Liu Jingmei
Department of Nephrology, Tangshan Vocational and Technical College Affiliated Hospital, Tangshan City, China

Predictive Analysis of the Mortality Rate of Patients with Heart Failure Complicated by Acute Kidney Failure Based on the Fluid Balance: A Retrospective Study Using the MIMIC-IV Database

Background Heart failure (HF) is a global health issue, and its complication with acute kidney failure (AKF) increases the risk of mortality. This study aimed to investigate the predictive value of fluid balance for mortality in patients with HF complicated by AKF. A retrospective analysis was performed using the MIMIC–IV database to evaluate the relationship between fluid balance and mortality in patients with HF complicated by AKF.

Material and methods Adult patients with HF and AKF and who were listed in the MIMIC–IV database between 2008 and 2019 were included. The patients were divided into survival and non-survival groups. The primary outcome measure was fluid intake and output in the first three days in the intensive care unit (ICU). The main outcome being in-ICU mortality and the secondary outcome being 28-day mortality after ICU admission. A multivariable Cox proportional hazards model was used to assess the relationship between fluid balance and the risk of death, after adjusting for potential confounding factors.

Results A total of 1433 eligible patients were included. The study found that compared to the death group, patients in the survival group maintained lower positive balance on day 1 (453.51 ml vs 1813.66 ml), negative balance on day 2 (–246.75 ml vs 646.00 ml), and negative balance on day 3 (–350.21 ml vs 312.92 ml). Additionally, fluid balance on the first day predicted ICU mortality rate (AUC 0.658, $p<0.01$), on the second day it predicted ICU mortality rate (AUC 0.654, $p<0.01$), and on the third day it also predicted ICU mortality rate (AUC 0.634, $p<0.01$).

Conclusion Positive fluid balance in patients with HF and AKF is independently associated with higher in-hospital mortality. Monitoring and managing fluid balance may provide clinicians with an important tool to improve patient outcomes.

Keywords Heart failure; acute kidney failure; fluid balance; mortality rate; prediction model

For citations Liu Jingmei. Predictive Analysis of the Mortality Rate of Patients with Heart Failure Complicated by Acute Kidney Failure Based on the Fluid Balance: A Retrospective Study Using the MIMIC-IV Database. Kardiologiia. 2025;65(1):20–26. [Russian: Лю Цзинмэй. Прогнозирование смертности пациентов с сердечной недостаточностью, осложненной острой почечной недостаточностью, на основе баланса жидкости: ретроспективное исследование с использованием базы данных MIMIC-IV. Кардиология. 2025;65(1):20–26].

Corresponding author Liu Jingmei. E-mail: 26967808@qq.com

Introduction

Heart failure (HF) is a major health challenge globally. The high incidence and mortality rate of HF posing a huge burden on the societal healthcare system [1–3]. Acute kidney failure (AKF) is a frequent complication of HF, and it further exacerbates the patient's clinical condition, leading to a worsened prognosis. The interaction between cardiac and renal function is complex, and their combined failure increases the difficulty of treatment and also imposes higher demands on the clinical management of the patient [4–6].

