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Which Matters More: Intraoperative or Postoperative Fluid Balance? Insights From a Surgical ICU Cohort

Cerrahi Yoğun Bakım Hastalarında İntraoperatif ve Postoperatif Sıvı Dengesi: Hangisi Daha Önemli?

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Abstract

Background: Perioperative fluid management is a key component of surgical care, yet the relative impact of intraoperative versus postoperative fluid balance on intensive care unit (ICU) outcomes remains unclear. This study aimed to evaluate the effect of intraoperative, postoperative, and total perioperative fluid balance on major ICU outcomes in patients undergoing elective surgery.

Materials and Methods: This retrospective observational study included 570 adult patients who were admitted intubated to the ICU after elective surgery between January 1 and December 31, 2024. Fluid balance was calculated as a percentage of body weight and categorized into positive (≥5%) or negative-to-normal (<5%) for three time periods: intraoperative, postoperative, and cumulative perioperative. ICU outcomes included mechanical ventilation (MV) duration, ICU length of stay, and ICU mortality. Univariable regression analyses were performed, followed by multivariable logistic regression to identify independent predictors of ICU mortality.

Results: Positive fluid balance in all three timeframes was significantly associated with longer MV duration in unadjusted analyses. Postoperative and cumulative fluid overload were significantly associated with prolonged ICU stay (β=0.23, p=0.021 and β=0.11, p=0.014, respectively). Intraoperative fluid percentage showed a significant inverse association with ICU mortality (OR=0.71, p=0.039), whereas postoperative and cumulative balances were not. In multivariable analysis, SOFA and APACHE II scores and surgical duration were independently associated with ICU mortality. Additionally, total fluid percentage demonstrated a statistically significant inverse association with mortality (OR=0.65, p=0.006).

Conclusions: Postoperative positive fluid balance was the strongest predictor of adverse ICU outcomes, particularly prolonged ICU stay. Intraoperative positive fluid balance demonstrated an unexpected inverse relationship with mortality. These findings highlight the importance of targeted perioperative fluid stewardship and support the need for prospective studies to clarify causal relationships.

Keywords: Fluid therapy, Postoperative period, Intensive care units

Öz

Amaç: Perioperatif sıvı yönetimi, cerrahi bakımın temel bir bileşenidir. Ancak intraoperatif ve postoperatif sıvı dengesinin yoğun bakım ünitesi (YBÜ) sonuçları üzerindeki göreceli etkisi net değildir. Bu çalışmanın amacı, elektif cerrahi geçiren hastalarda intraoperatif, postoperatif ve toplam perioperatif sıvı dengesinin temel YBÜ sonuçları üzerindeki etkisini değerlendirmektir.

Materyal ve metod: Bu retrospektif gözlemsel çalışmaya, 1 Ocak-31 Aralık 2024 tarihleri arasında elektif cerrahi sonrası entübe şekilde YBÜ'ye kabul edilen 570 erişkin hasta dâhil edildi. Sıvı dengesi, vücut ağırlığının yüzdesi olarak hesaplandı ve üç zaman dilimi için (intraoperatif, postoperatif, toplam perioperatif) ≥%5 olanlar pozitif, <%5 olanlar negatif-normal olarak sınıflandırıldı. YBÜ sonuçları; mekanik ventilasyon süresi, YBÜ kalış süresi ve YBÜ mortalitesi olarak belirlendi. Tek değişkenli regresyon analizlerinin ardından, mortalitenin bağımsız belirleyicilerini saptamak için çok değişkenli lojistik regresyon kullanıldı.

