Effect of a Restrictive Fluid Therapy Strategy Without Routine Maintenance Fluids on Acid-Base Balance and Renal Function in Critically Ill Patients

Yoğun Bakım Hastalarında Rutin İdame Sıvısı Uygulanmayan Restriktif Sıvı Tedavisi Yaklaşımının Asit-Baz Dengesi ve Böbrek Fonksiyonları Üzerine Etkisi

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Abstract

Background: This study aimed to compare the effects of conventional maintenance fluid administration and a restrictive fluid management strategy without routine maintenance fluids on acid–base balance and renal function in critically ill patients.

Materials and Methods: In this single-center, retrospective observational study, adult ICU patients hospitalized during two consecutive clinical periods were analyzed. During the first period, routine maintenance fluids were administered, whereas during the second period, fluid therapy was individualized without routine maintenance fluids based on daily clinical and laboratory assessment. Demographic data, administered intravenous fluid volume, electrolytes, blood gas parameters, serum urea and creatinine levels, and non-lactate strong ion difference (SIDnl) were recorded at ICU admission (day 0) and day 5. Acute kidney injury (AKI) was assessed according to KDIGO criteria.

Results: The restrictive fluid period was associated with significantly lower total intravenous fluid administration, lower AKI incidence, and lower maximum AKI stage. Serum urea and creatinine levels were similar between groups at baseline and day 5. Although baseline SIDnl values were lower in the restrictive group, they normalized during follow-up, and day 5 SIDnl values were comparable between groups. Mortality was numerically lower in the restrictive group but did not reach statistical significance.

Conclusions: Omission of routine maintenance fluids and implementation of an individualized restrictive fluid strategy were associated with reduced fluid exposure, lower AKI incidence, and lower AKI severity in critically ill patients. These findings suggest that minimizing unnecessary fluid administration may contribute to renal protection in the ICU.

Keywords: Restrictive fluid therapy, Maintenance fluids, Acute kidney injury, Fluid overload, Acid-base balance

Öz

Amaç: Bu çalışma, yoğun bakım ünitesinde rutin idame solüsyonu uygulanan dönem ile idame solüsyonu verilmeden, hastanın günlük sıvı gereksiniminin klinik ve laboratuvar parametreler doğrultusunda değerlendirildiği restriktif sıvı yönetimi yaklaşımının asit-baz dengesi ve böbrek fonksiyonları üzerine etkilerini karşılaştırmayı amaçlamıştır.

Materyal ve metod: Bu tek merkezli, retrospektif, gözlemsel çalışmada, ardışık iki klinik dönemde yoğun bakımda yatan erişkin hastaların verileri incelendi. Birinci dönemde rutin idame sıvısı uygulanırken, ikinci dönemde idame sıvısı verilmeden hastaların sıvı gereksinimi günlük klinik değerlendirme ile karşılandı. Demografik veriler, verilen intravenöz sıvı miktarı, elektrolitler, kan gazı parametreleri, serum üre ve kreatinin değerleri ile non-laktat güçlü iyon farkı (strong ion difference, SIDnl) değerleri yatış günü (0. gün) ve 5. gün için kaydedildi. Akut böbrek hasarı (ABH), KDIGO kriterlerine göre değerlendirildi.

Bulgular: Restriktif sıvı yönetimi uygulanan dönemde toplam verilen intravenöz sıvı miktarı, ABH insidansı ve maksimum ABH evresi anlamlı olarak daha düşük bulundu. Buna karşın serum üre ve kreatinin düzeyleri girişte ve 5. günde iki grup arasında benzerdi. Restriktif grupta başlangıç SIDnl değerleri daha düşük olmasına rağmen, izlem sürecinde normal aralığa yaklaşmış ve 5. gün SIDnl değerleri gruplar arasında benzer bulunmuştur. Mortalite restriktif grupta daha düşük saptanmış ancak istatistiksel anlamlılığa ulaşmamıştır.

Sonuç: Rutin idame sıvılarının uygulanmaması ve bireyselleştirilmiş restriktif sıvı yönetimi yaklaşımı, yoğun bakım hastalarında daha düşük sıvı maruziyeti ile birlikte daha düşük ABH insidansı ve ABH şiddeti ile ilişkili bulunmuştur. Bu bulgular, gereksiz sıvı yüklenmesinin azaltılmasının böbrek fonksiyonlarının korunmasına katkı sağlayabileceğini düşündürmektedir.