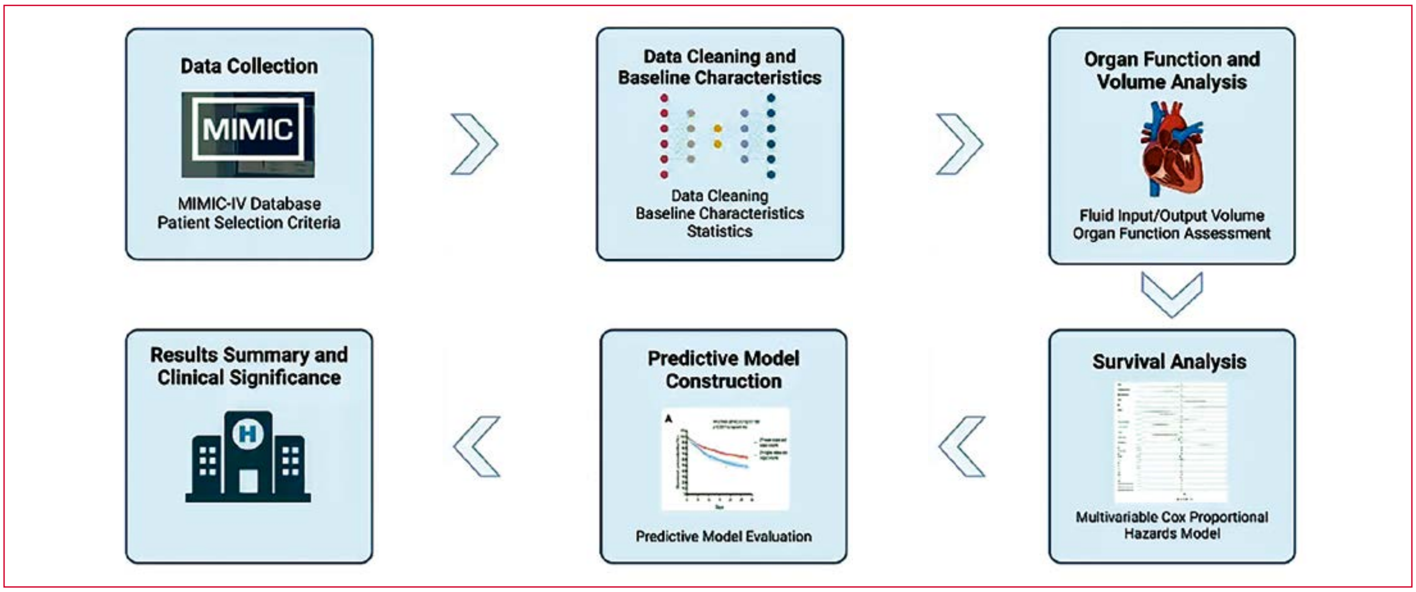
In clinical practice, fluid management is a key component of the treatment of HF patients [7–9]. Inappropriate management of fluid balance can lead to hemodynamic instability, thereby affecting the functions of both the heart and kidneys. Although studies have shown a correlation between fluid overload and adverse outcomes in HF failure patients, there is still a lack of in-depth exploration regarding the predictive value of fluid balance on the mortality rates of HF patients with concomitant AKF.

With the rapid development of medical information technology, large clinical databases provide abundant resources for clinical research [9–11]. The Medical Information Mart for Intensive Care IV (MIMIC–IV) database is an open, detailed database centered on intensive care unit (ICU) patients that offers researchers a unique opportunity to assess and analyze clinical interventions and outcomes [12–14].

By utilizing clinical data from the MIMIC–IV database, this study aimed to retrospectively analyze the fluid balance status of HF patients with concomitant AKF. The relationship of the fluid balance status with ICU mortality rates and with mortality rates within 28 days after ICU discharge was explored. We hypothesized that fluid balance status can predict the

 ISSN 0022-9040. Кардиология. 2025;65(1). DOI: 10.18087/cardio.2025.1.n2718

Central illustration. Predictive Analysis of the Mortality Rate of Patients with Heart Failure Complicated by Acute Kidney Failure Based on the Fluid Balance: A Retrospective Study Using the MIMIC-IV Database



mortality risk of HF patients with concomitant AKF. Thus, accurate monitoring and management of fluid balance is an important tool in predicting the mortality risk of patients, and it is vital for providing personalized guidance of clinical treatment.

Through an in-depth analysis of the relationship between fluid balance and patient mortality rates, this study aimed to provide scientific evidence for the clinical fluid management of HF patients with concomitant AKF, thereby improving the clinical prognosis and reducing mortality rates. This has important clinical significance and social value by optimizing the allocation of clinical resources and by enhancing the quality of intensive care.

Material and methods

Study Design and Data Source

This was a retrospective cohort study of data sourced from the MIMIC–IV database, a publicly accessible database containing a large amount of clinical data from intensive care unit (ICU) patients [15].

Study Population

A total of 1433 eligible patients were included. The inclusion criteria comprised individuals with a diagnosis of HF and AKF as described in the MIMIC–IV database. These patients were ≥18 yrs old and had been admitted to the ICU for the first time. Patients with incomplete data or obvious data entry errors were excluded. Patient information collected included demographics, comorbidities, vital signs, laboratory results, medication use, fluid balance data (including fluid intake and output), and other clinically relevant data. Patients were categorized into survival and non-survival groups based on their mortality during their ICU stay. The primary outcome measure was ICU mortality rate, and the secondary outcome measure was mortality rate within 28 days post-ICU discharge. For this study, fluid balance was defined as the difference between daily fluid intake and output during the first 72 hrs in the ICU.

