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Clinical characteristics and early predictors of post-drowning acute respiratory distress syndrome in children: A retrospective cohort study in Hainan

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Abstract

Background: This study characterized the clinical features of post-drowning acute respiratory distress syndrome (ARDS) in children.

Methods: We retrospectively enrolled 212 drowning patients treated in the pediatric intensive care units (PICUs) of two large tertiary referral centers, namely Sanya Maternal and Child Hospital and Hainan General Hospital, Hainan Province, China, between January 2016 and December 2025. Patients were divided into ARDS and non-ARDS groups and their clinical data collected and compared. Variables showing intergroup differences were screened based on clinical experience, published evidence, least absolute shrinkage and selection operator (LASSO) regression, and variance inflation factor (VIF) assessment and subsequently subjected to multivariable analysis.

Results: Children in the ARDS versus non-ARDS group had a longer drowning duration, higher proportion of seawater drownings, and greater overall disease severity manifested by irregular breathing, a prolonged capillary refill time, elevated inflammatory markers, and decompensated metabolic acidosis (all $P < 0.05$). Patients in the ARDS group were more likely to show a white-out appearance on chest radiography and develop concomitant infections. Moreover, they were more likely to have multiple organ dysfunction syndrome (MODS), require invasive mechanical ventilation, and have a long PICU stay and had a higher mortality rate than those in the non-ARDS group (all $P < 0.05$). After LASSO, VIF, and manual screenings, six key variables were included in the binary logistic regression, of which five were associated with post-drowning ARDS: drowning duration ≥ 5 min (odds ratio [OR], 2.731; 95% confidence interval [CI], 1.132–6.589; $P = 0.025$), Pediatric Critical Illness Score (PCIS) (OR, 0.889; 95% CI, 0.848–0.933; $P < 0.001$), neutrophil-to-lymphocyte ratio (NLR) (OR, 1.536; 95% CI, 1.208–1.952; $P < 0.001$), lactate level (OR, 1.929; 95% CI, 1.465–2.540; $P < 0.001$), and a white-out appearance on chest radiography (OR, 5.369; 95% CI, 1.990–14.482; $P < 0.001$).

Conclusions: Children with versus without post-drowning ARDS have more severe illness and are more likely to develop concomitant infections and MODS. Greater vigilance for post-drowning ARDS is warranted in children with a drowning duration ≥ 5 min, elevated NLR, elevated lactate level, lower PCIS, and white-out appearance on chest radiography.

Background

Drowning remains a major public health issue in pediatric injury prevention. Global Burden of Disease data show that, although drowning mortality rates have declined since 1990, children continue to comprise a substantial share of drowning-related deaths and disabilities worldwide; moreover, China still bears a considerable burden of drowning-related morbidity and mortality [1–3]. The consequences of drowning extend beyond hypoxemia alone. In addition to acute respiratory failure and neurological injury, severe complications such as acute kidney injury, disseminated intravascular coagulation, and multiple organ dysfunction syndrome (MODS) may occur, underscoring the systemic nature of post-drowning injuries [4–7]. Among these complications, lung injury is among the most important and a major determinant of early management and short-term outcomes.

The role of water type in drowning-associated lung injury remains of particular clinical interest. Although aspiration under different osmotic conditions is assumed to produce distinct pulmonary effects, contemporary reviews and systematic analyses suggest that seawater and freshwater aspiration ultimately share similar lung injury pathways, including surfactant dysfunction, alveolar–capillary barrier disruption, intrapulmonary shunting, atelectatic changes, and non-cardiogenic pulmonary edema [8, 9]. However, whether water type influences acute respiratory distress syndrome (ARDS) development and severity remains unclear, especially in children. To date, pediatric drowning studies have focused mainly on hospitalization patterns, lung injury in a broad sense, radiographic abnormalities, and

overall prognosis, whereas evidence specifically addressing the clinical characteristics and associated early predictors of post-drowning ARDS in children remains limited [10–12].

Most recent pediatric studies have examined clinically significant drowning-associated lung injury, chest radiographic findings, and short-term outcomes rather than ARDS as a rigorously defined severe respiratory endpoint. Hainan, a tropical coastal province in southern China, provides a distinctive setting in which seawater and freshwater drownings are common. Its warm climate, frequent beach activities, widespread water recreation, and high tourism rates create a high-exposure environment in which pediatric drowning cases regularly occur, offering an opportunity to characterize regional patterns of drowning-related lung injury and compare ARDS-related manifestations across different water exposures.

