scientific reports

Check for updates

OPEN

Association between hematocrit-to-albumin ratio and acute kidney injury in patients with acute pancreatitis: a retrospective cohort study

Wen Wu[1,2,3], Yupei Zhang[1,2,3], Xingguang Qu[1,2], Chunzhen Zhang[1,2] & Zhaohui Zhang[1,2]✉

Acute pancreatitis (AP) can result in acute kidney injury (AKI), which is linked to poor outcomes. We aimed to assess the relationship between the hematocrit-to-albumin ratio (HAR) and AKI in this population. This retrospective cohort study included consecutive patients diagnosed with AP and admitted to hospital. Data were systematically extracted from electronic medical records, covering baseline demographic and clinical characteristics. Total 1514 AP patients were enrolled, with 17% (257/1514) developing AKI. Multivariable-adjusted regression analysis, curve fitting, threshold effects analyses, and subgroup analyses were conducted to evaluate the relationship between HAR and AKI incidence in AP patients. Compared to the reference tertile of HAR, the adjusted OR values for the lower and higher tertiles of HAR were 1.25 (95% CI, 0.82–1.91, $P = 0.297$) and 1.50 (95% CI, 1.03–2.20, $P = 0.037$), respectively, after adjusting for covariates. The curve fitting results showed a J-shaped relationship between HAR and AKI (non-linear, $p = 0.001$), with an inflection point of 8.969. Furthermore, validation using the Medical Information Mart for Intensive Care (MIMIC-IV) database AP population revealed a similar relationship with an inflection point at 10.257. Our findings suggest a J-shaped relationship between HAR and AKI in AP patients, indicating higher risk of AKI when HAR exceeds 8.969.

Keywords Acute pancreatitis, Acute kidney injury, Serum hematocrit/albumin ratio, Cohort study

Acute pancreatitis (AP) is an inflammatory condition of the pancreas characterized by its sudden onset and variable clinical course[1–3].Over the past several decades, the incidence of AP has been increasing, leading to numerous hospital admissions and a significant economic burden[4,5]. The majority of patients experience with mild, self-limited acute pancreatitis and with a favorable prognosis[6]. Although the overall mortality rate of AP is below 5%, severe cases, often associated with the progression of systemic inflammatory response syndrome (SIRS) to multiorgan dysfunction syndrome, exhibit a mortality rate ranging from 30 to 50%[4,7,8].

Acute kidney injury (AKI) occurs in 10 to 42% of patients with AP. The development of AKI is associated with high mortality rate, prolongs hospital stays and higher risk of chronic kidney disease development[9,10]. While some studies have investigated biomarkers and developed predictive models for AKI in AP patients, these studies often suffer from small sample sizes and lack robust predictive accuracy[11,12]. Therefore, the challenge of early AKI identification and timely therapeutic intervention in AP patients remains critical.

Hematocrit (HCT) represents the volume percentage of red blood cells in the blood. Previous studies have identified HCT as a biomarker for predicting mortality risk in sepsis and septic shock[13,14]. Albumin (ALB), a negative acute-phase reactant synthesized by the liver, constitutes 40% to 60% of total plasma protein and decreases during inflammation[15]. Prior studies has demonstrated a correlation between the difference in HCT and ALB levels (HCT-ALB) and various conditions, including eclampsia, severe infections[16,17], and the prognosis of elderly sepsis ICU patients[18]. This study is the first to investigate the relationship between HCT-to-ALB ratio (HAR) and AKI in patients with acute pancreatitis.

[1]Department of Critical Care Medicine, Yichang Central People's Hospital, Yichang 443003, Hubei, China. [2]The First College of Clinical Medical Science, China Three Gorges University, Yichang 443003, Hubei, China. [3]Wen Wu and Yupei Zhang have contributed equally to this paper as co-first author. ✉email: zhaohuizhang0630@163.com

Methods

Study design

Database and study population from the Chinese hospital

Studies involving human participants were reviewed and approved by the Hospital of Medicine Ethics Committee (ethical approval number: 2023-130-01), and all information about cases was obtained from a retrospective chart of patients with electronic medical records who underwent acute pancreatitis at the First College of Clinical Medical Science of China Three Gorges University from January 2019 to October 2023. Due to the retrospective nature of the study, the Ethics Committee of the First College of Clinical Medical Science of China Three Gorges University waived the need of obtaining informed consent.

Database and study population from the MIMIC-IV 2.0 Database

To better verify the applicability of the model in Chinese patients, we also reviewed participants from the MIMIC-IV 2.0 Clinical Database (MIMIC-IV 2.0), which holds information on more than 672 patients meeting the inclusion criteria admitted to Beth Israel Deaconess Medical Center's ICUs in Boston, MA, from 2008 to 2019.The database is accessible to anybody who has passed the Collaborative Institutional Training Initiative exam (Certification number 46658537 for Wen Wu).

Inclusion and exclusion criteria

The inclusion criteria for this retrospective study were as follows: Patients who were admitted to the First College of Clinical Medical Science of China Three Gorges University; patients who were diagnosed with AP; The exclusion criteria were as follows: patients who were younger than 18 years, or older than 85 years; Pregnant or breastfeeding women; Length of hospital stay ≤ 24 h; patients with CKD; patients with malignant tumor; patients with chronic pancreatitis; patients who received renal transplantation or nephrectomy; incomplete medical data.

A total of 523,740 admissions were recorded in the MIMIC-IV database, of which 76,540 were admitted to the ICU. Hospital admission information for patients with AP was extracted according to International Classification of Diseases, with a total of 1609 had been admitted to the ICU (supplementary). After further screening, patients who meet the following criteria will be excluded (1): Patients younger than 18 years or older than 85 years of age at the time of the first admission; (2) Patients admitted repeatedly for acute pancreatitis, for whom only the first admission data were retained; (3) Patients who stayed in the ICU for less than 24 h; (4) Patients admitted with end-stage renal disease or malignancy; (5) Patients without recorded blood hematocrit and serum albumin data within 24 h of admission. Ultimately, 672 patients were enrolled in this study. The patient collecting and reviewing process was shown in Fig. 1.

Clinical definitions and laboratory data

Diagnosis and Severity Classification of AP

According to the revised Atlanta classification (2012), the diagnosis of AP was established when at least two of the three diagnostic criteria, namely clinical presentation (typical epigastric abdominal pain), laboratory parameters (serum amylase or lipase levels at least three times higher than the upper limit of normal), and abdominal cross-sectional radiographic evidences (including abdominal ultrasound, computed tomography, or magnetic resonance imaging), were met[19,20]. A limited number of diagnosed AP patients were eventually confirmed by undergoing exploratory laparotomy.