Anahtar Kelimeler: Restriktif sıvı tedavisi, İdame sıvısı, Akut böbrek hasarı, Sıvı yüklenmesi, Asit-baz dengesi

Introduction

In intensive care units (ICUs), fluid management plays a crucial role in maintaining hemodynamic stability and preventing organ dysfunction in critically ill patients. Although fluid therapy is indispensable in the management of ICU patients, both insufficient and excessive fluid administration may adversely affect organ function (1). Traditionally, clinicians have tended to initiate maintenance fluids regardless of individual patient requirements. However, recent studies have increasingly emphasized the detrimental consequences of fluid overload (1, 2). Observational studies and meta-analyses have demonstrated that a positive fluid balance is associated with increased mortality, prolonged ICU length of stay, and a higher incidence of acute kidney injury (AKI) in critically ill patients (2-8). These findings highlight the importance of managing fluid therapy "as a drug," in a targeted and carefully titrated manner (9).

Within the framework of the Stewart acid–base approach, the Strong Ion Difference (SID) represents a key parameter reflecting the difference between strong cations (primarily Na^+ and K^+) and strong anions (primarily Cl^-) in plasma, and it has been increasingly used in the evaluation of metabolic acid–base disorders in critically ill patients compared with traditional methods (10). The non-lactate strong ion difference (SID_{nl}) has been associated with ICU mortality (11, 12). High-chloride crystalloids may reduce SID_{nl} and contribute to hyperchloremic metabolic acidosis, which may adversely affect renal perfusion, glomerular filtration, and overall kidney function (13). Conversely, restrictive and goal-directed fluid strategies may limit unnecessary maintenance fluid exposure, reduce tissue edema, and potentially preserve renal function (14-16).

This study aims to compare two consecutive clinical periods in the ICU: a period in which routine maintenance fluids were administered and a period in which maintenance fluids were omitted and fluid therapy was provided using a restrictive approach based on daily clinical and laboratory assessment. The study evaluates the effects of these two strategies on renal function, changes in SID, and mortality. Although numerous studies have focused on the relationship between fluid overload and renal function, there is limited evidence comparing fluid management strategies through a Stewart-based SID framework, particularly across two consecutive clinical periods within the same center. Therefore, this study is expected to contribute to the re-evaluation of ICU fluid management strategies from a more physiological and individualized perspective, considering both acid–base balance and renal outcomes.

Materials and Methods

Study Design and Setting
This was a single-center, retrospective, observational, and comparative cohort study conducted in the adult intensive care units of Mehmet Akif İnan Training and Research Hospital (Şanlıurfa, Türkiye). Two consecutive clinical periods during which different fluid management strategies were routinely practiced were compared.

Ethical Approval
Ethical approval was obtained from the Gaziantep University Non-Interventional Clinical Research Ethics Committee prior to the study (approval no: 2026/78, date: January 21, 2026). Due to the retrospective nature of the study and the use of de-identified patient data, the requirement for informed consent was waived. All patient information was anonymized prior to extraction, and no identifiable data were stored. The study adhered to the principles of the Declaration of Helsinki and relevant national regulations concerning data confidentiality and research ethics.

Study Period and Patient Screening
During the period between June 1, 2025 and January 1, 2026, all patients admitted to the General 1 and General 2 adult intensive care units were screened for eligibility. The first six months of the study period corresponded to the conventional maintenance fluid strategy, whereas the subsequent six months corresponded to the restrictive fluid strategy. Data extraction was performed manually through the institutional electronic medical record system and ICU documentation charts. All collected variables were subsequently transferred into a structured Excel database for cleaning and statistical analysis.

Fluid Management Strategy Groups
Two predefined cohorts were identified based on the fluid management strategy implemented during each non-overlapping period:

1. Maintenance Fluids Group: Patients admitted during the period in which isotonic crystalloid maintenance fluids were routinely administered independent of hemodynamic fluid responsiveness.

2. Restrictive Strategy Group: Patients admitted during the period in which no routine maintenance fluids were given. Instead, fluid administration was based on daily clinical and laboratory assessment and guided by small-volume crystalloid boluses (typically 100–250 mL) with subsequent reassessment.

Eligibility Criteria

Inclusion Criteria

Patients were included if they met all of the following:

- Age ≥18 years,

- ICU stay ≥5 days,

- Availability of daily serum electrolyte, acid–base, and 24-hour fluid balance data for days 0–5,

- Clear documentation of fluid management period (routine vs restrictive).