Statistical Analysis

Continuous variables were presented as mean ± SD or median (Interquartile range) according to data distribution, whereas categorical variables were expressed as proportions. The Kolmogorov-Smimov test was employed to evaluate the normality of continuous parameters. The analysis of continuous variables was performed using t-test or ANOVA if they presented a normal distribution and using Mann–Whitney U-test or Kruskal–Wallis test if they were non-normal distribution. A multivariable Cox proportional hazards model was constructed to assess the relationship between fluid balance and mortality risk [16], adjusting for potential confounders such as age, sex, comorbidities, the Acute Physiology and Chronic Health Evaluation II (APACHE II) score, and the Sequential Organ Failure Assessment (SOFA) score. In survival analysis, Kaplan-Meier curves are used to evaluate the survival probability of patients in different fluid balance states, and the Log-rank test was used to compare survival differences between groups. Receiver Operating Characteristic (ROC) curve analysis was conducted to evaluate the predictive value of fluid balance for ICU mortality. The Area Under the Curve (AUC) and the Youden index were used to determine the optimal cutoff point.

Results

A total of 1433 critically ill patients with HF complicated by AKF were included in this study. The median age of the included patients was 80.5 yrs (interquartile range:

70–87 yrs), with 777 (54.2%) being male. Based on ICU mortality, the patients were divided into survival n=1122 and non-survival groups n=311). Compared to the survival group, the non-survival group showed no statistical differences in terms of gender, age, diabetes, and other comorbidities. The non-survival group had a higher incidence of heart attacks (59, 19%) compared to the survival group (125, 11%). In terms of vital signs, the non-survival group had a higher respiratory rate (21 units/min vs 19 units/min), and in terms of blood tests, they had higher white blood cell (WBC) counts (12.5 (K/ul) vs 9.7 (K/ul), poorer liver and kidney function, blood gas values, higher SOFA scores, mechanical assist rates, and higher positive fluid balance. For details, refer to Tables 1 and 2.

Primary outcomes

We used Kaplan–Meier survival analysis curves to analyze the occurrence rates of major outcomes in each

Table 1. Baseline patients' characteristics and outcomes

Characteristics	Total (n=1433)	Survivors (n=1122)	No-survivors (n=311)	p value
Age (yrs)	80 (70, 87)	80.5 (70, 87)	78 (70, 85)	0.008
Gender				0.884
male	777 (54.2)	610 (54.4)	167 (53.7)	-
female	656 (45.8)	512 (45.6)	144 (46.3)	-
Comorbities				
Hypertension	351 (24.5)	284 (25.3)	67 (21.5)	0.196
Type 1 diabetes mellitus	22 (1.5)	20 (8)	2 (0.6)	0.236
Type 2 diabetes mellitus	604 (42.1)	485 (43.2)	119 (38.3)	0.133
Myocardial infarction	184 (12.8)	125 (11.1)	59 (19)	<0.001
Malignant tumor	319 (22.3)	258 (23)	61 (19.6)	0.234
Chronic kidney diseases	626 (43.7)	493 (43.9)	133 (42.8)	0.761
Cirrhosis	79 (5.5)	61 (5.4)	18 (5.8)	0.921
Tuberculosis	31 (2.2)	26 (2.3)	5 (1.6)	0.589
Pneumonia	569 (39.7)	430 (38.3)	139 (44.7)	0.049
Stroke	165 (11.5)	134 (11.9)	31 (10)	0.387
Hyperlipidemia	617 (43.1)	491 (43.8)	126 (40.5)	0.338
COPD	193 (13.5)	148 (13.2)	45 (14.5)	0.624
Hepatitis	34 (2.4)	25 (2.2)	9 (2.9)	0.637
Hypothyroid-ism	283 (19.7)	226 (20.1)	57 (18.3)	0.528
Vital Signs				
Heart rate (bpm)	86 (74, 101)	86 (74, 101)	88 (77, 103)	0.027
Respiratory rate (insp/min)	20 (16, 24)	19 (16, 24)	21 (17, 25)	<0.001
MAP (mmHg)	77 (66, 90)	78 (67, 91)	73 (63, 88)	0.002
SpO_2 (%)	97 (94, 100)	97 (95, 100)	97 (94, 100)	0.472
Temperature (°C)	36.61 (36.33, 36.94)	36.67 (36.39, 36.94)	36.56 (36.11, 36.94)	0.021
Blood test results				
WBC (K/ul)	10.1 (7.35, 14.5)	9.7 (7.1, 13.6)	12.5 (8.4, 17.1)	<0.001
Platelet count (K/ul)	191 (138, 254)	194 (138, 256)	186 (135, 246)	0.117
Hemoglobin (g/dl)	9.9 (8.6, 11.4)	9.9 (8.6, 11.4)	10 (8.5, 11.3)	0.951
RDW (%)	15.8 (14.5, 17.5)	15.76 (14.6, 17.4)	16 (14.5, 18)	0.513
Albumin (g/dl)	3 (2.62, 3.4)	3.01 (2.67, 3.43)	2.9 (2.54, 3.4)	0.013
Sodium (meq/l)	138 (135, 141)	139 (135, 141)	138 (134, 141)	0.147
Potassium (meq/l)	4.2 (3.8, 4.7)	4.2 (3.8, 4.7)	4.3 (3.9, 4.9)	0.003
Calcium, total (mg/dl)	8.4 (8.0, 8.9)	8.5 (8.0, 8.9)	8.4 (7.8, 8.9)	0.131
Chloride (mg/dl)	102 (97, 106)	102 (98, 106)	101 (96, 106)	0.143
Glucose (mg/dl)	128 (103, 174)	126.5 (102, 168)	137 (107, 192)	0.003
Aniongap (meq/l)	15 (13, 18)	15 (13, 18)	17 (14, 20)	<0.001