Bulgular: Her üç dönemde de pozitif sıvı dengesi, ayarlanmamış analizlerde anlamlı şekilde daha uzun mekanik ventilasyon süresi ile ilişkiliydi. Postoperatif ve toplam sıvı yüklenmesi, YBÜ kalış süresi ile anlamlı ilişkili bulundu (sırasıyla; β=0,23, p=0,021 ve β=0,11, p=0,014). İntraoperatif sıvı oranı, YBÜ mortalitesi ile ters yönlü anlamlı ilişki gösterdi (OR=0,71, p=0,039), ancak postoperatif ve toplam sıvı dengeleri ile anlamlı ilişki bulunmadı. Çok değişkenli analizde SOFA ve APACHE II skorları ile cerrahi süresi mortalite ile bağımsız ilişkiliydi. Ayrıca, toplam sıvı oranı da mortalite ile istatistiksel olarak anlamlı düzeyde ters yönlü bir ilişki gösterdi (OR=0,65, p=0,006).

Sonuç: Pozitif postoperatif sıvı dengesi, özellikle uzamış YBÜ kalış süresi ile en güçlü ilişkili parametreydi. Pozitif intraoperatif sıvı dengesi ise beklenmedik şekilde düşük mortalite ile ilişkiliydi. Bu bulgular, hedefe yönelik perioperatif sıvı yönetiminin önemini vurgulamakta ve nedensel ilişkilerin açıklığa kavuşturulması için ileriye dönük çalışmalara ihtiyaç olduğunu göstermektedir.

Anahtar Kelimeler: Sıvı tedavisi, Postoperatif dönem, Yoğun bakım üniteleri

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Introduction

Perioperative fluid therapy remains a cornerstone of surgical care, yet its optimal management, particularly volume and timing, continues to be debated. Both liberal and restrictive strategies have been evaluated in randomized trials, with inconsistent findings across patient populations and surgical types (1-3). Liberal fluid administration has been associated with complications such as pulmonary edema, delayed wound healing, and prolonged hospitalization (4,5). Overly restrictive strategies, on the other hand, may result in tissue hypoperfusion, acute kidney injury (AKI), and increased mortality (6,7).

In the intensive care unit (ICU), the impact of perioperative fluid balance on critical outcomes such as mechanical ventilation (MV) duration, ICU length of stay, and mortality is particularly relevant. Positive fluid balance has been consistently linked to adverse outcomes in mixed ICU cohorts (8,9), and postoperative fluid overload is increasingly recognized as a modifiable risk factor (10).

In the existing literature, when evaluating the effects of fluid therapy in major surgeries, the focus is often limited to the intraoperative period. However, managing major surgical patients does not end in the operating room-it continues into the postoperative period, frequently in the ICU. Therefore, relying solely on intraoperative fluid data may not adequately capture the cumulative physiological impact of perioperative fluid shifts.

The present study was designed to address this gap by separately analyzing fluid balance in intraoperative and postoperative periods and cumulatively over the first 24 hours. We aimed to evaluate the association of intraoperative and postoperative fluid management with ICU outcomes, including MV duration, ICU length of stay, and mortality, in a cohort of postoperative surgical patients. Through this, we hypothesized that postoperative fluid balance plays an equally-if not more-important role than intraoperative fluid balance in determining patient trajectories during critical care.

Materials and Methods

This retrospective observational study was conducted in an adult ICU at a tertiary academic hospital. The ICU is a Ministry of Health-accredited Level III facility with 20 beds and a dedicated team of full-time intensivists, fellows, and certified intensive care nurses. This study was approved by the Ondokuz Mayıs University Clinical Research Ethics Committee (approval no: 2025/239; date: April 30, 2025), which also did not require informed consent due to the retrospective design.

Patients admitted to the ICU following elective surgical procedures were screened between January 1, 2024, and December 31, 2024. Inclusion criteria were: age ≥18 years, elective surgery, endotracheal intubation at the time of ICU admission, and availability of complete data regarding perioperative fluid balance and ICU outcomes. Exclusion criteria included: patients admitted to the ICU extubated, patients who underwent emergency or trauma-related surgery, and those with missing data. Among the 1,213 records reviewed, 570 patients met the inclusion criteria and were included in the analysis.