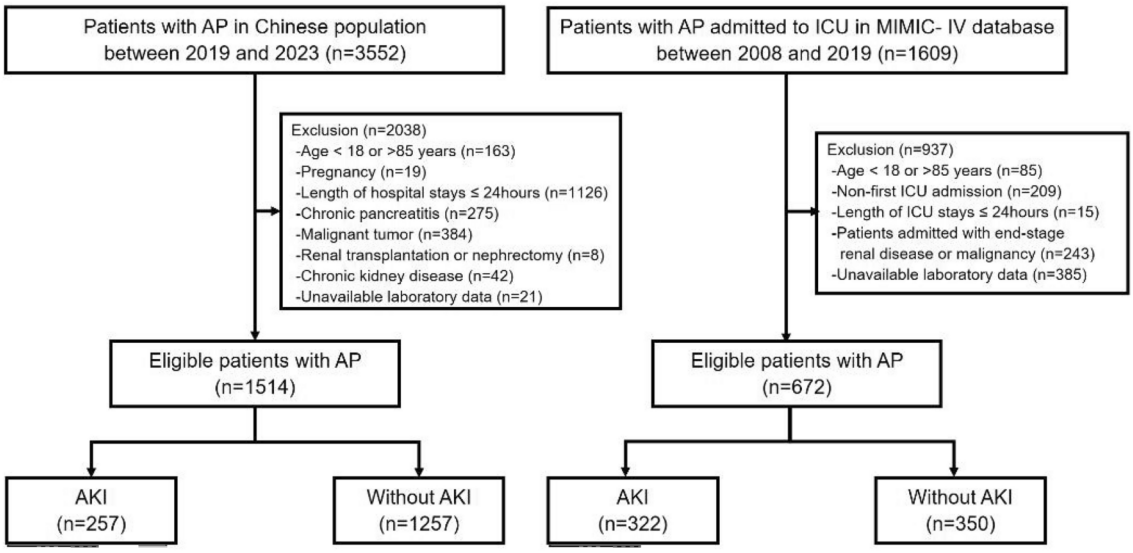

Fig. 1. Flowchart of the screening and enrollment of study participants. *AKI acute kidney injury; AP Acute pancreatitis.*

Adult patients with acute pancreatitis (AP) were categorized into three groups: mild AP (MAP), moderately severe AP (MSAP), and severe AP (SAP) depending on the presence of organ dysfunction and the duration of organ dysfunction being less than 48 h and more than 48 hours[3]. For adult AP patients with evolving disease severity, the most severe classification of AP during hospitalization was considered the ultimate one.

Diagnosis and classification of AKI

The diagnostic criteria of AKI were based on the guidelines of the Kidney Disease Improving Global Outcomes (KIDGO) (2012)[21]criteria, as follows:

(i) Serum creatinine increased by more than 26.5 μmol/L (0.3 mg/dL) or a percentage increase in serum creatinine level of ≥ 50% within 48 h; (ii) The urine volume lasted for more than 6 h and was less than 0.5 mg/kg/h; (iii) Serum creatinine increased 1.5 times higher than the baseline level. Baseline serum creatinine level was defined as the lowest serum creatinine level measured within 2 days prior to admission to hospital. If no serum creatinine level was measured, the serum creatinine level recorded in the first measurement within 2 days after admission to hospital was considered as baseline serum creatinine level.

The BISAP score

The Bedside Index for Severity in Acute Pancreatitis (BISAP) score[22] was developed in 2008 and designed as a predictor of mortality based on 5 variables: blood urea nitrogen (BUN) level greater than 25 mg/dL, impaired mental status, meeting at least two of the systemic inflammatory response syndrome (SIRS) criteria, age older than 60 years, or radiographic evidence of pleural effusion within the first 24 h of admission. Those with a score of 3 or above while receiving 1 point for each positive criterion were defined as having severe acute pancreatitis, and those with a score of 2 or less were defined as having mild acute pancreatitis according to the BISAP scoring system[23].

Data collection

General information was collected, including sex, age, the length of hospital stays, systolic blood pressure (SBP), demand for continuous renal replacement treatment (CRRT), mechanical ventilation (MV) and blood transfusion, sequential organ failure assessment (SOFA) score and Bedside Index of Severity in Acute Pancreatitis (BISAP) score within 24 h of admission. Blood routine parameters including white blood cell count, hemoglobin (HGB) content, and hematocrit (HCT) were also collected. Biochemical parameters including albumin (ALB), blood urea nitrogen (BUN), serum creatinine (CREA), fasting plasma glucose (FPG), sodium ion concentration (Na^+), calcium ion concentration (Ca^{2+}), alanine aminotransferase (ALT), aspartate aminotransferase (AST), triglyceride (TG), C-reactive protein (CRP), procalcitonin (PCT), The HCT/ALB ratio (HAR) was calculated by dividing the hematocrit (HCT, %) by the serum albumin level (ALB, g/dl). The endpoint event defined in this study was acute kidney injury (AKI) in hospital stay caused by acute pancreatitis (AP).

Statistical analysis

Continuous variables are shown as means with standard deviations, while categorical variables are shown as frequencies or percentages. For continuous variables, statistical differences were determined using one-way ANOVA (for normally distributed data) or Kruskal–Wallis H test (for skewed data), while the Chi-square or Fisher's exact test was used for categorical variables.

Subjects were grouped into tertiles by HAR levels (HAR < 9.39, 9.39 ≤ HAR < 10.83, HAR ≥ 10.83), multiple logistic regression analysis and smooth curve fitting were performed to explore the association between HAR and AKI. According to the guidelines in the Strengthening the Reporting of Observational Studies statement[24], we simultaneously analyzed both non-adjusted and multivariable-adjusted models. Covariates were adjusted if variables were within $P < 0.1$ as determined by univariate analysis, and if adding or removing the covariate from the model altered the corresponding odds ratio by at least 10%. We used 3 models: in the adjusted model 1, we adjusted for age and sex; in the adjusted model 2, we adjusted for age, sex, hypertension, diabetes mellitus (DM), coronary heart disease (CHD), heart rate (HR), respiratory rate (RR) and pulse oxygen saturation (SpO_2); in the adjusted model 3, we adjusted for age, sex, hypertension, DM, CHD, HR, RR, SpO_2, etiology, blood transfusion, SOFA score, BISAP score, white blood cell count (WBC), and fasting plasma glucose (FPG). Baseline variables that were considered clinically relevant or had a change in effect estimate of > 10% were chosen as confounders. The smooth curve fitting was established and adjusted according to the covariables contained in model 3. The nonlinear relationship between HAR and AKI was observed after logical regression. For the missing data, we used the multiple imputation method to fill in the missing values[25]. The details of the missing value are shown in supplementary Table S4. Descriptive analyses report observed data only, while regression models include all patients with multiple imputed data. Meanwhile, we utilized the same statistical analysis method on the MIMIC-IV database.

As additional exploratory analyses, possible modifications on the association of HAR and AKI were evaluated by stratified analyses and interaction testing.

A two-tailed $P < 0.05$ was considered to be statistically significant in all analyses. All the analyses were performed with the statistical software packages R (http://www.R-project.org, The R Foundation) and Free Statistics software versions 1.9.

Results

Patients' baseline and clinical data

The enrolled AP patients of Chinese population were divided into AKI group (n = 257) and non-AKI group (n = 1257) according to occurrence of AKI. There was no significant difference in patients' BMI, amylase and prealbumin between the two groups ($p > 0.05$), but there were significant differences in sex, age, length of

hospital stays, demand for MV, blood transfusion and CRRT, ALB, PCT, CRP, TG, CREA, and HAR ($p < 0.001$). All results of two databases are shown in Table 1. A total of 1,514 patients were recruited and 257 (17%) of them developed AKI. The baseline demographic characteristics of the study population, stratified by HAR tertiles, are summarized in Table 2. The mean age of the participants was 53.0 (41.0, 65.0) years old, of whom 53.6% were male, and 46.4% were female. Serum HAR levels were positively associated with white blood cell count, hemoglobin, hematocrit, C-reactive protein and demand for mechanical ventilation and CRRT. Furthermore, we also recruited 672 cases from the MIMIC-IV database as the validation cohort, among which 57.6% were male, and 42.4% were female. All results are shown in Table 2 and Supplementary Table S1. Supplementary Table S2 presents the baseline data of non-ICU and ICU patients in the Chinese population.

Univariate and multivariate analyses of HAR and AKI

Univariate analysis showed that age, sex, hypertension, coronary heart disease, systolic blood pressure, diastolic blood pressure, heart rate, respiratory rate, SpO_2, severity, etiology, blood transfusion, Ventilation, CRRT, SOFA score, BISAP score, WBC, ALB, TG and Ca^{2+} were significant confounding factors influencing AKI incidence ($p < 0.001$) (Supplementary Table S3).

