 [29.5–87.5] days vs. 12.5 [2.50–18.5] days, p < 0.001). No significant difference was found between the survivor and non-survivor groups in terms of the duration from ICU admission to the initiation of CRRT (1.72 [0.28–2.93] days vs. 1.09 [0.33–2.17] days, p = 0.478). Meanwhile, the duration of CRRT was significantly longer in the survivor group than in the non-survivor group (11.0 [4.24–37.1] days vs. 3.03 [2.07–10.0] days, p = 0.010). No significant difference was found in the number of patients who received mechanical ventilator support between the survivor and non-survivor groups (77.4% vs. 91.7%, p = 0.407). Moreover, the median duration of mechanical ventilator support was longer in the survivor group than in the non-survivor group, but this result was not significant (27.0 [3.50–50.0] days vs. 3.00 [2.00–14.5] days, p = 0.067). No significant difference was found in the duration of vasopressor use between the two groups (13.0 [4.00–39.5] days vs. 4.50 [3.00–10.0] days, p = 0.121). The most frequently used vasopressor was norepinephrine (83.7%), but no significant difference was found between the non-survivor and survivor groups (91.7% vs. 80.6%, p = 0.652). The use of vasopressin was more frequent in the non-survivor group than in the survivor group (66.7% vs. 29.0%, p = 0.037) (Table 2).

Table 1. Patients' characteristics

	All patients (n = 43)	Survivors (n = 31)	Non-survivors (n = 12)	*p* value
Age (years), mean (± SD)	61.1 ± 17.4	61.4 ± 16.5	60.3 ± 20.3	0.846
Sex, n (%)				
Male	26 (60.5)	17 (54.8)	9 (75.0)	0.306
BMI (kg/m^2), mean (± SD)	23.4 ± 3.7	23.9 ± 3.7	22.3 ± 3.5	0.216
CCI score, mean (± SD)	4.4 ± 2.3	4.7 ± 2.3	3.6 ± 2.1	0.148
APACHE II score, mean (± SD)	21.6 ± 7.1	22.1 ± 7.1	20.3 ± 7.3	0.466
Initial SOFA score, mean (± SD)	12.2 ± 3.1	11.7 ± 2.8	13.8 ± 3.5	0.047
Primary admission diagnosis				0.671
Sepsis	16 (37.2)	9 (29.0)	7 (58.3)	
Hepatic failure	10 (23.3)	8 (25.8)	2 (16.7)	
Trauma	6 (14.0)	5 (16.1)	1 (8.3)	
Rhabdomyolysis	6 (14.0)	5 (16.1)	1 (8.3)	
Postoperative bleeding	3 (7.0)	2 (6.5)	1 (8.3)	
Post-CPCR	2 (4.7)	2 (6.5)	0 (0)	
mNUTRIC score, mean (± SD)	5.00 (5.00–6.00)	5.00 (5.00–6.50)	5.00 (4.50–6.00)	0.779†
mNUTRIC score of ≥5, n (%)	34 (79.1)	25 (80.6)	9 (75.0)	0.692
Cancer, n (%)	13 (30.2)	9 (29.0)	4 (33.3)	0.783
Initial laboratory (mean, ± SD)				
WBC (10^3/μL)	10.3 (7.33–15.2)	10.7 (9.06–16.1)	7.94 (5.21–10.2)	0.026†
Hb (g/dL)	9.2 ± 1.4	9.2 ± 1.5	9.3 ± 1.1	0.838
Platelet (10^3/μL)	85.0 (52.0–161)	100 (66.5–168)	55.5 (27.5–107)	0.021†
Total lymphocyte count (cells/mm^3)	760 (475–1,155)	830 (570–1,155)	505 (250–1,030)	0.165†
BUN (mg/dL)	55.9 ± 28.6	58.1 ± 26.7	50.3 ± 33.5	0.429
Creatinine (mg/dL)	3.9 ± 2.6	4.4 ± 2.8	3.0 ± 1.9	0.130
Albumin (g/dL)	2.9 ± 0.5	3.1 ± 0.5	2.7 ± 0.5	0.018
CRP (mg/dL)	10.7 ± 8.2	9.8 ± 7.5	12.9 ± 9.8	0.271
pH	7.35 (7.27-7.41)	7.37 (7.30-7.42)	7.27 (7.21-7.30)	0.003†
pCO_2 (mmHg)	35.6 ± 10.4	35.6 ± 7.9	35.5 ± 15.6	0.995
pO_2 (mmHg)	121 ± 39.8	122 ± 44.1	120 ± 26.9	0.870
HCO_{3-} (mmol/L)	18.5 ± 6.4	19.6 ± 5.4	15.6 ± 8.0	0.127
Lactic acid (mmol/L)	2.50 (1.20–5.30)	1.90 (1.00–3.00)	6.65 (3.40–10.2)	<0.001†