Data were extracted from the hospital's electronic health record system. Demographic variables included age, sex, and weight. Clinical parameters included American Society of Anesthesiologists (ASA) physical status classification, Glasgow Coma Scale (GCS) score at ICU admission, Sequential Organ Failure Assessment (SOFA) score, Acute Physiology and Chronic Health Evaluation II (APACHE II) score, and Charlson Comorbidity Index. Surgical characteristics included the anatomical type and duration of surgery.

Fluid balance was evaluated in three perioperative timeframes: intraoperative (from anesthesia induction to ICU transfer), postoperative (from ICU admission to the end of the first ICU day), and cumulative perioperative (covering the 24-hour period including the surgical procedure and postoperative ICU stay). Net fluid balance in each period was calculated and normalized to body weight (%). A threshold of 5% was used to define positive fluid balance, based on previous studies in surgical and critical care populations that associated a ≥5% increase in body weight due to fluid accumulation with adverse outcomes such as prolonged mechanical ventilation, organ dysfunction, and mortality (8,11). Each fluid parameter was analyzed as a continuous and a binary variable according to this threshold. Accordingly, patients were categorized as having either positive fluid balance (≥5%) or negative-to-normal fluid balance (<5%). Advanced hemodynamic or imaging-based monitoring tools (e.g., PiCCO, central venous pressure, or echocardiography) were not routinely used; fluid balance was assessed solely based on input-output charting recorded in the electronic medical records. Fluid input included all intravenous crystalloids, colloids, blood products, and drug solutions. Fluid output included urine and surgical drain output. All patients had an indwelling Foley catheter, and urine output was measured hourly in a standardized manner and documented in the electronic medical records.

Primary ICU outcomes included MV duration in minutes, ICU length of stay in days, and ICU mortality. Data on intraoperative and ICU vasopressor use were also recorded.

Statistical Analysis

Statistical analyses were performed using SPSS version 25.0 (IBM Corp., Armonk, NY, USA). Continuous variables were assessed for normality using the Shapiro-Wilk test and are presented as

mean ± standard deviation (SD) or median with interquartile range (IQR), as appropriate. Categorical variables are expressed as counts and percentages. Group comparisons between patients with positive and negative-to-normal fluid balance were conducted using the Mann-Whitney U test for continuous variables and the chi-square test for categorical variables.

Univariable linear regression was used to evaluate associations between intraoperative, postoperative, and cumulative perioperative fluid balance percentages and ICU length of stay or MV duration. Univariable logistic regression was applied to assess associations with ICU mortality. Additionally, multivariable logistic regression was performed to identify independent predictors of ICU mortality. Covariates included total fluid percentage, age, surgical duration, APACHE II score, SOFA score, Charlson Comorbidity Index, and surgical type. A stepwise selection method was used, and collinearity was assessed before model inclusion. A two-sided p-value <0.05 was considered statistically significant.

Results

A total of 570 postoperative ICU patients were included in the analysis. The median age was 65 years (IQR: 55-72), and 57.2% of the patients were female. The median body weight was 78 kg (IQR: 68-87). The mean Charlson Comorbidity Index was 4.8±2.7, and the mean ASA score was 2.6±0.7. The median admission GCS score was 15 (IQR: 15-15), the median SOFA score was 1 (IQR: 1-2), and the mean APACHE II score was 12.6±4.5. The median duration of surgery was 240 minutes (IQR: 180-300). Abdominopelvic (36.7%), neurosurgery (28.4%), and thoracic surgery (21.1%) were the most common procedures, followed by head and neck (7.9%) and extremity surgeries (6%).

The median intraoperative fluid balance was 1,750 mL (IQR: 1,000-2,900), while the median postoperative ICU fluid balance was 1,000 mL (IQR: 600-1,725). The cumulative perioperative fluid balance, covering the surgical procedure and postoperative ICU stay, was 2,900 mL (IQR: 2,080-4,295). When normalized to body weight and categorized, 14.4% of patients had positive intraoperative fluid balance, 2.1% had positive postoperative fluid balance, and 31.9% had positive cumulative perioperative fluid balance.