Against this background, we conducted this retrospective cohort study at Hainan General Hospital and Sanya Maternal and Child Hospital, two major regional centers in northern and southern Hainan, with established pediatric intensive care and comprehensive rescue capacities. This study was designed to compare the clinical characteristics, laboratory findings, imaging features, and short-term outcomes of children with and without post-drowning ARDS and identify factors associated with post-drowning ARDS with the aim of informing early recognition, risk stratification, and clinical decision-making for pediatric post-drowning ARDS in coastal regions.

Methods

Study Population and Groups

This retrospective cohort study was conducted at Hainan General Hospital and Sanya Maternal and Child Hospital. By reviewing the hospitals' electronic medical record systems, we identified pediatric patients admitted to the pediatric intensive care units (PICUs) for drowning between January 2016 and December 2025. Because the study period spanned a decade, the medical records of children diagnosed with post-drowning ARDS were re-evaluated according to the Pediatric Acute Lung Injury Consensus Conference-2 (PALICC-2) criteria. Cases screened during the study period from January 2016 to December 2025 were required to meet all of the following **inclusion criteria**: (1) a clearly documented history of drowning exposure, with drowning identified as the primary diagnosis for the index hospitalization; (2) availability of reasonably reliable information on the submersion duration; (3) clear documentation of water type involved; (4) survival to hospital arrival and completion of the initial evaluation in the emergency department and/or PICU; (5) availability of key clinical data required for retrospective adjudication of ARDS according to the PALICC-2 criteria, with all ARDS diagnoses required to fulfill these criteria; (6) age < 18 years; (7) admission to the PICU of either participating center; and (8) sufficient completion of clinical records to allow extraction of the major study variables. A total of 404 drowning cases were reviewed based on the aforementioned criteria, of which 98 did not meet the inclusion criteria. The remaining 306 cases were then assessed against the following **exclusion criteria**: (1) drowning in unusual aquatic environments such as septic tanks; (2) non-accidental drowning, including suicide attempts; (3) respiratory illness within 1 week before the drowning that could confound the ARDS assessment; (4) withdrawal of treatment during hospitalization; (5) referral after prolonged and systematic treatment at another hospital; and (6) duplicate admissions or availability of repeated records related to the same drowning event. Application of the exclusion criteria excluded 94 patients; thus, 212 patients were ultimately included in the final analysis. These eligible patients were subsequently divided into ARDS (n = 78) and non-ARDS (n = 134) groups according to ARDS presence or absence (Fig. 1).

Data Collection

The retrieved clinical data included: (1) general characteristics including age, sex, and presence of underlying diseases; (2) drowning-related information including water type involved (seawater or freshwater) and submersion duration; (3) disease severity assessment of presence of irregular breathing, Glasgow Coma Scale (GCS) score, Pediatric Critical Illness Score (PCIS), and prolonged capillary refill time (CRT); (4) rapid laboratory and imaging findings including white blood cell count (WBC), neutrophil-to-lymphocyte ratio (NLR), hemoglobin (Hb) level, platelet count (Plt), C-reactive protein (CRP) level, glucose level, arterial blood pH, partial pressure of carbon dioxide, bicarbonate, base excess (BE), lactate (Lac) level, and the presence of a white-out appearance on chest radiography; and (5) treatment and prognosis details including concomitant infection, MODS, use of invasive mechanical ventilation (IMV), length of stay, and mortality.

Data Definitions

The terms used in this study were defined as follows. (1) Drowning was a process resulting in primary respiratory impairment from submersion/immersion in a liquid medium [13]. (2) ARDS was reassessed according to the PALICC-2 criteria to ensure consistency in diagnostic standards [14]. (3) Submersion duration was analyzed as a categorical variable because it was based on eyewitness reports and, therefore, subject to substantial recall bias. Using 5 min as the prespecified cutoff, submersion duration was recorded as being ≥ 5 min or < 5 min to reduce potential bias. (4) A prolonged CRT was defined as a capillary refill time ≥ 3 s [15]. (5) MODS was defined as dysfunction of two or more organ systems secondary to drowning such that homeostasis could not be maintained without intervention [16]. (6) Concomitant infection was defined as a microbiologically supported infection identified during the initial evaluation or hospitalization based on positive pathogen detection by conventional microbiological methods (e.g., culture) and/or molecular assays including next-generation sequencing or metagenomic next-generation sequencing from clinically relevant specimens together with compatible clinical manifestations, inflammatory evidence, and/or imaging findings. Results considered more consistent with colonization, commensal carriage, or contamination were excluded [17]. (7) A white-out appearance on chest radiography was defined as extensive confluent bilateral air-space opacification on the initial chest radiograph with near-complete or complete obscuration of both pulmonary fields and minimal residual aerated lung consistent with severe acute pulmonary parenchymal disease and not primarily explained by pleural effusion or simple atelectasis [14]. (8) Irregular breathing was defined as an abnormal respiratory rhythm and/or obviously irregular respiratory depth or effort documented on arrival or during the initial assessment, including irregularly timed breaths without a stable rhythm, recurrent respiratory pauses or apnea, gasping or agonal respirations, cluster or ataxic (Biot-like) breathing, or Cheyne–Stokes-like periodic breathing. (9) Apnea was defined as the cessation of respiratory effort for > 20 s or a shorter pause accompanied by bradycardia, cyanosis, or hypotonia [18].