BMI, body mass index; CCI, Charlson Comorbidity Index; APACHE, Acute Physiology and Chronic Health Evaluation; BUN, blood urea nitrogen; CPCR, cardiopulmonary cerebral resuscitation; CRP, C-reactive protein; HCO3–, bicarbonate; mNUTRIC, modified Nutrition Risk in the Critically Ill; pCO2, partial pressure of carbon dioxide; pO2, partial pressure of oxygen; SOFA, Sequential Organ Failure Assessment; SD, standard deviation; WBC, white blood cell

†Mann-Whitney U test

Patients' clinical data associated with nutritional risk

Approximately 79.1% (n = 34/43) of the patients with an mNUTRIC score of ≥5 had a high risk of malnutrition. However, no significant difference was found in the 28- or 90-day mortality rates between the low and high nutritional risk groups (33.3% vs. 26.5%, p = 0.692 and 33.3% vs. 47.1%, p = 0.708, respectively). Although the high nutritional risk group had a higher mortality rate during hospital stay than the low nutritional risk group, this difference was not significant (52.9% vs. 33.3%, p = 0.457). Similarly, the lengths of hospital and ICU stays were longer in the high nutritional risk group, but no significant difference was observed between the two groups (46.5 [15.0–68.0] days vs. 16.0 [11.0–56.0] days, p = 0.418; 13.5 [5.07–47.5] days vs. 10.7 [5.96–38.4] days, p = 0.872, respectively). Moreover, the high nutritional risk group had a longer duration of mechanical ventilation than the low nutritional risk group, but this finding was not significant (13.5 [2.00–48.0] days vs. 12.0 [3.00–32.0] days, p = 0.527) (Table 3).

Nutritional support parameters

The enrolled patients had an average daily calorie requirement of 1,573 ± 290 kcal, with no significant difference observed between the survivor and non-survivor groups (1,589 ± 301 kcal vs. 1,532 ± 268 kcal, p = 0.573). The average daily protein requirement was 94.4 ± 17.4 g, with no significant difference observed between the two groups (95.3 ± 18.0 g vs. 91.9 ± 16.1 g, p = 0.573). Interestingly, the average calorie supplement was significantly higher in the survivor group than in the non-survivor group (1,091 ± 325 kcal/day vs. 739 ± 373 kcal/day, p = 0.004), as was the average protein supplement (53.6 ± 20.7 g/day vs. 29.0 ± 33.6 g/day, p = 0.033). Furthermore, the amounts of calories (17.8 ± 6.5 kcal/kg/day vs. 12.4 ± 6.2 kcal/kg/day, p = 0.016) and proteins (0.88 ± 0.37 g/kg/day vs. 0.47 ± 0.53 g/kg/day, p = 0.029) supplied were significantly higher in the survivor group than in the non-survivor group. The amounts of calories supplied via EN (0.99 ± 1.69 kcal/kg/day vs. 0.02 ± 0.05 kcal/kg/day, p = 0.003) and protein supplied via EN (0.04 ± 0.08