COPD, chronic obstructive pulmonary disease; MAP, mean arterial pressure;
SpO_2, hemoglobin oxygen saturation; WBC, white blood cell; RDW, red cell distribution width.

ISSN 0022-9040. Кардиология. 2025;65(1). DOI: 10.18087/cardio.2025.1.n2718

Table 2. Organ function and input/output volume

Characteristics	Total (n=1433)	Survivors (n=1122)	No-survivors (n=311)	p value
pH	7.38 (7.31, 7.43)	7.39 (7.32, 7.44)	7.34 (7.26, 7.42)	<0.001
pCO_2 (mmHg)	42 (36, 51)	42 (36, 51)	42 (36, 52)	0.53
pO_2 (mmHg)	85 (46, 164)	87 (46, 164)	79 (47, 160)	0.822
Lactate(mmol/dl)	1.72 (1.2, 2.9)	1.7 (1.1, 2.7)	2.1 (1.3, 3.7)	<0.001
Respiratory rate (units/min)	1.4 (1.2, 1.9)	1.4 (1.2, 1.9)	1.5 (1.2, 1.9)	0.112
Urea nitrogen (mg/dl)	34 (21, 54)	32 (21, 52.25)	39 (25, 60)	0.001
Creatinine units	1.4 (1, 2.4)	1.4 (1.0, 2.3)	1.7 (1.1, 2.7)	<0.001
CK (IU/)	313 (194, 621)	90.5(23, 794)	223 (42, 1339)	<0.001
CK-MB (ng/ml)	6 (2, 23)	5 (2, 20)	10 (3, 34)	<0.001
Troponin (ng/ml)	0.15 (0.02, 1.01)	0.14 (0.02, 0.97)	0.2 (0.03, 1.33)	0.059
PTT (sec)	33.4 (28.4, 42.5)	33 (28.3, 41.2)	35 (29, 49)	0.001
ALT (IU/l)	27 (13, 81.5)	24.8 (12.0, 67.6)	39 (19, 116)	<0.001
AST (IU/l)	38 (19, 127)	35 (18, 100)	58 (25, 227)	<0.001
LD (IU/l)	313 (194, 621)	287(181.97, 551)	411 (256, 844)	<0.001
ICU scoring systems				
SOFA	5 (3,8)	5 (3,7)	8 (5,12)	<0.001
APS III	51 (41,65)	48 (39,59)	67 (52,84)	<0.001
SAPS II	42 (35,50)	40 (34,48)	50 (40,62)	<0.001
OASIS	34 (28,40)	32 (27,38)	40 (35,46)	<0.001
AKF				<0.001
No	273 (19.1)	258 (23)	15 (4.8)	
Yes	1160 (80.9)	864 (77)	296 (95.2)	
AKF-stage				<0.001
0	273 (19.1)	258 (23)	15 (4.8)	
1	248 (17.3)	223 (19.9)	25 (8)	
2	494 (34.5)	405 (36.1)	89 (28.6)	
3	418 (29.2)	236 (21)	182 (58.5)	
CRRT	122 (8.5)	52 (4.6)	70 (22.5)	<0.001
Sepsis				<0.001
No	571 (39.8)	509 (45.4)	62 (19.9)	
Yes	862 (60.2)	613 (54.6)	249 (80.1)	
No invasive ventilation	1058 (73.8)	877 (78.2)	181 (58.2)	<0.001
Invasive ventilation	493 (34.4)	284 (25.3)	209 (67.2)	<0.001
Antibiotics	1166 (81.4)	894 (79.7)	272 (87.5)	0.002
Antihypertensive drugs	1184 (82.6)	945 (84.2)	239 (76.8)	0.003
Vasoactive drugs	622 (43.4)	371 (33.1)	251 (80.7)	<0.001
Intake and output volume (ml)				
Day 1	625 (-692, 2504)	453 (-872, 2065)	1813 (158, 4508)	<0.001
Day 2	-104(-1164,964)	-246(-289,698)	646 (-31, 2140)	<0.001
Day 3	-212(-1233, 827)	-350 (1395, 614)	312 (-79, 1981)	<0.001