In the multiple logistic regression analysis (Table 3), as compared with the reference tertile of HAR (T2 9.39–10.83), the adjusted OR values for lower tertile of HAR (T1 < 9.39), and higher tertile of HAR (T3 ≥ 10.83) were 1.25(95% CI, 0.82–1.91, $p = 0.297$) and 1.50 (95% CI, 1.03–2.20, $p = 0.037$), respectively, were associated with a higher risk of AKI incidence, after adjusting for covariates. All results of two databases are presented in Table 3.

Smooth curve fitting, threshold effect analyses between HAR and AKI

After adjusting for covariates in model 3, we found a J-shaped relationship between HAR and AKI in curve fitting (P for non-linearity < 0.001) (Fig. 2). The data were fitted to a piecewise multiple logistic regression model with two different slopes. In our study, the P value for the likelihood ratio test was 0.029 and 0.001 (Table 4); therefore, we utilized a two-part model to fit the association between serum HAR levels and AKI incidence in patients with acute pancreatitis. We discovered an inflection point at 8.969 in Chinese population. Similarly, in the MIMIC-IV population, a J-shaped relationship between HAR and AKI was identified in curve fitting (*P* for non-linearity < 0.001) (Supplementary Fig. S1), with an inflection point at 10.257.

Subgroup analyses

To verify the stability of the J-shaped relationship between HAR and AKI, we performed curve fitting stratified by sex, age, hypertension, DM, SOFA score, and severity of AP, respectively. No significant interactions were found in any subgroups after stratifying by sex, age, hypertension, DM, SOFA score, and severity of AP (all P for interaction > 0.05) (Fig. 3 and Supplementary Fig. S2).

Discussion

This study investigated the relationship between serum hematocrit-to-albumin ratio (HAR) levels and the incidence of AKI in patients with AP. We found that HAR independently correlates with the occurrence of AKI, demonstrating a J-shaped association curve. Specifically, the incidence of AKI initially decreased and subsequently increased with rising HAR levels. Subgroup analyses and interaction tests revealed that this relationship remained stable across different population groups. To further validate these findings, we conducted an analysis of MIMIC-IV database, which also revealed a J-shaped association between serum HAR levels and AKI incidence.

In healthy individuals, hematocrit (HCT) and plasma albumin (ALB) levels are stable, with HCT ranging from 40 to 45% and ALB from 35 to 45 g/L under normal conditions, respectively[26]. Elevated HCT levels are associated with a poor prognosis of sepsis, cardiopulmonary bypass surgery and tumor[27,28]. In AP patients, HCT may increase due to substantial fluid loss, resulting in hemoconcentration and chronic hypoxia. Conversely, reductions in HCT are observed in various pathological states including anemia, bleeding, malnutrition, surgery, trauma, tumors and chronic infections. Additionally, the sole measurement of HCT presents limitations, as various conditions are associated with elevated HCT levels, including dehydration, heat stroke, excessive muscle activity, liver dysfunction, diabetic ketoacidosis, myeloproliferative disorders, and chronic pulmonary diseases.

ALB is critical for maintaining blood volume and plasma colloidal osmotic pressure. Under hypermetabolic conditions, albumin levels may decrease due to reduced synthesis, accelerated catabolism, and increased vascular permeability, which leading to protein leakage[29]. Various studies have established a significant association between albumin concentrations and inflammation severity, as well as with disease prognosis and mortality rates [15,30,31]. However, it is essential to recognize that albumin levels are influenced by factors such as nutritional status, dehydration, and chronic inflammation. These variables can affect the accuracy of prognostic assessments based solely on albumin concentrations.

The capacity index of HCT and ALB has been emphasized in numerous studies[32,33]. Taking into account these factors, the hematocrit-to-albumin ratio (HCT/ALB) may serve as a more dependable prognostic indicator compared to utilizing each measurement independently. Current studies mainly focus on the differences between HCT and ALB levels (HCT-ALB). Dai et al. proposed that an HCT-ALB level exceeding 12.65 could serve as a potential biomarker for diagnosing hypertensive pregnancy disorders, such as preeclampsia and eclampsia[17]. Furthermore, Dai et al. found that HCT-ALB levels are elevated in patients with septic shock compared to those with hemorrhagic shock. The HCT-ALB level above 6.8 proves useful in distinguishing these conditions[16]. Additionally, they also observed that HCT-ALB level above 10.25 might facilitate the rapid diagnosis of severe infections[34]. Wang et al. confirmed the importance of HCT-ALB levels in predicting the outcomes of elderly sepsis patients, using data from the MIMIC-IV and eICU-CRD databases[18]. Our research is the first to explore

Chinese population				MIMIC-IV population		
Characteristics	**No-AKI (n = 1257)**	**AKI (n = 257)**	***p*-value**	**No-AKI (n = 350)**	**AKI (n = 322)**	***p*-value**
Sex (%)			< 0.001			0.135
Male	642 (51.1)	170 (66.1)		192 (54.9)	195 (60.6)	
Female	615 (48.9)	87 (33.9)		158 (45.1)	127 (39.4)	
Age (years)	53.0 (41.0, 64.0)	56.0(44.0, 69.0)	0.002	54.0 (43.0, 67.0)	59.5 (47.0, 72.8)	0.001
Death (%)	5 (0.4)	18 (7)	< 0.001	18 (5.1)	78 (24.2)	< 0.001
LOS(days)	13.0 (10.0, 18.0)	16.0 (10.0, 26.0)	< 0.001	9.0 (5.0, 16.0)	16.0 (8.0, 26.0)	< 0.001
ICU (%)	115 (9.1)	132 (51.4)	< 0.001	350(100)	322(100)	
Hypertension (%)	304 (24.2)	88 (34.2)	< 0.001	204 (58.3)	171 (53.1)	0.177
DM (%)	177 (14.1)	48 (18.7)	0.059	121 (34.6)	134 (41.6)	0.06
CHD (%)	77 (6.1)	26 (10.1)	0.021	58 (16.6)	65 (20.2)	0.226
COPD (%)	48 (3.8)	16 (6.2)	0.081	N/A	N/A	
Weight (kg)	64.0 (56.0, 75.0)	65.0 (55.0, 75.0)	0.704	79.1 (68.8, 96.5)	83.2 (71.1, 99.4)	0.016
Height (cm)	163.0(158.0, 170.0)	167.0(158.0, 172.0)	0.001	170.0(163.0, 178.0)	170.0(163.0, 178.0)	0.877
BMI	24.1 (21.8, 26.7)	24.2 (20.8, 26.9)	0.437	N/A	N/A	
SBP (mmHg)	130.0(119.0, 143.0)	123.0(110.0, 140.0)	< 0.001	130.0(113.0, 146.0)	122.0(105.2, 143.0)	0.005
DBP (mmHg)	80.0 (74.0, 90.0)	80.0 (66.0, 89.0)	< 0.001	76.0 (64.0, 88.8)	68.0 (58.0, 81.8)	< 0.001
HR (bpm)	78.0 (72.0, 90.0)	90.0 (76.0, 110.0)	< 0.001	99.0 (83.0, 114.0)	98.0 (83.0, 115.0)	0.599
Temperature	36.5 (36.4, 36.6)	36.5 (36.4, 36.8)	0.013	N/A	N/A	
RR (bpm)	20.0 (19.0, 20.0)	20.0 (19.0, 21.0)	0.009	21.0 (17.0, 24.8)	22.0 (19.0, 27.0)	< 0.001
SpO_2(%)	99.0 (98.0, 100.0)	98.0 (96.0, 100.0)	< 0.001	N/A	N/A	
P/F	N/A	N/A		231.7 (172.9, 374.0)	207.9 (138.2, 296.3)	< 0.001
Ventilation (%)	73 (5.8)	85 (33.1)	< 0.001	1.6 (0.7, 3.2)	3.4 (1.2, 11.0)	< 0.001
Transfusion (%)	70 (5.6)	98 (38.1)	< 0.001	26 (7.4)	35 (10.9)	0.121
CRRT (%)	21 (1.7)	71 (27.6)	< 0.001	11 (3.1)	44 (13.7)	< 0.001
PLT ($\times 10^9$L)	181.0(139.0, 234.0)	172.0(110.0, 227.0)	0.004	198.0(138.2, 285.5)	177.0(122.2, 242.0)	< 0.001
PCT (ng/ml)	0.1 (0.0, 0.6)	1.1 (0.2, 6.5)	< 0.001	N/A	N/A	
CRP (mg/L)	31.4 (5.9, 119.0)	88.7 (16.9, 200.2)	< 0.001	N/A	N/A	
ALB(g/dl)	3.9 (3.5, 4.3)	3.5 (2.9, 4.0)	< 0.001	3.1 (2.7, 3.6)	3.0 (2.4, 3.3)	< 0.001
FPG (mmol/L)	6.6 (5.3, 8.9)	7.5 (5.7, 11.2)	< 0.001	6.7 (5.3, 9.3)	7.9 (5.9, 12.3)	< 0.001
TG (mmol/L)	1.5 (1.0, 3.4)	1.8 (1.2, 6.4)	< 0.001	1.6 (1.1, 3.3)	2.0 (1.2, 5.2)	0.008
Ca (mmol/L)	2.2 (2.1, 2.4)	2.1 (1.9, 2.3)	< 0.001	2.0 (1.9, 2.2)	2.0 (1.8, 2.1)	< 0.001
CREA (μmol/L)	65.8 (53.8, 77.0)	143.0 (107.0, 226.0)	< 0.001	70.7 (53.0, 88.4)	145.9 (97.2, 265.2)	< 0.001
AMY(U/L)	163.0 (64.5, 716.0)	202.0(92.0, 607.0)	0.065	168.0(64.5, 425.0)	280.0(78.2, 746.0)	< 0.001
PA (mg/L)	162.3(111.0, 210.0)	144.8(92.0, 230.0)	0.625	N/A	N/A	
Severity of AP (%) Mild and moderate	1181 (94)	162 (63)	< 0.001	N/A	N/A	
Severe	76 (6)	95 (37)				
Etiology of AP (%)			< 0.001	N/A	N/A	
Biliary	887 (70.6)	132 (51.4)				
Hyperlipidemic	289 (23)	65 (25.3)				
Alcoholic	42 (3.3)	9 (3.5)				
Others	39 (3.1)	51 (19.8)				
Lac (mmol/L)	N/A	N/A		1.5 (1.1, 2.0)	2.0 (1.4, 3.5)	< 0.001
HAR	10.0 (9.0, 11.0)	10.7 (9.2, 12.8)	< 0.001	11.4 ± 2.6	12.2 ± 3.6	0.002