Table 2. Patients' clinical data

	All patients (n = 43)	Survivors (n = 31)	Non-survivors (n = 12)	*p* value
Length of ICU stay (day)	11.9 (5.52–43.0)	28.9 (7.34–52.3)	5.83 (1.68–12.9)	0.002†
Length of hospital stay (day)	46.0 (14.5–66.5)	51.0 (29.5–87.5)	12.5 (2.50–18.5)	< 0.001†
ICU admission to CRRT initiation (day)	1.54 (0.28–2.70)	1.72 (0.28–2.93)	1.09 (0.33–2.17)	0.478†
Duration of CRRT (day)	7.06 (3.40–23.2)	11.0 (4.24–37.1)	3.03 (2.07–10.0)	0.010†
Use of mechanical ventilator, n (%)	35 (81.4)	24 (77.4)	11 (91.7)	0.407
Duration of mechanical ventilator use (day)	12.0 (2.50–38.0)	27.0 (3.50–50.0)	3.00 (2.00–14.5)	0.067†
Duration of vasopressor use (day)	8.00 (3.00–26.5)	13.0 (4.00–39.5)	4.50 (3.00–10.0)	0.121†
Vasopressor, n (%)				
Norepinephrine	36 (83.7)	25 (80.6)	11 (91.7)	0.652
Vasopressin	17 (39.5)	9 (29.0)	8 (66.7)	0.037
Epinephrine	6 (14.0)	3 (7.0)	3 (7.0)	0.325
Dobutamine	5 (11.6)	3 (9.7)	2 (16.7)	0.608

ICU, intensive care unit; CRRT, continuous renal replacement therapy
†Mann-Whitney U test

Table 3. Patients' clinical data and level of nutritional risk

	Low nutritional risk (mNUTRIC score ≤ 4) (n = 9)	High nutritional risk (mNUTRIC score ≥ 5) (n = 34)	*p* value
28-day mortality, n (%)	3 (33.3)	9 (26.5)	0.692
90-day mortality, n (%)	3 (33.3)	16 (47.1)	0.708
Mortality during hospital stay, n (%)	3 (33.3)	18 (52.9)	0.457
Length of hospital stay (day)	16.0 (11.0–56.0)	46.5 (15.0–68.0)	0.418†
Length of ICU stay (day)	10.7 (5.96–38.4)	13.5 (5.07–47.5)	0.872†
Duration of CRRT (day)	10.0 (4.18–19.2)	7.99 (3.05–26.4)	0.849†
Duration of mechanical ventilator use (day)	12.0 (3.00–32.0)	13.5 (2.00–48.0)	0.527†
Use of a mechanical ventilator, n (%)	7 (77.8)	28 (82.4)	0.754

mNUTRIC score, modified Nutrition Risk in Critically Ill score; ICU, intensive care unit; CRRT, continuous renal replacement therapy
†Mann-Whitney U test

g/kg/day vs. 0.01 ± 0.01 g/kg/day, $p = 0.010$) were significantly higher in the survivor group than in the non-survivor group. The amounts of calories supplied via PN (16.8 ± 6.09 kcal/kg/day vs. 12.4 ± 6.18 kcal/kg/day, $p = 0.037$) and proteins supplied via PN (0.84 ± 0.35 g/kg/day vs. 0.47 ± 0.53 g/kg/day, $p = 0.044$) were significantly higher in the survivor group than in the non-survivor group. The adequacy of calorie (71.8 ± 25.9% vs. 48.7 ± 23.9%, $p = 0.011$) and protein (58.9 ± 24.9% vs. 30.8 ± 34.9%, $p = 0.022$) supplies was also significantly higher in the survivor group than in the non-survivor group. Although the number of patients who met the target calorie level was higher in the survivor group than in the non-survivor group, the difference was not significant (45.2% vs. 16.7%, $p = 0.158$). Similarly, no statistical difference was found between the two groups in terms of the proportion of patients who met the target protein level (32.3% vs. 25.0%, $p = 0.727$). Although the calorie and protein supplies were higher on the first day of CRRT in the survivor group than in the non-survivor group, these differences were not significant (703 ± 382 kcal vs. 568 ± 284 kcal, $p = 0.274$ and 30.4 ± 26.8 g vs. 20.2 ± 37.5 g, $p = 0.322$, respectively). However, on the last day of CRRT, the supplied calories (1,314 ± 388 kcal vs. 838 ± 509 kcal, $p = 0.010$) and proteins (66.3 ± 27.9 g vs. 36.0 ± 45.6 g, $p = 0.049$) were significantly higher in the survivor group than in the non-survivor group. No significant difference was observed between the two groups in terms of the date of EN initiation (7.6 ± 6.9 days vs. 6.5 ± 2.1 days, $p = 0.825$) or the date of supplementary PN initiation (2.8 ± 1.7 days vs. 2.2 ± 0.4 days, $p = 0.371$) (Table 4).