The median MV duration was 400 minutes (IQR: 300-555), the median ICU length of stay was 1 day (IQR: 1-1), and ICU mortality occurred in 3.2% of patients. Baseline demographic, clinical, and surgical characteristics are presented in Table 1.

ICU outcomes were compared to intraoperative, postoperative, and cumulative perioperative fluid balance categories. Patients with positive intraoperative fluid balance had significantly longer median MV duration compared to those with negative-to-normal balance (570 [500-690] min vs. 372 [300-510] min, p<0.001). In contrast, ICU length of stay and mortality did not differ significantly (both p>0.05). For postoperative fluid balance, patients with positive balance had markedly prolonged MV duration (630 [555-580] min vs. 395 [300-550] min, p<0.001) and longer ICU stay (2 [1-5] vs. 1 [1-1] days, p=0.013). ICU mortality was higher in the positive balance group (16.7% vs. 2.9%), although the difference did not reach statistical significance (p= 0.061). Regarding cumulative perioperative fluid balance, both MV duration and ICU stay were significantly higher in patients with positive balance compared to those with negative-to-normal balance (500 [362-618] vs. 360 [300-485] min, p<0.001; 1 [1-2] vs. 1 [1-1] days, p= 0.012, respectively). ICU mortality did not differ significantly between these groups (p=0.522). Details of these comparisons are summarized in Table 2.

Univariable regression models found no significant association between fluid balance and MV duration, regardless of the intraoperative, postoperative, or cumulative perioperative period. Postoperative and cumulative perioperative fluid percentages were significantly associated with longer ICU stay (β=0.23, 95% CI: 0.03-0.43, p=0.021 and β=0.11, 95% CI: 0.02-0.21, p=0.014, respectively). Intraoperative fluid percentage was not significantly associated with ICU length of stay (β=0.10, 95% CI: -0.01-0.21, p=0.087). A statistically significant inverse association was observed between intraoperative fluid percentage and ICU mortality (OR=0.71, 95% CI: 0.51-0.98, p=0.039), whereas postoperative and cumulative perioperative fluid balances showed no significant association with ICU mortality (p=0.442 and p=0.221, respectively). Complete results of these univariable regression models are presented in Table 3.

Multivariable regression models identified SOFA (OR=2.71, 95% CI: 1.87-3.93, p<0.001), APACHE II (OR=1.24, 95% CI: 1.07-1.45, p=0.005), and surgical duration (OR=1.007, 95% CI: 1.001-1.013, p=0.021) as independent predictors of ICU mortality. Total fluid percentage demonstrated a significant inverse association with mortality (OR=0.65, 95% CI: 0.48-0.88, p=0.006), suggesting a potential protective effect. Charlson index and age were not significantly associated with mortality (p=0.312 and p=0.917, respectively). Compared to the reference group (extremity and head and neck surgery), none of the major surgical types - abdominopelvic (OR=3.90, 95% CI: 0.40-37.53, p=0.239), neurosurgery (OR=0.53, 95% CI: 0.05-5.52, p=0.593), or thoracic surgery (OR=1.38, 95% CI: 0.08-22.84, p=0.820) - demonstrated a statistically significant difference in ICU mortality. Complete results of the multivariable model are presented in Table 4.