Statistical Analysis

The data were analyzed using SPSS (version 27.0) and R (version 4.5.3). No data were missing for any variables included in the final analyses. Continuous variables are expressed as mean ± standard deviation or median (interquartile range), as appropriate, while categorical variables are presented as counts and percentages. Intergroup comparisons were performed using the independent-samples t-test or Mann–Whitney U test for continuous variables and the chi-squared test or Fisher's exact test for categorical variables, as appropriate. Candidate variables for multivariate analysis were screened using least absolute shrinkage and selection operator (LASSO) regression. Variables retained by the LASSO regression were further evaluated using variance inflation factor (VIF) analysis, Spearman correlation analysis, and clinical judgment before inclusion in the multivariable logistic regression model. The multivariate logistic regression was subsequently performed to identify factors independently associated with

post-drowning ARDS. All statistical tests were two-sided, and values of $P < 0.05$ were considered statistically significant.

Results

Clinical Characteristics of Post-Drowning ARDS

A total of 212 pediatric post-drowning patients were included in this study, of whom 78 developed ARDS, yielding an ARDS incidence of 36.8%. Among the patients with ARDS, 67 were male (85.9%) and 11 were female (14.1%), with a mean age of 7.0 ± 2.6 years. Thirty-eight patients (48.7%) experienced a seawater drowning, while 40 (51.3%) experienced a freshwater drowning. The drowning duration was ≥ 5 min in 28 cases (35.9%). The median GCS score was 8.5 (7.0–11.0), while the median PCIS was 62.0 (53.0–72.0). A prolonged CRT was observed in 30 patients (38.5%), while irregular breathing was noted in 43 patients (55.1%). Patients with ARDS exhibited systemic inflammatory activation and decompensated acidosis, with a mean WBC count of 14.03 ± 4.28 × 10^9/L, median NLR of 3.65 (2.49–5.46), and median CRP level of 47.65 (37.70–62.80) mg/L. The median pH was 7.25 (7.16–7.35), BE was − 8.5 (-15.8 to -3.4) mmol/L, and Lac was 4.5 (3.7–5.8) mmol/L. Chest radiography revealed a white-out appearance in 29 patients (37.2%). MODS occurred in 18 patients (23.1%), while concomitant infections were noted in 31 patients (39.7%). IMV was required in 40 patients (51.3%). The median PICU stay was 10.0 (6.0–21.0) days, and nine patients (11.5%) died.

Intergroup Differences in Clinical Characteristics

No significant differences were noted in sex distribution or mean age between the patients with versus without ARDS ($P > 0.05$). Compared with the non-ARDS group, the ARDS group had a higher proportion of seawater drownings ($P = 0.002$) and drowning durations ≥ 5 min ($P = 0.046$) as well as lower GCS and PCIS scores (both $P < 0.001$). The ARDS group also had a higher frequency of a prolonged CRT ($P = 0.034$) and irregular breathing ($P = 0.021$). Moreover, WBC counts, NLR, and CRP levels were significantly higher in the ARDS group (all $P < 0.001$). Hb levels and Plt counts also differed significantly between the two groups (both $P < 0.05$), although their median and mean values remained within the normal clinical reference ranges. Acidosis was more severe in patients with ARDS as reflected by lower pH and BE values and higher Lac levels (all $P < 0.001$). The ARDS group also had a significantly higher proportion of patients with white-out appearances on chest radiography ($P < 0.001$), MODS ($P = 0.008$), and concomitant infections ($P = 0.003$). Moreover, in the ARDS group, IMV was used more frequently ($P = 0.028$), PICU stays were longer ($P < 0.001$), and the mortality rate was higher ($P = 0.001$) (Table 1).