Table 1. Baseline characteristics of included patients grouped by the occurrence of AKI in two databases of Chinese population and MIMIC-IV. *LOS* Length of hospital stay, *DM* Diabetes mellitus, *CHD* Coronary heart disease, *SBP* Systolic blood pressure, *DBP* Diastolic blood pressure, *HR* Heart rate, *RR* Respiratory rate, SpO_2 Pulse oxygen saturation, P/F PaO_2/FiO_2, Ventilation noninvasive or invasive mechanical ventilation, Transfusion blood transfusion, *CRRT* Continuous renal replacement treatment, *WBC* White blood cell count, *HGB* Hemoglobin, *HCT* Hematocrit, *PCT* Procalcitonin, *CRP* C-reactive protein, *AST* Aspartate aminotransferase, *ALB* Albumin, *FPG* Fasting plasma glucose, *TG* Triglyceride, Na Sodium, Ca Calcium, *CREA* Creatinine, Lac Lactic acid, *AKI* Acute kidney injury, *SOFA* Sequential organ failure assessment score, *BISAP* Bedside Index of Severity in Acute Pancreatitis score, *HAR* Dividing the hematocrit level (%) by the ALB level (g/dl).

Characteristics	Chinese population				MIMIC-IV population			
	T1 (n = 505) < 9.39	T2 (n = 504) 9.39–10.83	T3 (n = 505) ≥ 10.83	*p*	T1 (n = 224) < 10.133	T2 (n = 224) 10.133–12.793	T3 (n = 224) ≥ 12.793	*p*
Sex (%)				< 0.001				< 0.001
Male	169 (33.5)	289 (57.3)	354 (70.1)		124 (55.4)	121 (54)	142 (63.4)	
female	336 (66.5)	215 (42.7)	151 (29.9)		100 (44.6)	103 (46)	82 (36.6)	
Age (years)	53. (41.0, 65.0)	53.0 (41.0, 66.0)	54.0 (41.0, 65.0)	0.957	54.0 (44.0, 69.0)	58.0 (46.0, 72.0)	56.0 (45.0, 70.0)	0.598
Death (%)	5 (1)	7 (1.4)	11 (2.2)	0.291	28 (12.5)	24 (10.7)	44 (19.6)	0.017
ICU (%)	56 (11.1)	64 (12.7)	127 (25.1)	< 0.001	N/A	N/A	N/A	N/A
LOS (days)	16.3 ± 11.2	15.1 ± 12.4	18.5 ± 14.2	< 0.001	10.0 (5.0, 19.0)	10.5 (5.0, 19.0)	14.0 (7.0, 26.0)	< 0.001
Hypertension (%)	130 (25.7)	123 (24.4)	139 (27.5)	0.525	115 (51.3)	125 (55.8)	135 (60.3)	0.164
DM (%)	81 (16)	66 (13.1)	78 (15.4)	0.38	84 (37.5)	88 (39.3)	83 (37.1)	0.876
CHD (%)	35 (6.9)	34 (6.7)	34 (6.7)	0.99	50 (22.3)	45 (20.1)	28 (12.5)	0.019
SBP (mmHg)	126.0 (116.0, 143.0)	130.0 (119.0, 143.0)	130.0 (116.0, 143.0)	0.206	131.5 (112.0, 148.2)	124.0 (110.0, 139.2)	125.5 (108.0, 148.0)	0.074
DBP (mmHg)	80.0 (70.0, 89.0)	80.0 (72.0, 90.0)	81.0 (74.0, 91.0)	0.004	72.0 (60.0, 82.2)	72.0 (60.0, 86.2)	74.0 (62.0, 89.0)	0.324
HR (bpm)	78.0 (70.0, 88.0)	79.5 (72.0, 90.2)	85.0 (76.0, 102.0)	< 0.001	93.0 (80.0, 108.0)	95.0 (83.0, 113.0)	105.5 (90.0, 122.0)	< 0.001
RR (bpm)	20.0 (18.0, 20.0)	20.0 (19.0, 20.0)	20.0 (19.0, 21.0)	< 0.001	21.0 (16.0, 25.0)	21.0 (18.0, 24.0)	23.5 (20.0, 28.0)	< 0.001
SpO_2 (%)	99.0 (98.0, 100.0)	99.0 (97.0, 100.0)	98.0 (97.0, 100.0)	< 0.001	N/A	N/A	N/A	N/A
P/F	N/A	N/A	N/A	N/A	266.6 (188.9, 382.0)	217.9 (156.2, 328.8)	199.8 (133.8, 295.7)	< 0.001
Ventilation (%)	35 (6.9)	39 (7.7)	84 (16.6)	< 0.001	165 (73.7)	193 (86.2)	198 (88.4)	< 0.001
Transfusion (%)	52 (10.3)	42 (8.3)	74 (14.7)	0.005	20 (8.9)	18 (8)	23 (10.3)	0.71
CRRT (%)	16 (3.2)	23 (4.6)	53 (10.5)	< 0.001	15 (6.7)	15 (6.7)	25 (11.2)	0.138
WBC ($\times 10^9$/L)	8.4 (5.7, 12.1)	9.9 (6.8, 13.6)	11.1 (7.8, 15.6)	< 0.001	10.0 (5.9, 15.2)	11.4 (7.7, 17.1)	13.6 (10.4, 19.3)	< 0.001
HGB (g/L)	117.0 (104.0, 130.0)	131.0 (118.0, 145.2)	142.0 (126.0, 155.0)	< 0.001	101.0 (86.0, 114.0)	114.0 (104.0, 128.0)	129.0 (111.0, 143.0)	< 0.001
HCT (%)	35.3 (31.7, 38.4)	39.4 (35.9, 42.5)	42.1 (37.3, 46.0)	< 0.001	30.0 (26.0, 33.6)	34.5 (31.2, 38.4)	39.0 (34.1, 43.3)	< 0.001
PCT (ng/ml)	0.1 (0.0, 0.4)	0.1 (0.0, 0.6)	0.5 (0.1, 2.0)	< 0.001	N/A	N/A	N/A	N/A
CRP (mg/L)	14.3 (3.3, 79.6)	26.0 (6.2, 103.2)	106.8 (24.8, 202.9)	< 0.001	N/A	N/A	N/A	N/A
AST (U/L)	47.0 (23.0, 187.0)	39.5 (23.0, 135.5)	39.0 (23.0, 111.0)	0.108	69.5 (36.0, 173.5)	72.0 (34.0, 230.0)	75.5 (35.0, 141.0)	0.922