Exclusion Criteria

- Patients were excluded if they had:

- End-stage renal disease requiring chronic hemodialysis or peritoneal dialysis prior to ICU admission,

- Death within the first 96 hours (preventing 5-day evaluation),

- Transfer to another center within the first 5 days,

- Missing or unreliable laboratory or fluid balance data,

- Initiation of renal replacement therapy (intermittent HD or CRRT) during the first 5 days,

- Major surgery, trauma, or massive transfusion requiring high-volume fluid resuscitation during the first 5 days,

- Administration of hypertonic saline, sodium bicarbonate infusion, high-dose electrolyte replacement capable of directly altering acid–base status, blood product transfusion, or mannitol therapy.

Data Collection and Variables

For each patient, demographic and clinical characteristics were recorded at baseline. Laboratory parameters including serum electrolytes (sodium, potassium, chloride), serum urea, creatinine, blood gas values, and albumin were obtained at ICU admission (day 0) and then collected daily for five consecutive days. In the same period, daily fluid intake and AKI assessments were also recorded. All data were retrieved from the hospital's electronic medical records and patient monitoring forms.

Operational Definitions

Standardization of interpretation was achieved by calculating the SID_{nl} as (12):

$SID_{nl} = [Na^+] + [K^+] − [Cl^−]$

Acute kidney injury (AKI) was classified according to KDIGO criteria (17). During the restrictive period, fluid responsiveness was operationally inferred from documented clinical improvement following small-volume crystalloid boluses (100–250 mL), based on one or more of the following: increased urine output, improved mean arterial pressure or heart rate, or improvement in perfusion markers such as lactate trajectory or capillary refill.

Ventilator-free days (VFDays) were defined as an ICU-based measure and calculated as the intensive care unit length of stay minus the duration of mechanical ventilation (both expressed in days).

Outcomes

Primary Outcome

The primary outcome was the incidence of AKI within the first five days of ICU admission, defined and staged according to the Kidney Disease: Improving Global Outcomes (KDIGO) criteria, which incorporate both serum creatinine and urine output parameters (17).

Secondary Outcome

The secondary outcome was to compare 0-day and 5-day mortality, serum urea, creatinine, and arterial blood gas parameters between the two groups.

Rationale for the 5-day Observation Window

Although maintenance fluids are administered in relatively small amounts on a daily basis, their cumulative effect becomes more pronounced as ICU length of stay increases. To capture this cumulative and physiologically relevant impact—

particularly on electrolyte balance, acid–base status, and renal function—a 5-day observation period was selected as a standardized early clinical window.

Results

Baseline Characteristics

A total of 116 patients were included in the analysis and were divided into restrictive and conventional fluid management groups. Baseline demographic characteristics and comorbidities were comparable between the two groups. The prevalence of hypertension, COPD, diabetes mellitus, and coronary artery disease did not differ significantly between groups. Similarly, median age was comparable between the restrictive and conventional groups (67 [55–76] vs 66 [38–77] years, p=0.55), and the proportion of female patients was similar (34% vs 41%, p=0.56).

Baseline severity of illness was also comparable. There were no significant differences in APACHE II scores (12 [10.8–19] vs 16 [11–20.3], p=0.11) or SOFA scores (10 [8–13.3] vs 11.5 [8–16], p=0.15) between the restrictive and conventional groups, respectively. ICU length of stay was numerically shorter in the restrictive group but did not reach statistical significance (7.5 [6–11] vs 9 [6–13] days, p=0.20).

The incidence of AKI was significantly lower in the restrictive group compared with the conventional group (12% vs 50%, p<0.0001). In addition, AKI severity was lower in the restrictive group, with median AKI stage values of 0 (0–0) versus 0.5 (0–2.25) in the conventional group (p<0.0001). Mortality rates were numerically lower in the restrictive group but did not differ significantly between groups (39.7% vs 46.5%, p=0.57). Ventilator-free days were similar between groups (145 [86–168] vs 95 [22–216], p=0.38).

Overall, while baseline demographic characteristics and illness severity were comparable, the restrictive fluid strategy was associated with a significantly lower incidence and severity of AKI (Table 1).