Organ dysfunction

In the analysis of organ dysfunction among patients who underwent CRRT in the surgical ICU, cardiovascular (81.4%) and renal dysfunctions (81.4%) were the predominant types. Subsequently, respiratory dysfunction had a prevalence rate of 67.4%, while central nervous system (CNS), liver, and coagulation dysfunctions had prevalence rates of 51.2%, 44.2%, and 41.9%, respectively.

When examining the relationship between the type of organ dysfunction and 28-day mortality rate, patients with coagulation dysfunction had the highest 28-day mortality rate (44.4%, $p = 0.047$), followed by those with liver dysfunction (36.8%, $p = 0.250$), cardiovascular dysfunction (31.4%, $p = 0.302$), renal dysfunction (31.4%, $p = 0.302$), respiratory dysfunction (27.6%, $p = 0.946$), and CNS dysfunction (27.3%, $p = 0.924$). Logistic regression analysis was performed to further explore the association between organ dysfunction and 28-day mortality. Among the organ dysfunctions, only coagulation dysfunction had a

Table 4. Nutritional support parameters in patients with AKI requiring CRRT

	All patients (n = 43)	Survivors (n = 31)	Non-survivors (n = 12)	*p* value
Average calorie requirement (kcal/day)	1,573 ± 290	1,589 ± 301	1,532 ± 268	0.573
Average protein requirement (g/day)	94.4 ± 17.4	95.3 ± 18.0	91.9 ± 16.1	0.573
Supplied calorie (kcal/day)	993 ± 371	1,091 ± 325	739 ± 373	0.004
Supplied protein (g/day)	46.8 ± 26.9	53.6 ± 20.7	29.0 ± 33.6	0.033
Supplied calorie (kcal/kg/day)	16.3 ± 6.8	17.8 ± 6.5	12.4 ± 6.2	0.016
Supplied protein (g/kg/day)	0.76 ± 0.46	0.88 ± 0.37	0.47 ± 0.53	0.029
Supplied calorie via EN (kcal/kg/day)	0.72 ± 1.49	0.99 ± 1.69	0.02 ± 0.05	0.003
Supplied protein via EN (g/kg/day)	0.03 ± 0.07	0.04 ± 0.08	0.01 ± 0.01	0.010
Supplied calorie via PN (kcal/kg/day)	15.6 ± 6.38	16.8 ± 6.09	12.3 ± 6.18	0.037
Supplied protein via PN (g/kg/day)	0.74 ± 0.43	0.84 ± 0.35	0.47 ± 0.53	0.044
Adequacy of supplied calorie (%)	65.3 ± 27.2	71.8 ± 25.9	48.7 ± 23.9	0.011
Adequacy of supplied protein (%)	51.0 ± 30.4	58.9 ± 24.9	30.8 ± 34.9	0.022
Satisfaction of target calorie, n (%)	16 (37.2)	14 (45.2)	2 (16.7)	0.158
Satisfaction of target protein, n (%)	13 (30.2)	10 (32.3)	3 (25.0)	0.727
The first day of CRRT, calorie (kcal)	665 ± 359	703 ± 382	568 ± 284	0.274
The first day of CRRT, protein (g)	27.6 ± 30.1	30.4 ± 26.8	20.2 ± 37.5	0.322
The last day of CRRT, calorie (kcal)	1,181 ± 472	1,314 ± 388	838 ± 509	0.010
The last day of CRRT, protein (g)	57.9 ± 35.9	66.3 ± 27.9	36.0 ± 45.6	0.049
Initiation of EN (ICU Day)	7.5 ± 6.5	7.6 ± 6.9	6.5 ± 2.1	0.825
Initiation of supplemental PN (ICU day)	2.7 ± 1.6	2.8 ± 1.7	2.2 ± 0.4	0.371

AKI, acute kidney injury; CRRT, continuous renal replacement therapy; EN, enteral nutrition; PN, parenteral nutrition; ICU, intensive care unit

significant effect on the 28-day mortality (OR = 4.2 [1.02–17.3], $p = 0.047$) (Table 5).