ALB (g/dl)	4.1 (3.8, 4.5)	3.9 (3.6, 4.3)	3.4 (2.9, 3.8)	< 0.001	3.5 (3.1, 3.8)	3.1 (2.8, 3.4)	2.5 (2.2, 3.0)	< 0.001
FPG (mmol/L)	6.5 (5.3, 8.7)	6.5 (5.1, 9.0)	7.1 (5.6, 9.9)	0.001	7.2 (5.6, 9.3)	7.4 (5.4, 10.2)	7.6(5.5, 10.0)	0.733
TG (mmol/L)	1.5 (0.9, 3.2)	1.5 (1.0, 3.8)	1.6 (1.0, 3.8)	0.233	1.8(1.1, 3.3)	1.5 (1.0, 2.7)	2.2 (1.2, 5.8)	< 0.001
Na (mmol/L)	139.8 (137.3, 141.9)	140.0 (137.1, 141.9)	138.8 (136.0, 141.2)	< 0.001	138.0 (135.0, 141.0)	138.0 (135.0, 141.2)	138.0 (135.0, 141.0)	0.984
Ca (mmol/L)	2.2 (2.1, 2.4)	2.2 (2.1, 2.4)	2.1 (1.9, 2.3)	< 0.001	2.1 (2.0, 2.2)	2.1 (1.9, 2.2)	1.9 (1.7, 2.0)	< 0.001
CREA (μmol/L)	62.0 (51.0, 76.0)	68.0 (57.0, 82.8)	73.0 (60.0, 99.0)	< 0.001	97.2 (61.9, 170.2)	88.4 (61.9, 141.4)	97.2 (61.9, 176.8)	0.209
Lac (mmol/L)	N/A	N/A	N/A	N/A	1.6 (1.1, 2.2)	1.6 (1.2, 2.6)	1.9 (1.3, 3.7)	< 0.001
AKI (%)	69 (13.7)	67 (13.3)	121 (24)	< 0.001	104 (46.4)	86 (38.4)	132 (58.9)	< 0.001
SOFA	2.4 ± 2.1	2.5 ± 2.4	3.3 ± 2.9	< 0.001	5.0 (3.0, 8.0)	4.0 (3.0, 8.0)	6.5 (3.0, 10.0)	0.011
Etiology (%)				0.198	N/A	N/A	N/A	N/A
Biliary	351 (69.5)	343 (68.1)	325 (64.4)					
Hyperlipidemic	111 (22)	121 (24)	122 (24.2)					
Alcoholic	11 (2.2)	16 (3.2)	24 (4.8)					
Others	32 (6.3)	24 (4.8)	34 (6.7)					
Severity (%)				< 0.001	N/A	N/A	N/A	N/A
Mild and moderate	476 (94.3)	458 (90.9)	409 (81)					
Severe	29 (5.7)	46 (9.1)	96 (19)					
BISAP	1.0 (0.0, 2.0)	1.0 (0.0, 2.0)	2.0 (0.0, 2.0)	< 0.001	N/A	N/A	N/A	N/A

Table2. Baseline characteristics of included patients grouped by tertile of HAR in two databases of Chinese population and MIMIC-IV. *LOS* Length of hospital stay, *DM* Diabetes mellitus, *CHD* Coronary heart disease, *SBP* Systolic blood pressure, *DBP* Diastolic blood pressure, *HR* Heart rate, *RR* Respiratory rate, *SpO_2* Pulse oxygen saturation, P/F PaO_2/FiO_2, Ventilation noninvasive or invasive mechanical ventilation, Transfusion blood transfusion, *CRRT* Continuous renal replacement treatment, WBC white blood cell count, *HGB* Hemoglobin, *HCT* Hematocrit, *PCT* Procalcitonin, *CRP* C-reactive protein, *AST* Aspartate aminotransferase, *ALB* Albumin, *FPG* Fasting plasma glucose, *TG* Triglyceride, Na Sodium, Ca Calcium, *CREA* creatinine, Lac Lactic acid, *AKI* Acute kidney injury, *SOFA* Sequential organ failure assessment score, *BISAP* Bedside Index of Severity in Acute Pancreatitis score, *HAR* Dividing the hematocrit level (%) by the ALB level (g/dl). Mean and interquartile range for continuous variables: *P* value was calculated by weighted linear regression model. % for categorical variables: *P* value was calculated by weighted chi-square test, $P < 0.05$ was considered statistically significant.

	Non-adjusted model	Model 1	Model 2	Model 3
	OR (95%Cl), *P* value	OR (95% Cl), *P* value	OR (95% Cl), *P* value	OR (95% Cl), *P* value
Chinese population				
HAR, Continuous	1.24 (1.17–1.32), < 0.001	1.21(1.13–1.29), < 0.001	1.09 (1.02–1.17), 0.013	1.1 (1.02–1.18), 0.016
HAR, Categories				
Tertile 1	1.03 (0.72–1.48), 0.863	1.20 (0.83–1.74), 0.337	1.31 (0.89–1.93), 0.17	1.25 (0.82–1.91),0.297
Tertile 2	Reference	Reference	Reference	Reference
Tertile 3	2.06 (1.48–2.85), < 0.001	1.93 (1.38–2.69), < 0.001	1.45 (1.02–2.05), 0.04	1.50 (1.03–2.20), 0.037
P for trend	< 0.001	0.003	0.464	0.275
MIMIC-IV population				
HAR, Continuous	1.08 (1.03–1.14), 0.002	1.08 (1.02–1.13),0.004	1.05 (1.00–1.11), 0.06	0.98 (0.92–1.05), 0.649
HAR, Categories				
Tertile 1	1.39 (0.95–2.03), 0.086	1.43 (0.98–2.09), 0.065	1.57 (1.06–2.32), 0.025	1.69 (1.07–2.67), 0.024
Tertile 2	Reference	Reference	Reference	Reference
Tertile 3	2.30 (1.58–3.36), < 0.001	2.30 (1.57–3.38), < 0.001	2.08 (1.39–3.12), < 0.001	1.66 (1.03–2.68), 0.038
P for trend	0.008	0.014	0.201	0.826