Table 1. Baseline patient characteristics and clinical outcomes according to fluid management strategy. Data are presented as n (%) or median (IQR)

	Restrictive	Traditional	p-value
Comorbidities			0.87
HT	35	30	
COPD	6	8	
DM	17	14	
CAD	9	9	
Age	67 (55-76)	66 (38-77)	0.55
Female	20 (34%)	24 (41%)	0.56
LOS in ICU	7.5 (6-11)	9 (6-13)	0.2
APACHE II	12 (10.8-19)	16 (11-20.3)	0.11
SOFA	10 (8-13.3)	11.5 (8-16)	0.15
AKI incidence	7 (12%)	29 (50%)	<0.0001
AKI stage	0 (0-0)	0.5 (0-2.25)	<0.0001
Mortality	23 (39.7%)	27 (46.5%)	0.57
Vfdays	6.0 (3.6–7.0)	4.0 (0.9–9.0)	0.38

APACHE II: Acute Physiology and Chronic Health Evaluation II, AKI: Acute kidney injury, CAD, Coronary artery disease: COPD: Chronic obstructive pulmonary disease, DM: Diabetes mellitus, HT: Hypertension, ICU: Intensive care unit, LOS: Length of stay: SOFA: Sequential Organ Failure Assessment, Vfdays: Ventilator-Free Days
*p<0.05 indicates statistical significance

Laboratory and Acid-Base Parameters

Laboratory and acid–base parameters measured at ICU admission (day 0) and day 5 were comparable between the restrictive and conventional fluid management groups. Baseline serum creatinine and urea levels did not differ significantly between groups at ICU admission and remained comparable at day 5. Similarly, arterial blood gas parameters, including pH and CO_2 levels, showed no significant intergroup differences at either time point.

Electrolyte profiles were largely similar between groups. Serum sodium and potassium concentrations did not differ significantly at day 0 or day 5. Chloride levels showed a borderline difference at ICU admission, with slightly higher values observed in the restrictive group (106 [102–111] vs 102 [100–106] mmol/L,

p=0.053), but this difference was no longer present at day 5. Bicarbonate concentrations, lactate levels, SBE values were comparable between groups at both time points. No significant differences were observed in arterial acid–base status based on conventional parameters.

In contrast, baseline Strong Ion Difference (SID_{nl}) was significantly lower in the restrictive group compared with the conventional group at ICU admission (36 [34–41] vs 40 [37–42], p=0.03). However, this difference did not persist at day 5, where SID_{nl} values were similar between groups (39 [37–45] vs 43 [39–47], p=0.07).

Overall, laboratory parameters and acid–base variables were largely comparable between groups, with the exception of a lower baseline SID_{nl} in the restrictive group (Table 2).

Table 2. Comparison of laboratory, electrolyte, and acid-base parameters at ICU admission (day 0) and day 5 between restrictive and conventional fluid management groups

	Day	Restrictive	Traditional	p-value
Cre	0	0.8 (0.7-1)	0.9 (0.7-1.1)	0.17
	5	0.7 (0.5-1.1)	0.8 (0.6-1.3)	0.11
Urea	0	36 (27-50)	35 (26-50)	0.53
	5	45(32-73)	50 (35-81)	0.31
pH	0	7.38 (7.31-7.43)	7.39 (7.31-7.43)	0.84
	5	7.42 (7.38-7.45)	7.42 (7.38-7.47)	0.95
Na	0	138 (136-140)	138 (137-141)	0.67
	5	142 (139-148)	141 (138-147)	0.82
Cl	0	106 (102-111)	102 (100-106)	0.053
	5	109 (104-110)	106 (100-111)	0.27
K	0	4.3 (3.8-4.6)	4.2 (3.9-4.6)	0.89
	5	4 (3.6-4.2)	4 (3.7-4.4)	0.6
SIDnl	0	36 (34-41)	40 (37-42)	0.03*
	5	39 (37-45)	43 (39-47)	0.07
PaCO2	0	40 (32-47)	37 (32-43)	0.3
	5	40 (36-44)	39 (33-47)	0.51
SBE	0	-1 (-6- 1.25)	-2.4 (-7- 0.25)	0.4
	5	1.9 (0-4)	1.65 (-2- 5)	0.39
HCO3	0	23 (18.8-25)	22 (18-24)	0.32
	5	25 (23-28)	25.5 (23-28)	0.73

Cl: Chloride, Cre: Creatinine, HCO_3^-: Bicarbonate, K: Potassium, Lac: Lactate, Na: Sodium, $PaCO_2$: Partial pressure of arterial carbon dioxide, pH: Potential of hydrogen, SBE: Standard base excess, SIDnl: Non-lactate strong ion difference, Urea: Blood urea, ICU: Intensive care unit

Fluid Administration Characteristics

Fluid administration differed significantly between the restrictive and traditional groups. The traditional group received markedly higher total crystalloid volumes compared with the restrictive group [7,000 (4,000–12,000) mL vs 1,750 (500–2,000) mL, p<0.001]. Similarly, daily fluid volume was substantially higher in the traditional group [750 (457–1,060) mL/day vs 173 (69–286) mL/day, p<0.001].