Table 1. Baseline characteristics of the study population	
Variable	**Value**
General patient characteristics	
Age (years), median (IQR)	65 (55-72)
Sex, female, n (%)	326 (57.2%)
Weight (kg), median (IQR)	78 (68-87)
Clinical Illness Severity Scores	
Charlson Comorbidity Index, mean ± SD	4.8±2.7
ASA Score, mean ± SD	2.6±0.7
Admission GCS, median (IQR)	15 (15-15)
SOFA Score, median (IQR)	1 (1-2)
APACHE II Score, mean ± SD	12.6±4.5
Surgical characteristics	
Duration of surgery (min), median (IQR)	240 (180-300)
Type of surgery, n (%)	
Neurosurgery	162 (28.4%)
Head and neck surgery	45 (7.9%)
Thoracic surgery	120 (21.1%)
Abdominopelvic surgery	209 (36.7%)
Extremity surgery	34 (6%)
Perioperative fluid balance	
Intraoperative (mL), median (IQR)	1,750 (1,000-2,900)
Negative-to-normal fluid balance, n (%)	488 (85.6%)
Positive fluid balance, n (%)	82 (14.4%)
Postoperative ICU (mL), median (IQR)	1,000 (600-1,725)
Negative-to-normal fluid balance, n (%)	558 (97.9%)
Positive fluid balance, n (%)	12 (2.1%)
Cumulative perioperative fluid balance (mL), median (IQR)	2,900 (2,080-4,295)
Negative-to-normal fluid balance, n (%)	388 (68.1%)
Positive fluid balance, n (%)	182 (31.9%)
ICU outcomes	
Mechanical ventilation duration (min), median (IQR)	400 (300-555)
ICU length of stay (days), median (IQR)	1 (1-1)
ICU mortality, n (%)	18 (3.2%)

Data are presented as mean ± SD, median (IQR), or number (percentage), as appropriate. Fluid balance was calculated as net input minus output (in mL) and normalized to body weight; values ≥5% were considered positive. Cumulative perioperative balance covers the 24 hours, including surgery and postoperative ICU stay.
ASA: American Society of Anesthesiologists, GCS: Glasgow Coma Scale, SOFA: Sequential Organ Failure Assessment, APACHE II: Acute Physiology and Chronic Health Evaluation II, ICU: Intensive care unit

Table 2. Comparison of ICU outcomes according to fluid balance in different periods						
Fluid group	**MV duration (median, IQR)**	**P-Value**	**ICU stay (median, IQR)**	**P-value**	**ICU mortality n (%)**	**P-value**
Intraoperative						
Negative-to-normal fluid balance (n=488)	372 (300-510)	**0.000**	1 (1-1)	0.589	16 (3.3%)	0.951
Positive fluid balance (n=82)	570 (500-690)		1 (1-1)		2 (2.4%)	

Table 2. Continued						
Postoperative ICU						
Negative-to-normal fluid balance (n=558)	395 (300-550)	**0.000**	1 (1-1)	**0.013**	16 (2.9%)	0.061
Positive fluid balance (n=12)	630 (555-580)		2 (1-5)		2 (16.7%)	
Cumulative perioperative fluid balance						
Negative-to-normal fluid balance (n=388)	360 (300-485)	**0.000**	1 (1-1)	**0.012**	14 (3.6%)	0.522
Positive fluid balance (n=182)	500 (362-618)		1 (1-2)		4 (2.2%)	

Data are presented as median (IQR) for continuous variables and number (percentage) for categorical variables. Mechanical ventilation (MV) duration is expressed in minutes, and ICU length of stay is expressed in days. P-values reflect comparisons between fluid balance groups using Mann-Whitney U or chi-square tests. Fluid balance was calculated as net input minus output (in mL) and normalized to body weight; values ≥5% were defined as positive. Cumulative perioperative balance covers the 24 hours, including surgery and postoperative ICU stay.
ICU: Intensive care unit, MV: Mechanical ventilation

Table 3. Association between fluid balance and ICU outcomes				
Fluid group	**Outcume**	**Effect (95% CI)**	**P-Value**	**Model fit**
Intraoperative fluid balance ratio	MV duration (min)	-15.0 (-72.8-42.8)	0.61	R^2=0.0
	ICU stay (days)	0.1 (-0.01-0.21)	0.087	R^2=0.01
	ICU mortality	0.71 (0.51-0.98)	**0.039**	AIC=158.1
Postoperative fluid balance ratio	MV duration (min)	73.94 (-27.74-175.62)	0.154	R^2=0.0
	ICU stay (days)	0.23 (0.03-0.43)	**0.021**	R^2=0.01
	ICU mortality	1.11 (0.85-1.44)	0.442	AIC=163.3
Cumulative perioperative fluid balance	MV duration (min)	5.8 (-41.09-52.68)	0.808	R^2=0.0
	ICU stay (days)	0.11 (0.02-0.21)	**0.014**	R^2=0.01
	ICU mortality	0.88 (0.72-1.08)	0.221	AIC=162.0