Table 3. Multiple logistic regression analysis for HAR and AKI in Chinese population and MIMIC-IV database. *AKI* Acute kidney injury, *HAR* Hematocrit to ALB ratio, T Tertile, *OR* Odds ratio, 95%CI 95% Confidence interval. Results for each model are presented as OR (95% CI), *P* value. HAR of Chinese population Tertile 1: < 9.39; Tertile 2: 9.39–10.83; Tertile 3: ≥ 10.83. Model 1 of Chinese population: adjusted for age and sex. Model 2 of Chinese population: adjusted for age, sex, hypertension, DM, CHD, HR, RR and SpO_2. Model 3 of Chinese population: adjusted for age, sex, hypertension, DM, CHD, HR, RR, SpO_2, etiology, blood transfusion, SOFA score, BISAP score, WBC, and FPG. HAR of MIMIC-IV database Tertile 1: < 10.13; Tertile 2: 10.13–12.79; Tertile 3: ≥ 12.79. Model 1 of MIMIC-IV database: adjusted for age and sex. Model 2 of MIMIC-IV database: adjusted for age, sex, hypertension, DM, CHD, HR, RR and P/F. Model 3 of MIMIC-IV database: adjusted for age, sex, hypertension, DM, CHD, HR, RR, P/F, blood transfusion, SOFA score, Lac, WBC, and FPG.

the association between the HAR and AKI in acute pancreatitis, where hematocrit and albumin levels reflect volume status, inflammation, and nutritional condition, which were key elements in AKI pathogenesis.

In individuals diagnosed with acute pancreatitis, the incidence of AKI increases during the acute phase characterized by capillary leakage syndrome (CLS), systemic inflammatory response syndrome (SIRS), hypovolemia. During this phase, individuals with acute pancreatitis encounter pathogenic micro-organisms that trigger the immune system and prompt the release of numerous inflammatory mediators such as tumor necrosis factor and interleukins[35]. These mediators can compromise the integrity of the vascular endothelial barrier, enhance capillary permeability, and lead to substantial plasma extravasation[36]. The gap between capillary endothelial cells measures approximately 6–7 nm, while the diameter of albumin is slightly larger at 7.2 nm. This size discrepancy results in substantial extravasation of albumin and water from the vascular to the interstitial spaces, causing to tissue edema and intravascular hypovolemia. Moreover, patients with acute pancreatitis often experience a hypermetabolic state, increasing albumin consumption, while intestinal dysfunction can lead to significant albumin loss, ultimately reducing serum albumin levels.

Conversely, the diameter of red blood cells is much larger, measuring 7–8 μm (about 1000 times larger than the gap between endothelial cells), preventing them from passing through the endothelial gaps and leading to an elevated HCT in the context of hypovolemia. These pathophysiological collectively contribute to the development of pathologic capillary leakage syndrome, which further exacerbates the risk of AKI and results in an elevated HAR[37,38]. Our findings suggest a J-shaped relationship between HAR and AKI in AP patients, there is higher risk of AKI when HAR exceeds 8.969. However, the inflection point in MIMIC-IV cohort was observed at a HAR value of 10.257. This discrepancy may be attributable to racial differences between the study populations and variations in laboratory testing methodologies.

Overall, the HAR connects the pathophysiologic trajectory of AP by reflecting both the volume status and the SIRI-induced capillary leak syndrome. The severity of AP with CLS is linked to an increased HAR due to hemoconcentration and albumin extravasation. The dynamic shifts in HAR may provide valuable insights for managing AP. An increase in HAR should alert clinicians to consider the possibilities of volume depletion, which may contribute to AKI development. Accordingly, therapeutic measures, including albumin infusion and the restoration of effective circulating blood volume, should be tailored based on HAR levels to improve the prognosis of AKI[39,40].

Our study boasts several strengths. First, it is the largest to date that investigates acute pancreatitis-related AKI within the Chinese population, with external validation provided by the MIMIC-IV database. Second, we employed statistical methods to elucidate the curvilinear relationship between HAR levels and AKI risk, moving beyond a simple linear model. We conducted sensitivity analyses based on varying HAR levels, and identified the inflection point via smooth curve fitting instead of arbitrary thresholds categorization.

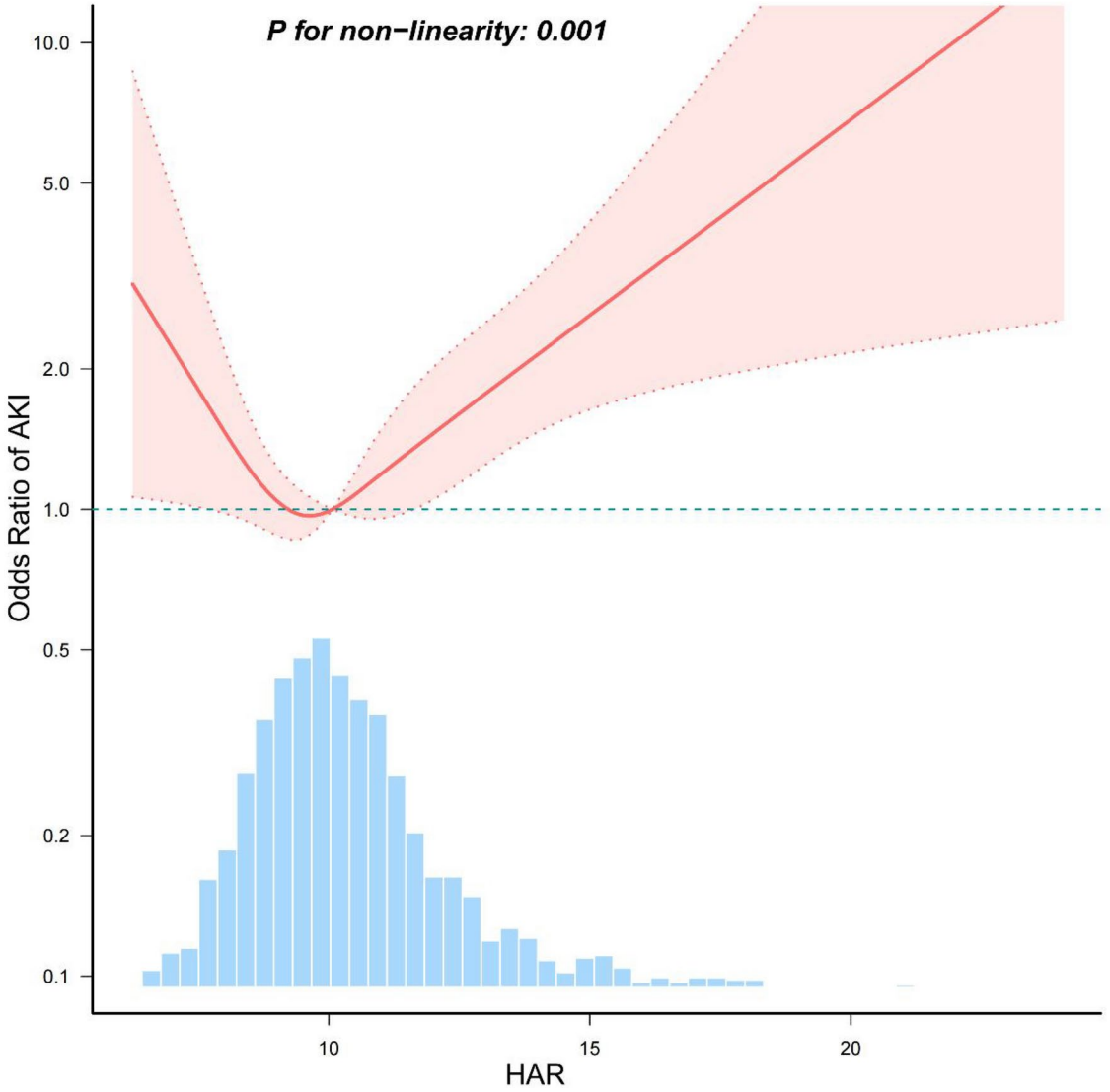

Fig. 2. Restricted cubic spline analysis of nonlinear association between HAR and AKI in patients with acute pancreatitis in the Chinese population. Adjusted for all covariates as model 3. Solid lines represent the odds ratio of AKI and dotted lines represent the corresponding 95% CI. OR = 1 was set as the reference line. (takes the upper limit of 100%).