Regarding fluid types, Isolyte was administered in a similar proportion of patients in both groups; however, cumulative administered volume was significantly higher in the traditional group [5250 (3,625–9,875) mL vs 1500 (1,000–2,125) mL,

p<0.001]. Isotonic saline use was markedly more frequent and at higher volumes in the traditional group compared with the restrictive group [34 vs 9 patients; 7,750 (4,375–13,250) mL vs 2000 (2,000–3,000) mL, p<0.001].

Five percent dextrose was administered only in the restrictive group [17 patients; 2,000 (1,000–2,750) mL]. Additionally, no fluid administration was recorded in 9 patients in the restrictive group during the observation period.

Overall, patients managed with the traditional fluid strategy were exposed to substantially higher cumulative and daily crystalloid volumes, primarily driven by greater isotonic saline and balanced crystalloid administration (Table 3).

Table 3. Comparison of fluid type distribution and cumulative fluid exposure between restrictive and traditional fluid management strategies

Variable	Restrictive	Traditional	p-value
Fluid type (mL)			
Isolyte	22 (38%), 1,500 (1,000–2,125)	24 (41%), 5,250 (3,625–9,875)	<0.001*
Isotonic saline	9 (16%), 2,000 (2,000–3,000)	34 (59%), 7,750 (4,375–13,250)	<0.001*
5% dextrose	17 (30%), 2,000 (1,000–2,750)	—	
No fluid	9 (16%)	—	
Total crystalloid volume (mL)	1750 (500-2,000)	7,000 (4,000-12,000)	<0.001*
Daily fluid volume (mL/day)	173 (69–286)	750 (457–1,060)	<0.001*
*p<0.05 indicates statistical significance			

Multivariable Analysis and Model Performance

To identify independent predictors of AKI development, a multivariable logistic regression analysis was performed including fluid management strategy, illness severity scores (APACHE II and SOFA), age, and baseline renal function parameters. After adjustment for these covariates, fluid management strategy remained a strong independent determinant of AKI occurrence. Patients managed with the conventional (maintenance-based) fluid strategy had a significantly higher risk of developing AKI compared with those treated using the restrictive approach (OR 0.121 for restrictive strategy; 95% CI 0.039–0.326; p<0.001). When expressed inversely, this corresponds to an approximately eight-fold higher AKI risk associated with the conventional fluid strategy.

Other variables included in the model, including APACHE II score, SOFA score, baseline creatinine, baseline urea level, and age, were not independently associated with AKI after adjustment, although baseline creatinine showed a non-significant trend toward increased risk. These findings suggest that fluid strategy had a stronger association with AKI development than baseline illness severity or renal function in this cohort.

Model discrimination was good, with an area under the receiver operating characteristic (ROC) curve of 0.826 (95% CI 0.743–0.909; p<0.0001), indicating strong ability of the model to distinguish between patients who developed AKI and those who did not. Model calibration was also acceptable, with a non-significant Hosmer–Lemeshow test (p=0.418), suggesting good agreement between predicted and observed outcomes.

Overall model classification accuracy was 78.4%, with a positive predictive value of 83.1% and a negative predictive value of 66.7%.