Each fluid parameter, calculated as net fluid balance normalized to body weight, was evaluated using univariable regression. Results are presented as odds ratios (ORs) for mortality and beta coefficients (β) for continuous outcomes, with 95% confidence intervals. Cumulative perioperative balance refers to the total fluid balance over the 24 hours encompassing the surgical procedure and postoperative ICU stay.
ICU: Intensive care unit, MV: Mechanical ventilation, OR: Odds ratio, CI: Confidence interval

Table 4. Multivariable regression analysis of ICU mortality			
Variable	**OR**	**%95 CI**	**P-value**
Total fluid balance ratio	0.652	0.480-0.884	**0.006**
Surgical duration	1.007	1.001-1.013	**0.021**
Age	0.997	0.936-1.062	0.917
APACHE II Score	1.243	1.069-1.445	**0.005**
SOFA Score	2.711	1.871-3.928	**<0.001**
Charlson Comorbidity Index	0.851	0.622-1.164	0.312
Abdominopelvic surgery	3.896	0.404-37.527	0.239
Neurosurgery	0.527	0.050-5.515	0.593
Thoracic surgery	1.384	0.084-22.840	0.820

Results are presented as odds ratios (ORs) with 95% confidence intervals (CIs) from multivariable logistic regression analysis. Variables included fluid balance, surgical and clinical characteristics, and type of surgery. The reference group for surgical comparison was combined head and neck and extremity procedures.
OR: Odds ratio, CI: Confidence interval

Discussion

Perioperative fluid management plays a pivotal role in postoperative recovery and has been associated with a range of outcomes, including respiratory complications, prolonged ICU stay, and mortality (8,9). However, the relative impact of intraoperative versus postoperative fluid administration on ICU course remains a subject of ongoing investigation. This study examined the independent relationships of fluid balance in three critical periods (intraoperative, postoperative, and cumulative perioperative) with key ICU outcomes.

In unadjusted comparisons, positive fluid balance was associated with prolonged MV duration in all time frames. Postoperative and cumulative perioperative fluid overload were associated with significantly longer MV durations. However, regression analysis revealed no statistically significant association between fluid percentages and MV duration, suggesting that this relationship may be mediated by other clinical variables such as pre-existing respiratory function or surgical complexity. These findings mirror previous reports in mixed ICU populations where fluid overload was linked to delayed extubation but failed to remain significant after adjustment (10,12). In contrast, studies in cardiac surgery and sepsis cohorts have shown that fluid excess impairs pulmonary mechanics and prolongs ventilation time (13,14). These findings suggest that while fluid overload may contribute to respiratory compromise, it is not a sole determinant of ventilation duration and is likely influenced by other perioperative factors.

Postoperative fluid balance showed the strongest and most consistent association with ICU length of stay. Patients with postoperative fluid overload had significantly longer ICU stays, and this relationship persisted in regression models. These findings support the hypothesis that fluid overload, particularly in the postoperative period, contributes to endothelial dysfunction, tissue edema, and delayed recovery (15,16). Previous studies have identified positive fluid balance as an independent risk factor for prolonged ICU stay in various surgical and critically ill populations (17,18). Interestingly, cumulative perioperative fluid balance also demonstrated a significant association, although slightly weaker, suggesting that the early postoperative period may represent the most critical window for fluid optimization (19).