Chinese population			MIMIC-IV population	
Two-piecewise linear regression model	**OR 95%CI**	***P* value**	**OR 95%CI**	***P* value**
Inflection point (K)	8.969		10.257	
HAR < K	0.615 (0.38, 0.996)	0.048	0.684 (0.499, 0.937)	0.018
HAR ≥ K	1.162 (1.035, 1.304)	0.011	1.256 (1.097, 1.44)	0.001
Likelihood Ratio test		0.029		0.001

Table 4. Threshold effect analysis of HAR and AKI using two-piecewise regression models in two databases. *AKI* Acute kidney injury, *HAR* Hematocrit to albumin ratio, *OR* Odds ratio, 95%CI 95% Confidence interval.

Our research has certain limitations. Initially, the retrospective data collection at a single academic center could have resulted in selection bias. Secondly, in our current dataset, a significant portion of patients were non-ICU cases, where detailed fluid administration records are often less meticulously maintained, posing challenges in accurately recording fluid balance during resuscitation. Finally, despite the strong association between HAR and AKI, our findings cannot establish causality due to the observational nature of the study. More prospective studies are necessary to confirm these relationships.

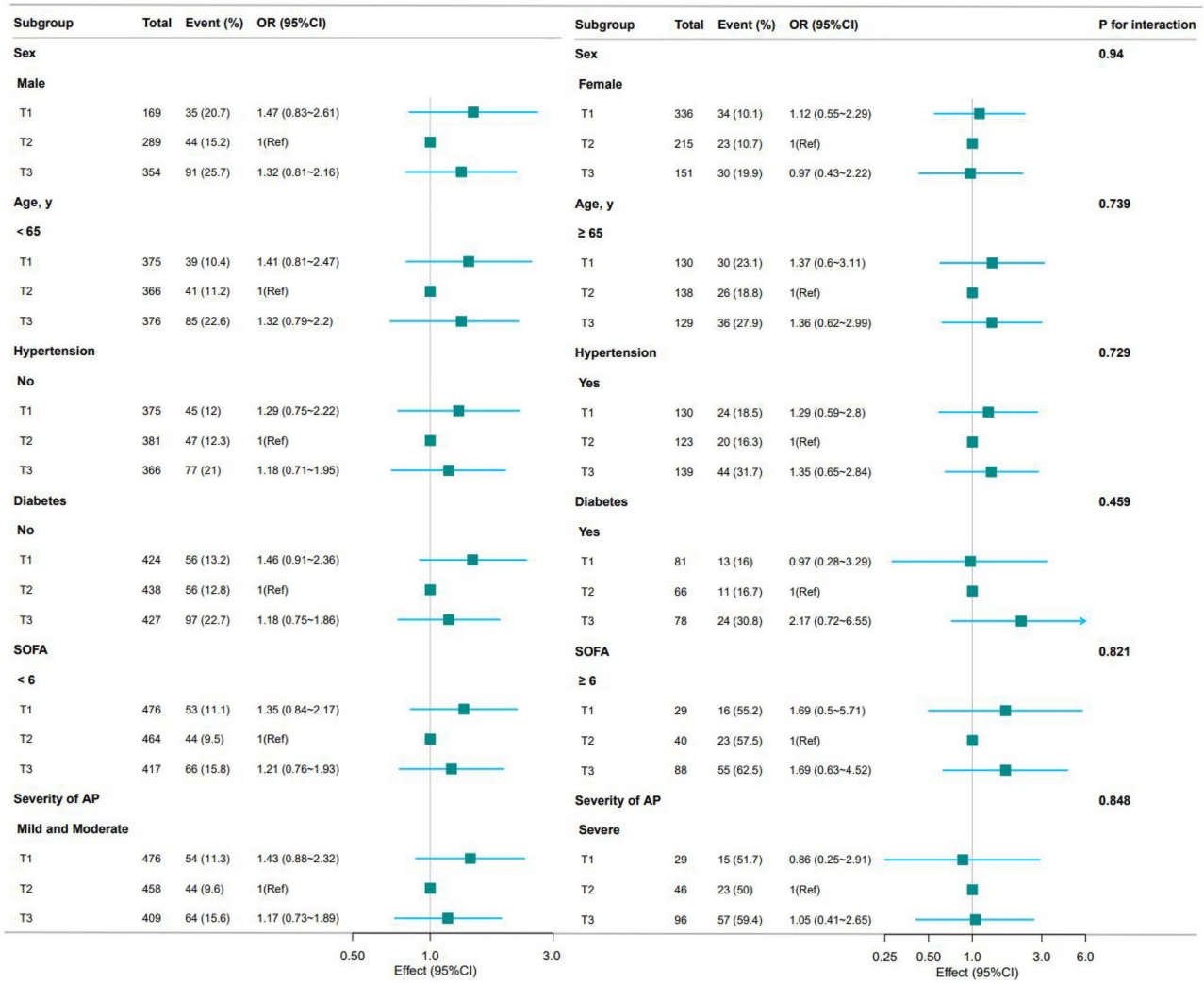

Fig. 3. Subgroup analyses for the association between HAR and AKI. Each stratified group was adjusted for model 3 (age, sex, hypertension, DM, CHD, HR, RR, SpO_2, etiology, blood transfusion, BISAP score, WBC, and FPG).

Conclusions

This study discovered a significant correlation between the serum HAR and the incidence of AKI. The relationship exhibited a J-shaped curve, with an inflection point at 8.969. Further research is essential to validate these results and elucidate the underlying mechanisms of the HAR-AKI association.

Data availability

Data is provided within the manuscript or supplementary information files.

Received: 29 May 2024; Accepted: 25 October 2024
Published online: 07 November 2024

References

1. Lee, P. J. & Papachristou, G. I. New insights into acute pancreatitis. *Nat. Rev. Gastroenterol. Hepatol.* **16**, 479–496 (2019).
2. Whitcomb, D. C. Acute pancreatitis. *N Engl. J. Med.* **354**(20), 2142–2150 (2006).
3. Banks, P. A. et al. Classification of acute pancreatitis—2012: Revision of the Atlanta classification and definitions by international consensus. *Gut* **62**, 102–111 (2013).
4. Silva-Vaz, P. et al. Murine models of acute pancreatitis: A critical appraisal of clinical relevance. *IJMS* **20**, 2794 (2019).
5. Van Dijk, S. M. et al. Acute pancreatitis: Recent advances through randomised trials. *Gut* **66**, 2024–2032 (2017).
6. Singh, V. K. et al. An assessment of the severity of interstitial pancreatitis. *Clin. Gastroenterol. Hepatol.* **9**, 1098–1103 (2011).
7. Wu, B. U. et al. Dynamic measurement of disease activity in acute pancreatitis: The pancreatitis activity scoring system. *Am. J. Gastroenterol.* **112**, 1144–1152 (2017).
8. Kaplan, M. et al. Predictive value of C-reactive protein/albumin ratio in acute pancreatitis. *Hepatobiliary Pancreat Dis. Int.* **16**, 424–430 (2017).