The ROC curve illustrating the discriminative performance of the multivariable model is presented in Figure 1.
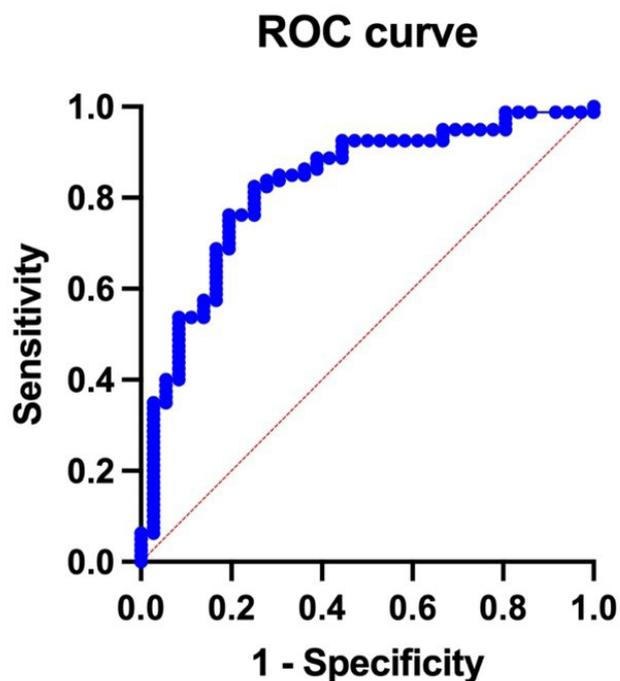

Figure 1. Receiver operating characteristic (ROC) curve demonstrating the predictive performance of the study variable for the primary outcome. The diagonal dashed line represents the line of no discrimination (AUC=0.5), while the ROC curve illustrates the observed model performance across sensitivity and specificity thresholds

Discussion

The present study demonstrates that a restrictive fluid management strategy, based on the omission of routine maintenance fluids and individualized daily fluid assessment, was associated with a significantly lower incidence and severity of AKI, while baseline demographic characteristics, illness severity scores, and most laboratory and acid–base parameters remained comparable between groups. Despite similar baseline clinical profiles, patients managed with the conventional maintenance-based approach exhibited substantially higher AKI rates, supporting the hypothesis that cumulative fluid exposure may directly contribute to renal injury in critically ill patients. Although not reaching statistical significance, mortality tended to be lower and ventilator-free days tended to be higher in the restrictive group.

In the cohort of the present study, patients managed with a conventional maintenance-based fluid strategy were exposed to higher cumulative fluid volumes and a greater risk of fluid overload. This approach was associated with a markedly increased risk of AKI, corresponding to an approximately eight-fold higher risk compared with the restrictive strategy after adjustment for illness severity and baseline renal function. Consistent with our findings demonstrating a lower incidence and severity of AKI in patients managed with a restrictive fluid strategy, growing evidence suggests that cumulative fluid exposure may directly contribute to renal injury in critically ill patients. In the ICU setting, excessive fluid exposure may promote AKI through mechanisms such as tissue edema, increased intra-abdominal pressure, and elevated interstitial pressure within the renal parenchyma (5). Accordingly, fluid therapy has been described as a "double-edged sword," requiring careful balance between avoiding hypovolemia and tissue hypoperfusion on one hand, and preventing hyperhydration and fluid overload–associated organ dysfunction on the other (9). In the current literature, fluid overload has been shown to be not merely a marker of disease severity, but also an independent risk factor for the development and severity of AKI, supported by observational studies and systematic reviews (9,18). In critically ill patients, unnecessary fluid administration may result in physiological derangements across multiple organ systems, including the kidneys, and even "hidden fluids" used for maintenance or drug delivery (fluid creep) may cumulatively reach clinically meaningful volumes and contribute to this process (18). Moreover, several authors have emphasized that liberal fluid strategies and inadequate "de-resuscitation" during the recovery phase may adversely affect renal outcomes, whereas more restrictive and carefully titrated approaches may improve clinical results (19). In a retrospective study by Van Regenmortel et al., maintenance and replacement fluids were identified as major contributors to total cumulative fluid exposure rather than resuscitation fluids, indicating that maintenance solutions may represent an under-recognized source of fluid burden (20). Taken together, these findings support our observation that the restriction or omission of maintenance fluids was associated with a lower incidence and severity of AKI, suggesting that minimizing unnecessary fluid exposure may attenuate renal injury in critically ill patients (9, 18-20).

AKI incidence and severity were significantly higher in the conventional group; however, serum urea and creatinine levels were comparable between groups both at ICU admission and on day 5. This finding may indicate that a proportion of AKI cases were early-stage or transient and therefore not yet reflected by

substantial changes in serum creatinine. In addition, dilutional effects related to higher cumulative fluid exposure may have masked small creatinine increases. Another possible explanation is that some patients had already entered a recovery phase by day 5, resulting in normalization of biochemical renal markers despite earlier renal injury.