Predictive factors for mortality

In our univariable analyses, low albumin levels (OR = 0.14 [0.03–0.80], $p = 0.026$) and high lactic acid levels (OR = 1.26 [1.04–1.52], $p = 0.018$) were associated with 28-day mortality. In the multivariable analysis, after adjusting for each risk and confounding factor, only high lactic acid levels remained independently associated with 28-day mortality (OR = 1.25 [1.00–1.55], $p = 0.048$) (Table 6).

Logistic regression analysis was performed to estimate the association between nutritional supply parameters and 28-day mortality. A lower than average calorie supply per body weight (OR = 0.87 [0.77–0.98], $p = 0.025$), a lower protein supply (OR = 0.11 [0.02–0.64], $p = 0.014$), a lower calorie supply via PN (OR = 0.99 [0.99–1.00], $p = 0.019$), a lower protein supply via PN (OR = 0.96 [0.93–0.99], $p = 0.017$), an inadequate calorie supply (OR = 0.96 [0.93–0.99], $p = 0.018$), and an inadequate protein supply (OR = 0.97 [0.94–0.99], $p = 0.011$) were significantly associated with increased 28-day mortality rates. After adjusting for age, sex, BMI, CCI score, and mNUTRIC score, a lower than average calorie supply per body weight (OR = 0.78 [0.64–0.94], $p = 0.011$), a lower protein supply (OR = 0.08 [0.01–0.68], $p = 0.021$), a lower calorie supply via PN (OR = 0.99 [0.99–1.00], $p = 0.028$), a lower protein supply via PN (OR = 0.97 [0.94–0.99], $p = 0.045$), an inadequate calorie supply (OR = 0.93 [0.89–0.98], $p = 0.008$), and an inadequate protein supply (OR = 0.96 [0.93–0.99], $p = 0.017$) remained significantly associated with increased 28-day mortality rates (Table 7).

DISCUSSION

In ICU patients with critical illness requiring CRRT due to AKI, systemic muscle wasting can occur due to hypercatabolism, electrolyte imbalances, and amino acid deficiencies, leading to prolonged ICU stays and decreased functional capacity after recovery.[6, 9] In patients with critical illness with AKI, assessment of nutritional status based solely on body weight or BMI can be difficult due to fluid resuscitation or muscle loss, and they are potentially at high risk for malnutrition.[5, 18-21] Similar to other studies on nutritional support and clinical outcomes in patients with critical illness, this study also found that those with an mNUTRIC score of >5, indicating high nutritional risk, accounted for 79.1% of the patients.[22, 23] Patients at high nutritional risk have significantly longer ICU stays, longer periods of mechanical ventilation, and higher mortality rates than those at low nutritional risk.[10, 16, 24] However, the length of hospital stay, length of ICU

Table 5. Logistic regression analysis of the association between organ dysfunction and 28-day mortality

Variable	n	Mortality	OR (95% CI) crude	*p* value
Cardiovascular	35 (81.4)	11/35 (31.4)	3.2 (0.35–29.3)	0.302
Renal	35 (81.4)	11/35 (31.4)	3.2 (0.35–29.3)	0.302
Respiratory	29 (67.4)	8/29 (27.6)	0.95 (0.23–3.93)	0.946
Central nervous system	22 (51.2)	6/22 (27.3)	0.94 (0.25–3.55)	0.924
Liver	19 (44.2)	7/19 (36.8)	2.22 (0.57–8.6)	0.250
Coagulation	18 (41.9)	8/18 (44.4)	4.2 (1.02–17.3)	0.047