9. Lin, H.-Y. et al. Acute renal failure in severe pancreatitis: A population-based study. *Upsala J. Med. Sci.* **116**, 155–159 (2011).
10. Hamada, S., Masamune, A. & Shimosegawa, T. Management of acute pancreatitis in Japan: Analysis of nationwide epidemiological survey. *WJG* **22**, 6335 (2016).
11. Lu, L. et al. The systemic immune-inflammation index may be a novel and strong marker for the accurate early prediction of acute kidney injury in severe acute pancreatitis patients. *J. Invest. Surg.* **35**, 962–966 (2022).
12. Yang, D. et al. Development and validation of a predictive model for acute kidney injury in patients with moderately severe and severe acute pancreatitis. *Clin. Exp. Nephrol.* **26**, 770–787 (2022).
13. Block, S., Büchler, M., Bittner, R. & Beger, H. G. Sepsis indicators in acute pancreatitis. *Pancreas* **2**, 499–505 (1987).
14. Juncal, V. R., Britto Neto, L. A. D., Camelier, A. A., Messeder, O. H. C. & Farias, A. M. D. C. Impacto clínico do diagnóstico de sepse à admissão em UTI de um hospital privado em Salvador. *Bahia. J. Bras. pneumol.* **37**, 85–92 (2011).
15. Ni, T. et al. Association between albumin or prealbumin levels at different stages and prognosis in severe acute pancreatitis: a 5-year retrospective study. *Sci. Rep.* **12**, 16792 (2022).
16. Dai, D. et al. Feasibility study of the difference between hematocrit and albumin for identifying hemorrhagic shock and septic shock. *Zhonghua Wei Zhong Bing Ji Jiu Yi Xue* **30**, 1137–1140 (2018).
17. Dai, D.-M. et al. Hematocrit and plasma albumin levels difference may be a potential biomarker to discriminate preeclampsia and eclampsia in patients with hypertensive disorders of pregnancy. *Clin. Chim. Acta* **464**, 218–222 (2017).
18. Wang, Z. et al. The relationship between hematocrit and serum albumin levels difference and mortality in elderly sepsis patients in intensive care units—a retrospective study based on two large database. *BMC Infect Dis.* **22**, 629 (2022).
19. Beyer, G. et al. Clinical practice guideline: Acute and chronic pancreatitis. *Deutsches Ärzteblatt Int.* **119**, 495–501 (2022).
20. Zhou, W., Dong, S., Chen, Z., Li, X. & Jiang, W. New challenges for microRNAs in acute pancreatitis: Progress and treatment. *J. Transl. Med.* **20**, 192 (2022).
21. Khwaja, A. KDIGO clinical practice guidelines for acute kidney injury. *Nephron. Clin. Pract.* **120**, c179–c184 (2012).
22. Annane, D. et al. Hydrocortisone plus fludrocortisone for adults with septic shock. *N Engl. J. Med.* **378**, 809–818 (2018).
23. Hagjer, S. & Kumar, N. Evaluation of the BISAP scoring system in prognostication of acute pancreatitis—a prospective observational study. *Int. J. Surg.* **54**, 76–81 (2018).
24. von Elm, E. et al. The strengthening the reporting of observational studies in epidemiology (STROBE) statement: Guidelines for reporting observational studies. *Lancet* **370**, 1453–1457 (2007).
25. Zhang, Z. Multiple imputation with multivariate imputation by chained equation (MICE) package. *Ann. Transl. Med.* **4**, 30 (2016).
26. Vercueil, A., Grocott, M. P. W. & Mythen, M. G. Physiology, pharmacology, and rationale for colloid administration for the maintenance of effective hemodynamic stability in critically Ill patients. *Transfus. Med. Rev.* **19**, 93–109 (2005).
27. Hannan, E. L. et al. Predictors of postoperative hematocrit and association of hematocrit with adverse outcomes for coronary artery bypass graft surgery patients with cardiopulmonary bypass. *J. Cardiac Surg.* **25**, 638–646 (2010).
28. Peng, D., Li, Z.-W., Liu, F., Liu, X.-R. & Wang, C.-Y. Predictive value of red blood cell distribution width and hematocrit for short-term outcomes and prognosis in colorectal cancer patients undergoing radical surgery. *World J. Gastroenterol.* **30**, 1714–1726 (2024).
29. Braamskamp, M. J. A. M., Dolman, K. M. & Tabbers, M. M. Clinical practice: Protein-losing enteropathy in children. *Eur. J. Pediatr.* **169**, 1179–1185 (2010).
30. Kim, H. J. & Lee, H. W. Important predictor of mortality in patients with end-stage liver disease. *Clin. Mol. Hepatol.* **19**, 105 (2013).
31. Xu, H., Zheng, X., Ai, J. & Yang, L. Hemoglobin, albumin, lymphocyte, and platelet (HALP) score and cancer prognosis: A systematic review and meta-analysis of 13,110 patients. *Int. Immunopharmacol.* **114**, 109496 (2023).
32. Ling, H. Z. et al. Calculated plasma volume status and prognosis in chronic heart failure. *Eu. J. Heart Fail* **17**, 35–43 (2015).
33. Crosignani, A. et al. Intravenous fluid therapy in patients with severe acute pancreatitis admitted to the intensive care unit: A narrative review. *Ann. Intensive Care* **12**, 98 (2022).
34. Dai, D.-M. et al. Difference in hematocrit and plasma albumin levels as an additional biomarker in the diagnosis of infectious disease. *Aoms* **16**, 522–530 (2020).
35. Minasyan, H. Sepsis and septic shock: Pathogenesis and treatment perspectives. *J. Crit. Care* **40**, 229–242 (2017).
36. Berg, D. & Gerlach, H. Recent advances in understanding and managing sepsis. *F1000Res* **7**, 1570 (2018).
37. Orfanos, S. E. et al. Angiopoietin-2 is increased in severe sepsis: Correlation with inflammatory mediators. *Crit. Care Med.* **35**(1), 199–206 (2007).
38. Ghim, M. et al. Visualization of three pathways for macromolecule transport across cultured endothelium and their modification by flow. *Am. J. Physiol.-Heart Circul. Physiol.* **313**, H959–H973 (2017).
39. Zhao, L., Huang, Y., He, T. & Hu, X. Clinical study on hematocrit used as a predictor for evaluation of resuscitation effect in the early shock stage after burn. *Zhonghua Shao Shang Za Zhi* **29**, 235–238 (2013).
40. Li, L. et al. Early rapid fluid therapy is associated with increased rate of noninvasive positive-pressure ventilation in hemoconcentrated patients with severe acute pancreatitis. *Dig. Dis. Sci.* **65**, 2700–2711 (2020).

Acknowledgements

We extend our gratitude to Dr. Jie Liu from the Department of Vascular and Endovascular Surgery, Chinese PLA General Hospital, for his insightful review and comments on the manuscript. We also thank Mingzi Tao and Tao Wu for their contributions to structured data extraction.

Author contributions

Wen Wu and Yupei Zhang conceived, designed the study and obtained the data, which was analyzed by Wen Wu and Chunzhen Zhang. Yupei Zhang and Wen Wu interpreted the data and results and drafted the manuscript. Zhaohui Zhang and Xingguang Qu critically revised the manuscript for intellectual content. All authors contributed to revising the article and approved the final version.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing interests

The authors declare no competing interests.

Ethics approval

This retrospective study was approved by the Ethics Committee of the First College of Clinical Medical Science of China Three Gorges University (ethical approval number: 2023-130-01), and informed consent was waived.

This study was conducted in accordance with the Declaration of Helsinki.

Additional information

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1038/s41598-024-77842-4.

Correspondence and requests for materials should be addressed to Z.Z.

Reprints and permissions information is available at www.nature.com/reprints.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.