Table 1
Baseline characteristics of drowning patients with and without ARDS

Variables	ARDS (n = 78)	Non-ARDS (n = 134)	t/Z/χ^2	P value
Demographic and clinical characteristics				
Male sex, n (%)	67 (85.9)	116 (86.6)	0.019	0.891
Age, years	7.0 ± 2.6	7.3 ± 2.7	0.763	0.446
Seawater drowning, n (%)	38 (48.7)	37 (27.6)	9.607	0.002*
Drowning duration ≥ 5 min, n (%)	28 (35.9)	31 (23.1)	3.999	0.046*
Underlying disease, n (%)	3 (3.8)	14 (10.4)	2.913	0.088
GCS	8.5 (7.0, 11.0)	11.0 (10.0, 12.0)	-6.247	< 0.001*
PCIS	62.0 (53.0, 72.0)	73.0 (71.0, 77.0)	-6.571	< 0.001*
Prolonged CRT, n (%)	30 (38.5)	33 (24.6)	4.518	0.034*
Irregular breathing, n (%)	43 (55.1)	52 (38.8)	5.311	0.021*
Laboratory parameters				
WBC, $\times 10^9$/L	14.03 ± 4.28	10.79 ± 4.33	-5.281	< 0.001*
NLR	3.65 (2.49, 5.46)	2.58 (2.04, 3.55)	4.105	< 0.001*
Hemoglobin, g/L	123.0 (108.0, 133.0)	125.5 (114.0, 138.0)	-1.968	0.049*
Platelet count, $\times 10^9$/L	206.23 ± 56.81	223.37 ± 49.40	2.303	0.022*
CRP, mg/L	47.65 (37.70, 62.80)	29.80 (20.30, 40.10)	6.698	< 0.001*
Glucose, mmol/L	10.4 (8.5, 12.6)	10.7 (9.1, 13.6)	0.973	0.331
pH	7.25 (7.16, 7.35)	7.34 (7.30, 7.38)	-5.093	< 0.001*
$PaCO_2$, mmHg	40.5 (35.8, 47.3)	38.6 (32.2, 41.2)	1.328	0.148
BE, mmol/L	-8.5 (-15.8, -3.4)	-3.7 (-6.3, 0)	-5.193	< 0.001*
Lactate, mmol/L	4.5 (3.7, 5.8)	3.4 (2.2, 4.4)	6.014	< 0.001*
Clinical outcomes and complications				
White-out appearance on chest radiography, n (%)	29 (37.2)	13 (9.7)	23.432	< 0.001*
MODS, n (%)	18 (23.1)	13 (9.7)	7.065	0.008*

Note:*P<0.05

Variables	ARDS (n = 78)	Non-ARDS (n = 134)	$t/Z/\chi^2$	P value
Demographic and clinical characteristics				
Concomitant infection, n (%)	31 (39.7)	28 (20.9)	8.720	0.003*
IMV, n (%)	40 (51.3)	48 (35.8)	4.854	0.028*
ICU length of stay, days	10.0 (6.0, 21.0)	7.0 (5.0, 13.0)	6.517	< 0.001*
In-hospital death, n (%)	9 (11.5)	2 (1.5)	10.114	0.001*
Note:*P<0.05				

Variable Screening by LASSO Regression, VIF Assessment, and Clinical Judgment

LASSO regression was used to identify the candidate predictors of post-drowning ARDS. As a regularization approach, LASSO shrinks the coefficients of less informative variables toward zero, thereby facilitating variable selection, reducing overfitting, and improving model stability. Thirteen candidate variables were retained by the LASSO regression, including seawater drowning, drowning duration ≥ 5 min, GCS score, PCIS, WBC count, NLR, CRP level, Hb level, Plt count, pH, BE, Lac level, and a white-out appearance on chest radiography (Fig. 2). The VIF analysis showed no apparent multicollinearity among these variables (all VIF < 5) (Fig. 3). However, given the limited sample size, the inclusion of all 13 variables in the multivariable model might have compromised model stability. These candidate variables were further screened using Spearman's correlation and clinical judgment analyses. Similarly, although pH, BE, and Lac level are related to acid–base/metabolic status, their clinical implications are not identical. Moreover, pH was significantly positively correlated with BE ($\rho = 0.648$, $P < 0.001$), whereas pH and BE were significantly negatively correlated with Lac level (pH vs. Lac: $\rho = -0.320$, $P < 0.001$; BE vs. Lac: $\rho = -0.315$, $P < 0.001$) (Table 2). Nevertheless, Lac level was retained as a representative acid–base/metabolic variable because it is a more clinically informative early marker of tissue hypoperfusion and illness severity that more directly reflects tissue hypoxia and enhances anaerobic metabolism than pH or BE. Ultimately, seawater drowning, drowning duration ≥ 5 min, PCIS, NLR, Lac level, and a white-out appearance on chest radiography were entered into the multivariable analysis.