OR, odds ratio; CI, confidence interval

Table 6. Multivariable logistic regression analysis of the 28-day mortality rate

Variable	Univariable		Multivariable	
	OR (95% CI)	*p* value	OR (95% CI)	*p* value
Age (years), mean (± SD)	0.99 (0.96–1.04)	0.841		
Sex, n (%)	2.47 (0.56–10.9)	0.233		
BMI (kg/m^2), mean (± SD)	0.89 (0.73–1.07)	0.215		
Charlson Comorbidity Index score, mean (± SD)	0.79 (0.59–1.09)	0.151	0.94 (0.64–1.37)	0.733
Initial SOFA score	1.27 (0.99–1.64)	0.064		
APACHE II score, mean (± SD)	0.96 (0.87–1.07)	0.458	0.91 (0.79–1.04)	0.165
mNUTRIC score ≥ 5	0.72 (0.15–3.50)	0.684		
WBC	0.86 (0.74–1.00)	0.056		
Albumin	0.14 (0.03–0.80)	0.026	0.33 (0.05–2.05)	0.231
Lactic acid	1.26 (1.04–1.52)	0.018	1.25 (1.00–1.55)	0.048

CRRT, continuous renal replacement therapy; OR, odds ratio; CI, confidence interval; BMI, body mass index; SOFA, Sequential Organ Failure Assessment; APACHE, Acute Physiology and Chronic Health Evaluation; mNUTRIC, modified Nutrition Risk in Critically Ill; WBC, white blood cell

Table 7. OR of nutritional supply parameter associated with 28-day mortality in the logistic regression analysis

Variable	Crude		Adjusted	
	OR (95% CI)	*p* value	OR (95% CI)	*p* value
Supplied calorie (kcal/kg/day)	0.87 (0.77–0.98)	0.025	0.78 (0.64–0.94)	0.011
Supplied protein (g/kg/day)	0.11 (0.02–0.64)	0.014	0.08 (0.01–0.68)	0.021
Supplied calorie via EN (kcal/kg/day)	0.95 (0.85–1.06)	0.358	0.93 (0.78–1.11)	0.409
Supplied protein via EN (g/kg/day)	0.42 (0.07–2.52)	0.343	0.25 (0.01–5.48)	0.377
Supplied calorie via PN (kcal/kg/day)	0.99 (0.99–1.00)	0.019	0.99 (0.99–1.00)	0.028
Supplied protein via PN (g/kg/day)	0.96 (0.93–0.99)	0.017	0.97 (0.94–0.99)	0.045
Adequacy of supplied calorie (%)	0.96 (0.93–0.99)	0.018	0.93 (0.89–0.98)	0.008
Adequacy of supplied protein (%)	0.97 (0.94–0.99)	0.011	0.96 (0.93–0.99)	0.017
Initiation of EN (ICU day)	0.97 (0.73–1.29)	0.810	1.71 (0.35–8.25)	0.505
Initiation of supplemental PN (ICU day)	0.61 (0.22–1.69)	0.344	0.05 (0.01–1.02)	0.051

OR, odds ratio; CI, confidence interval; BMI, body mass index; CCI, Charlson Comorbidity Index; mNUTRIC, modified Nutrition Risk in Critically Ill; EN, enteral nutrition; ICU, intensive care unit; PN, parenteral nutrition
†Adjustment was performed according to age, sex, BMI, CCI score, and mNUTRIC score

stay, and duration of mechanical ventilation in our study were not significantly longer in the high nutritional risk group than in the low nutritional risk group. Although no significant difference was found in the 28-day mortality rate (26.5% vs. 33.3%, $p = 0.692$), the 90-day mortality (47.1% vs. 33.3%, $p = 0.708$) and in-hospital mortality rates (52.9% vs. 33.3%, $p = 0.457$) were higher in the high nutritional risk group. In patients with critical illness, higher calorie and protein delivery rates were associated with significantly decreased ICU stays, total hospital stays, and mortality rates.[5, 10, 13] Similarly, the higher rates of adequate nutritional supply were associated with significantly decreased 28-day mortality in our study.