ALT, alanine transaminase; AKI, acute kidney injury; aminotransferase; PPT, partial thromboplastin time; CK, creatinine kinase; LD, lactate dehydrogenase; SOFA, Sequential Organ Failure Assessment; APS III, Acute Physiology Score III; SAPS II, Simplified Acute Physiology Score II; OASIS, Oxford Acute Severity Of Illness Score; AKF, acute kidney failure, diagnosis standard and classification standard in line with the KDIGO clinical practice guidelines; CRRT, continuous renal replacement therapy.

group based on fluid balance, as shown in Figures 1 and 2. Patients with positive fluid balance in the first three days and higher CM–MB values had a higher risk of hospitalization and intensive care unit mortality (log- p rank = 0.03, 0.009). We used ROC analysis to evaluate the clinical efficacy of fluid balance in the first three days. However, the AUC for fluid balance was not optimal (AUC for ICU mortality: 0.658, p=0.004, Figure 3A-3F). The cutoff values for fluid balance

Figure 1. Logistic forest map of the relationship between multiple factors and total ICU mortality

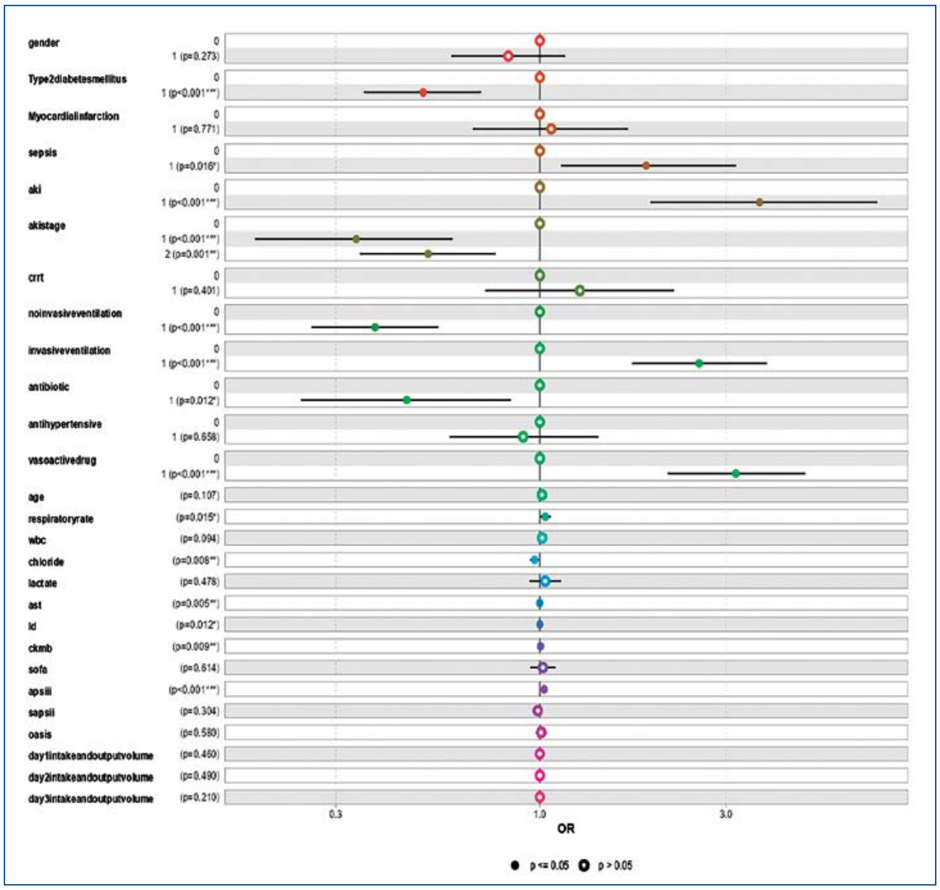
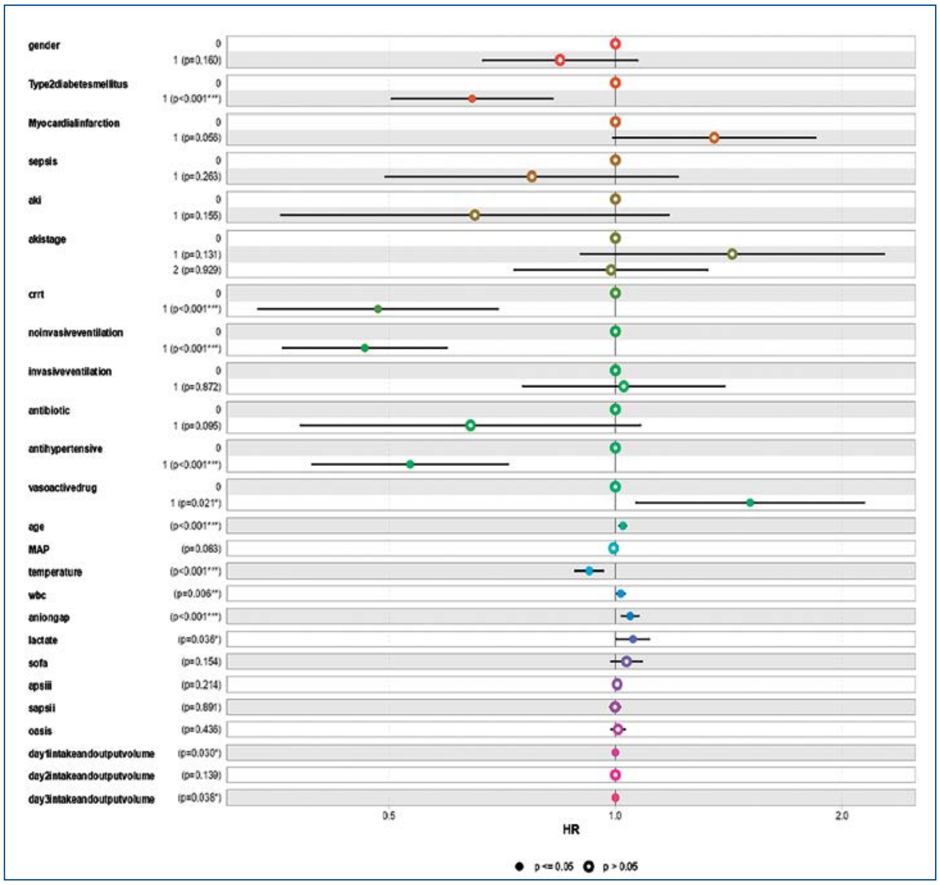