An inverse association between intraoperative fluid percentage and ICU mortality was observed, which contrasts with prior studies suggesting that liberal fluid therapy may increase mortality risk (16). This unexpected finding may be explained by reverse causation, as critically ill patients may have received less fluid due to hemodynamic instability or intentionally restrictive intraoperative strategies (20). Alternatively, patients who received higher intraoperative volumes may have achieved better hemodynamic stability and organ perfusion, potentially reducing the risk of AKI, a known contributor to ICU mortality (17,18). Similar protective effects have been reported in settings utilizing goal-directed intraoperative resuscitation to minimize hypoperfusion-related complications (21).

In the multivariable model, SOFA and APACHE II scores were independently associated with increased ICU mortality, underscoring the established prognostic value of organ dysfunction and physiological derangement in postoperative ICU patients (22). Surgical duration also emerged as an independent risk factor, potentially reflecting the impact of procedural complexity and prolonged anesthetic exposure. Interestingly, total fluid percentage retained a statistically significant inverse association with ICU mortality. Although counterintuitive, this finding is consistent with studies supporting the protective effect of goal-directed intraoperative resuscitation on organ perfusion and renal outcomes (1,13). Possible explanations include reverse causality, confounding by indication, or the benefits of hemodynamic optimization in selected surgical populations (4). Notably, surgical type (abdominopelvic, thoracic, neurosurgery) did not significantly affect ICU mortality when compared to extremity and head and neck procedures, suggesting that anatomical site alone may be less relevant than perioperative physiological burden or resuscitative strategy (1,4).

A key strength of this study is the comprehensive evaluation of fluid balance across three distinct perioperative periods, analyzed using both categorical and continuous approaches. Including ICU-specific outcomes, such as MV duration and ICU length of stay, further enhances its clinical applicability. Nonetheless, several limitations must be considered-first, the retrospective design limits causal inference. Second, intraoperative fluid administration was not stratified by fluid type (e.g., crystalloids vs. colloids), which may have influenced outcomes differently (3). Third, including a heterogeneous surgical population, including thoracic, abdominal, and neurosurgical procedures, may have introduced variability in fluid requirements and postoperative trajectories. Additionally, patients' preoperative fluid status at the time of operating room admission could not be assessed. As perioperative fluid therapy encompasses the pre-, intra-, and postoperative phases, the absence of preoperative data may limit the comprehensive interpretation of cumulative fluid balance. Fourth, advanced hemodynamic or imaging-based monitoring methods (e.g., PiCCO, central venous pressure, echocardiography) were not routinely used, which may have provided additional physiological insights beyond net input-output calculations. Moreover, relevant confounders such as surgical complexity, blood loss, and vasopressor use could not be fully accounted for. Lastly, the relatively low number of mortality events (n=18) may have limited the statistical power of the multivariable model, particularly for categorical variables such as surgical type.

Despite these limitations, among the three perioperative periods evaluated, postoperative fluid balance was most consistently associated with adverse ICU outcomes, particularly prolonged ICU stay. Intraoperative fluid balance showed a statistically significant but counterintuitive inverse association with ICU mortality, which warrants further exploration. These findings underscore the importance of fluid stewardship during and after surgery, especially in the early postoperative period. Future prospective studies with standardized fluid protocols-stratified by surgical type and patient risk profile-are needed to clarify the causal impact of perioperative fluid strategies on ICU outcomes. Additionally, investigating the underlying mechanisms linking fluid balance to organ dysfunction, acute kidney injury, and mortality may help identify actionable targets for clinical intervention.

Conclusion

In this retrospective study of elective surgical patients admitted to the intensive care unit, postoperative fluid balance emerged as the strongest predictor of adverse ICU outcomes, particularly prolonged ICU stay. However, intraoperative fluid balance demonstrated an inverse association with mortality; this unexpected finding warrants cautious interpretation and further investigation. Our results underscore the importance of considering intraoperative and early postoperative fluid management as a critical component of perioperative care. Future prospective studies using standardized fluid protocols are needed to validate these findings and guide fluid stewardship in surgical ICU care.

Ethical Approval: *This study was approved by the Ondokuz Mayıs University Clinical Research Ethics Committee (approval no: 2025/239; date: April 30, 2025).*

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