Although the importance of nutritional support in patients with critical illness has been increasingly recognized, its clinical application remains challenging. Recent studies have focused more evaluating the protein delivery rate rather than the calorie delivery rate and recommended at least 25 kcal/kg/day and 1.5 g/kg/day of protein in patients with AKI requiring CRRT.[6, 7, 11] In a similar patient population in domestic studies, the average calorie and protein deliveries were 16.6 kcal/kg and 0.63 g/kg, respectively, and the ratios of calorie and protein deliveries to the target amount were 68.1% and 43.1%, respectively.[25] In our study, the average calorie delivery was 16.3 kcal/kg, but the average protein delivery was 0.76 g/kg. However, these values are still far from the recommended amounts of calorie and protein deliveries in patients with AKI requiring CRRT according to some studies.[6, 7, 11] This may be due to the consideration of uremia caused by elevated blood urea nitrogen levels before CRRT application and the continued resuscitation of unstable patients with critical illness, which may impede the initial nutritional support. This could be one of the reasons why the non-survivors did not achieve the target energy level as they were in the acute phase of the disease in a certain period of their hospital stay; we may have been oriented to perform resuscitation in this case rather than provide nutritional support. To overcome this weak point, a multidisciplinary approach should be used when providing nutritional support. This is crucial in ensuring optimal nutritional support care.[26]

The importance of EN in nutritional support for patients with critical illness has already been established, with early EN contributing to reduced mortality rates, decreased length of hospital stay, and decreased incidence of infectious complications.[7, 17, 27] However, the factors that hinder the implementation of early EN include unstable vital signs, paralytic ileus, and maladaptive nutrition in patients with critical illness.[28, 29] In surgical ICU where the proportion of patients with intra-abdominal infections and those who require abdominal surgery due to trauma is higher, early EN is often not feasible.[30, 31] Our study had a limited number of enrolled patients, and the amounts of

calories and proteins supplied via EN were extremely low in the non-survivor group compared with that in the survivor group. Moreover, the exact impact of EN and PN on the clinical outcomes was difficult to identify. In multi-institutional studies evaluating the status of nutritional support in surgical ICUs, EN was initiated after an average of 6.2 days.[32] In our study, the delay was even longer at 7.5 days, likely due to the occurrence of paralytic ileus related to abdominal surgery and trauma and the need for CRRT. The timing of supplemental PN initiation remains a subject of much debate; however, recently, it has been recommended in patients with high nutritional risk who experience EN intolerance or in those not suitable for EN, to provide appropriate nutrition within 3–7 days.[10, 33] In our study, PN was initiated at an average of 2.7 days, which was started relatively earlier than that in other studies.[31, 32] This may be attributed to the more aggressive provision of nutritional support in our patients at high nutritional risk and who received suboptimal EN.

The significance of this study lies in its analysis of the nutritional status of a unique population of patients with critical illness requiring CRRT due to AKI in a surgical ICU and its investigation of the relationship between nutritional support and mortality rates. However, our study has some limitations. This was an exploratory study and used all data that satisfied the inclusion and exclusion conditions during the study period. However, owing to the specificity of the patient population, we were unable to include an adequate number of patients, and the retrospective nature of the medical record study limited the individual evaluations of the initial nutritional status upon admission to the ICU. The sample size was small; thus, drawing conclusions with clinical significance can be challenging. Therefore, a multi-institutional study that supplements the investigation of nutritional support with a clear analysis of the clinical outcomes should be conducted to overcome these limitations.

Conclusion

Our patients had a significantly insufficient supply of calories and proteins compared with the recommended guideline criteria. Increasing the supply and improving adequacy through the use of appropriate nutritional support strategies may improve the mortality rates. Moreover, a multidisciplinary approach is required for the systematic management of patients with a high risk of malnutrition.

CONFLICT OF INTEREST AND FUNDING DISCLOSURE

The authors declare no conflict of interest.

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DATA AVAILABILITY STATEMENT

The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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