Figure 2. Cox forest map of the relationship between multiple factors and total ICU mortality



from day 1 to day 3 were 1202, 139.5, and 100.36 ml, respectively. Values above these indicate a positive balance for predicting total ICU mortality.

Discussion

This study explored the relationship between fluid balance and mortality rates in patients with HF and ARF by conducting a retrospective analysis of data from the MIMIC–IV database. The findings indicate that positive fluid balance is independently associated with in-hospital mortality in patients with HF and AKF, providing a new perspective for clinical fluid management.

This study revealed significant differences in fluid balance between the survival and mortality groups in the first three days in the ICU. The survival group maintained lower positive fluid balance on the first day and negative fluid balance on the second and third days. This suggests that fluid accumulation may be associated with adverse clinical outcomes in critically ill patients with HF and AKF. This finding aligns with previous research linking fluid overload to high mortality rates in heart failure patients.

Effective fluid balance management is particularly crucial for patients with heart and kidney failure. The study emphasizes the importance of actively monitoring and adjusting fluid balance to reduce the risk of death in these patients [17–19]. Timely identification and correction of fluid accumulation may help improve the patient's hemodynamic status and alleviate the burden on the heart and kidneys.

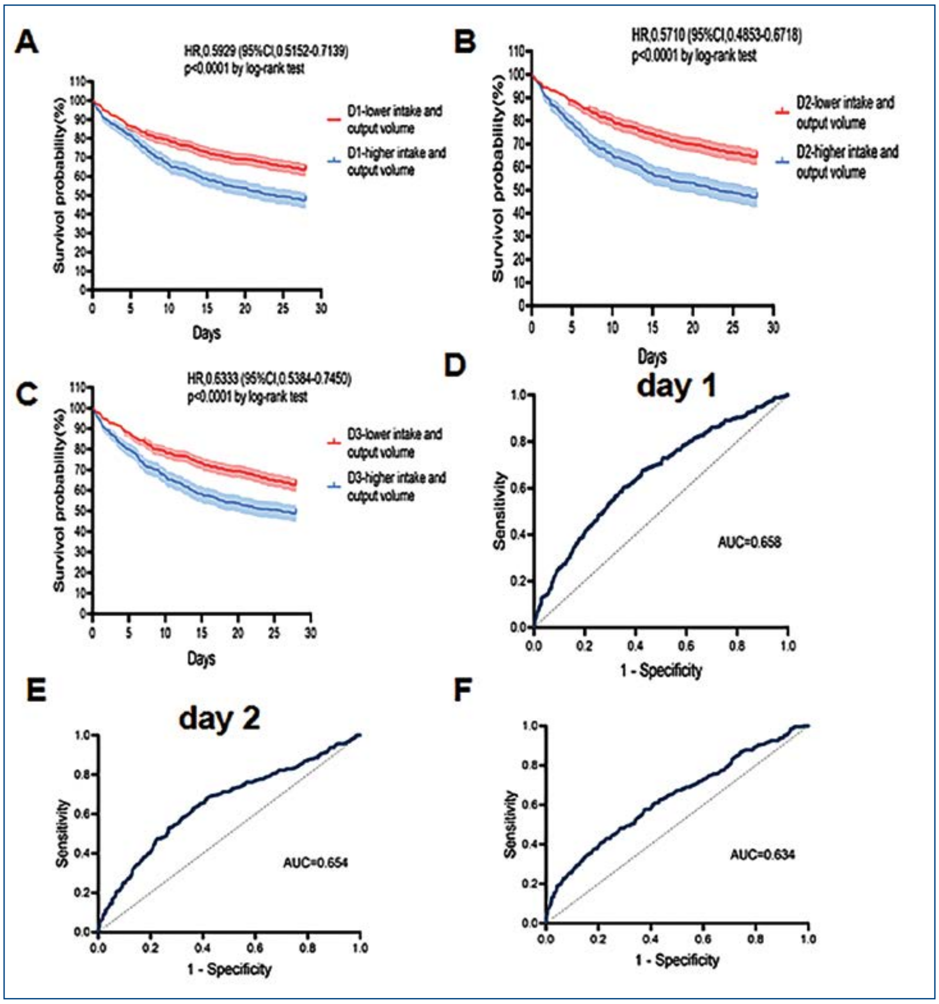
Additionally, the study finds that fluid balance in the early stages of ICU admission has predictive value for patient mortality. ROC curve analysis demonstrates that fluid balance on the first day moderately predicts ICU mortality risk (AUC 0.658), offering potential for early risk assessment. Calculation of the Youden

ISSN 0022-9040. Кардиология. 2025;65(1). DOI: 10.18087/cardio.2025.1.n2718

index suggests that setting appropriate thresholds can enhance prediction specificity and sensitivity. To assess the independent relationship between fluid balance and mortality risk, a multivariate Cox proportional hazards model was utilized, adjusting for potential confounders. By controlling the influence of other variables, this approach more accurately estimated the impact of fluid balance on mortality rates.

Despite providing valuable insights, the study has limitations. As a retrospective study, there may be selection bias and information bias. Moreover, while the MIMIC–IV database is comprehensive, these data may not be fully representative of all patients with HF heart and AKF. Furthermore, only fluid balance in the early stages of ICU admission was considered. The importance of long-term fluid management was not considered. Future research should further explore the relationship between fluid balance and other clinical outcomes such as long-term survival rates, quality of life, and healthcare resource utilization. Prospective studies could verify the findings of this research and explore strategies for more personalized fluid management.

Figure 3. Diagnostic value and survival analysis of intake and output volume in 28-day ICU mortality rate



Conclusion

In conclusion, this study underscores the importance of monitoring and managing fluid balance in patients with HF and AKF. With precise monitoring of fluid balance, clinicians can better assess the patient's risk of mortality and can implement appropriate interventions to improve patient outcomes.

No conflict of interest is reported.