Beyond its impact on renal function, fluid overload has been consistently associated with increased mortality in critically ill patients. Large meta-analyses and systematic reviews have shown that both weight-defined fluid overload and increasingly positive cumulative fluid balance are independently linked to higher ICU and hospital mortality, with a dose–response relationship such that each additional liter of positive balance confers a measurable increase in death risk (2, 21). In the meta-analysis by Messmer et al., fluid overload and positive fluid balance were associated with increased adjusted mortality not only in the general ICU population, but also in key subgroups such as sepsis, AKI and respiratory failure, and mortality rose by approximately 19% per liter of positive balance (2). Malbrain et al. similarly reported that non-survivors had a substantially more positive cumulative fluid balance than survivors and that restrictive or conservative fluid strategies were associated with lower mortality compared with more liberal regimens (21). In a multicenter cohort, Silversides et al. demonstrated that day-3 fluid balance was an independent predictor of 30-day mortality, and that achieving an even or negative balance—spontaneously or via deresuscitation—was associated with improved survival and shorter durations of mechanical ventilation and ICU stay (22). Recent studies show that when cumulative fluid overload exceeds 10% within the first 72 hours, patients have higher 90-day mortality and spend fewer days alive and free from mechanical ventilation (23). Additionally, contemporary cohort work highlights that non-therapeutic "fluid creep" is a major contributor to fluid overload and independently predicts ICU mortality, underscoring that even ostensibly benign maintenance and carrier fluids can adversely affect outcomes (24). Taken together, these studies support the concept that fluid overload is not merely a marker of disease severity but a modifiable determinant of survival, and they are in line with the lower mortality observed during the restrictive, non-maintenance period in this cohort.

Another physiological dimension relevant to fluid management relates to electrolyte composition and its influence on the SID. From a Stewart's perspective, 0.9% saline represents an acidotic solution with a SID of approximately zero, and its administration predictably lowers the plasma SID, promoting hyperchloremic metabolic acidosis (10, 13, 25). High-chloride isotonic solutions are also frequently used as diluents or carrier fluids in the ICU, further increasing exposure during routine care (25). This dilutional practice is clinically relevant, as hyperchloremia reduces renal perfusion via tubuloglomerular feedback, impairs acid–base homeostasis, and has been linked to worse outcomes in critical illness. Importantly, saline-based diluents constitute a substantial proportion of total crystalloid exposure in many units, and replacing isotonic saline with chloride-sparing alternatives has been associated with improvements in acid–base balance and survival. For example, transitioning from isotonic saline to 5% dextrose as a diluent has been shown to be associated with higher SID values, lower chloride levels, and a significant reduction in ICU mortality, despite comparable renal function markers (25). These findings support the concept that electrolyte composition—not only fluid volume—may meaningfully shape clinical outcomes in the ICU by modulating chloride burden, acid–base status, and downstream physiological responses.

In the cohort of this study, baseline SID_{nl} values were significantly lower in the restrictive group, suggesting a more acidotic profile at ICU admission. However, SID values normalized during follow-up, and by day 5 no statistically significant difference was observed between groups. This finding suggests that despite early electrolyte-related differences, subsequent clinical management and physiological adaptation may have contributed to restoration of acid–base equilibrium. Importantly, these results indicate that the lower incidence of AKI and mortality observed in the restrictive group was unlikely to be driven by persistent SID differences, but rather by overall fluid exposure and cumulative fluid burden.

Study Limitations

This study has several limitations that should be acknowledged. First, the retrospective design limits the ability to establish a causal relationship between fluid management strategy and clinical outcomes. Therefore, the findings of the present study should be interpreted as associations rather than evidence of causation. Although multivariable analyses were performed to adjust for illness severity and baseline renal function, residual confounding cannot be completely excluded. Second, the study was conducted in a single center with a relatively limited sample size, which may limit the generalizability of the findings to other ICU populations and clinical settings. Third, urine output data were not available for all patients. Therefore, AKI classification relied on the documented AKI assessments made by treating clinicians, who incorporated urine output measurements into their clinical evaluation. Finally, long-term renal outcomes and post-discharge mortality were not evaluated, and therefore

the potential impact of fluid strategy beyond ICU stay remains uncertain.

Conclusion

Omission of routine maintenance fluids and use of an individualized restrictive fluid strategy were associated with lower fluid exposure, reduced AKI incidence, and lower AKI severity in critically ill patients. Mortality was numerically lower in the restrictive period but did not reach statistical significance. These findings support minimizing unnecessary fluid administration as a potentially modifiable factor to improve renal outcomes in the ICU.

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