The article was received on 20/06/2024

REFERENCES

1. Berger JH, Shi Y, Matsuura TR, Batmanov K, Chen X, Tam K et al. Two-hit mouse model of heart failure with preserved ejection fraction combining diet-induced obesity and renin-mediated hypertension. bioRxiv. [DOI: 10.1101/2024.06.06.597821]. 2024. [Preprint]
2. Ciliberti P, Chinali M, Capelli C. Editorial: Ventricular mechanics in congenital heart disease and pediatric cardiology. Frontiers in Pediatrics. 2024;12:1433819. DOI: 10.3389/fped.2024.1433819
3. Rivera Boadla ME, Sharma NR, Khan MH, Khurana S, Gulati A, Tan S et al. Cancer as an Individual Risk Factor for Heart Failure: A Review of Literature. Cureus. 2024;16(5):e60592. DOI: 10.7759/cureus.60592
4. Pan T, Liu F, Hao X, Wang S, Wasi M, Song JH et al. BIGH3 mediates apoptosis and gap junction failure in osteocytes during renal cell carcinoma bone metastasis progression. Cancer Letters. 2024;596:217009. DOI: 10.1016/j.canlet.2024.217009
5. Rizwanullah, Ahmadi T, Ahmad A, Khan W, Rosario-Curcio JC. Euglycemic Diabetic Ketoacidosis With Acute Renal Failure: A Challenging Case for Clinicians. Cureus. 2024;16(5):e60171. DOI: 10.7759/cureus.60171
6. Yang X, Jin J, Cheng M, Xu J, Bai Y. The role of sacubitril/valsartan in abnormal renal function patients combined with heart failure: a meta-analysis and systematic analysis. Renal Failure. 2024;46(1):2349135. DOI: 10.1080/0886022X.2024.2349135
7. Caton JB, Jimenez S, Wang SX. Things We Do for No ReasonTM: Fluid Restriction for the Management of Acute Decompensated Heart Failure in Patients With Reduced Ejection Fraction. Journal of Hospital Medicine. 2021;16(12):754–6. DOI: 10.12788/jhm.3639
8. Gologorsky RC, Roy S. Ultrafiltration for management of fluid overload in patients with heart failure. Artificial Organs. 2020;44(2):129–39. DOI: 10.1111/aor.13549

9. Stickel S, Gin-Sing W, Wagenaar M, Gibbs JSR. The practical management of fluid retention in adults with right heart failure due to pulmonary arterial hypertension. European Heart Journal Supplements. 2019;21(Suppl K):K46–53. DOI: 10.1093/eurheartj/suz207
10. Narasimhan B, Aravinthkumar R, Correa A, Aronow WS. Pharmacotherapeutic principles of fluid management in heart failure. Expert Opinion on Pharmacotherapy. 2021;22(5):595–610. DOI: 10.1080/14656566.2020.1850694
11. Vidanapathirana M. Dengue haemorrhagic fever in chronic kidney disease and heart failure: challenges in fluid management. Tropical Medicine and Health. 2024;52(1):33. DOI: 10.1186/s41182-024-00600-9
12. Ding H, Li X, Zhang X, Li J, Li Q. The association of a frailty index derived from laboratory tests and vital signs with clinical outcomes in critical care patients with septic shock: a retrospective study based on the MIMIC-IV database. BMC Infectious Diseases. 2024;24(1):573. DOI: 10.1186/s12879-024-09430-w
13. Li X, Yue W. Comparative analysis of dexmedetomidine, midazolam, and propofol impact on epilepsy-related mortality in the ICU: insights from the MIMIC-IV database. BMC Neurology. 2024;24(1):193. DOI: 10.1186/s12883-024-03693-1
14. Su D, Wang F, Yang Y, Zhu Y, Wang T, Zheng K et al. The association between frailty and in-hospital mortality in critically ill patients with congestive heart failure: results from MIMIC-IV database. Frontiers in Cardiovascular Medicine. 2024;11:1361542. DOI: 10.3389/fcvm.2024.1361542
15. Lee Y, Ahn S, Han M, Lee JA, Ahn JY, Jeong SJ et al. The obesity paradox in younger adult patients with sepsis: analysis of the MIMIC-IV database. International Journal of Obesity. 2024;48(9):1223–30. DOI: 10.1038/s41366-024-01523-5
16. Cai W, Xu J, Wu X, Chen Z, Zeng L, Song X et al. Association between triglyceride-glucose index and all-cause mortality in critically ill patients with ischemic stroke: analysis of the MIMIC-IV database. Cardiovascular Diabetology. 2023;22(1):138. DOI: 10.1186/s12933-023-01864-x
17. Bruce BR, Leask J, De Vries BS, Shepherd HL. Midwives' perspectives of intravenous fluid management and fluid balance documentation in labour: A qualitative reflexive thematic analysis study. Journal of Advanced Nursing. 2023;79(2):749–61. DOI: 10.1111/jan.15518
18. Huisman DE, Bootsma BT, Ingwersen EW, Reudink M, Slooter GD, Stens J et al. Fluid management and vasopressor use during colorectal surgery: the search for the optimal balance. Surgical Endoscopy. 2023;37(8):6062–70. DOI: 10.1007/s00464-023-09980-1
19. Kukralova L, Dostalova V, Cihlo M, Kraus J, Dostal P. The Impact of Individualized Hemodynamic Management on Intraoperative Fluid Balance and Hemodynamic Interventions during Spine Surgery in the Prone Position: A Prospective Randomized Trial. Medicina (Kaunas). 2022;58(11):1683. DOI: 10.3390/medicina58111683

ISSN 0022-9040. Кардиология. 2025;65(1). DOI: 10.18087/cardio.2025.1.n2718