Table 2
Correlation analysis among candidate variables with overlapping clinical meaning and final variable retention

Variable domain	Variable 1	Variable 2	Correlation coefficient (ρ)	P value	Correlation direction	Variable retained for multivariable analysis	Basis for retention
Neurologic severity	GCS	PCIS	0.421	<0.001	Positive	PCIS	PCIS includes neurologic components and better reflects overall critical illness severity
Inflammatory burden	WBC	NLR	0.154	0.025	Positive	NLR	NLR was selected as the representative inflammatory marker
Inflammatory burden	CRP	NLR	0.127	0.032	Positive	NLR	NLR was selected as the representative inflammatory marker
Acid-base/metabolic status	pH	BE	0.648	<0.001	Positive	Lactate	Lactate was selected as the representative acid-base/metabolic marker
Acid-base/metabolic status	pH	Lactate	-0.320	<0.001	Negative	Lactate	Lactate better reflects tissue hypoperfusion and illness severity
Acid-base/metabolic status	BE	Lactate	-0.315	<0.001	Negative	Lactate	Lactate better reflects tissue hypoperfusion and illness severity

Multivariable Logistic Regression Analysis

The six variables retained after LASSO screening and further selection by VIF analysis, Spearman correlation analysis, and clinical judgment—seawater drowning, drowning duration ≥ 5 min, PCIS, NLR, Lac level, and a white-out appearance on chest radiography—were simultaneously entered into a multivariable logistic regression model using the Enter method, with ARDS occurrence as the dependent variable. The multivariable logistic regression showed that a drowning duration ≥ 5 min, lower PCIS, higher NLR, higher Lac level, and a white-out appearance on chest radiography were independently associated with post-drowning ARDS, whereas a seawater drowning did not remain statistically significant after the adjustment. Specifically, a drowning duration ≥ 5 min was associated with a higher likelihood of post-drowning ARDS (OR, 2.731; 95% CI, 1.132–6.589; P = 0.025). Each 1-point increase in PCIS was associated with a lower odds of ARDS (OR, 0.889; 95% CI, 0.848–0.933; P < 0.001). A higher NLR (OR, 1.536; 95% CI, 1.208–1.952; P < 0.001), higher Lac level (OR, 1.929; 95% CI, 1.465–2.540; P < 0.001), and a white-out appearance on

chest radiography (OR, 5.369; 95% CI, 1.990–14.482; P < 0.001) were also independently associated with post-drowning ARDS (Table 3).

Table 3
Multivariable logistic regression analysis of factors associated with ARDS after drowning

Variables	Coefficient	S.E.	Wald	df	P	Odds Ratio(OR)	95% Confidence Interval(CI)
Seawater drowning	0.757	0.418	3.281	1	0.070	2.133	0.940–4.840
Drowning duration ≥ 5 min	1.005	0.449	4.997	1	0.025	2.731	1.132–6.589
PCIS (per 1-point increase)	-0.117	0.024	22.951	1	< 0.001	0.889	0.848–0.933
NLR	0.429	0.122	12.268	1	< 0.001	1.536	1.208–1.952
Lactate, mmol/L	0.657	0.140	21.896	1	< 0.001	1.929	1.465–2.540
White-out appearance on chest radiography	1.681	0.506	11.018	1	< 0.001	5.369	1.990–14.482

1. Variables retained after LASSO screening and further selection based on correlation analysis and clinical judgment were simultaneously entered into the multivariable logistic regression model using the Enter method.

2. Model fit: Likelihood ratio test confirmed statistical significance (χ^2 = 123.951, df = 6, P < 0.001).

3. Abbreviations: S.E. = standard error; OR = odds ratio; CI = confidence interval.

Discussion

This retrospective cohort study of two regional pediatric critical care centers in Hainan focused on post-drowning ARDS as a clearly defined and clinically important severe outcome rather than the broader and less specific concepts of “lung injury” or “radiographic abnormality.” Our results showed that ARDS is not uncommon among pediatric drowning patients; once established, it is associated with a substantially greater systemic disease burden and worse short-term outcomes. Compared with children without ARDS, those with ARDS had a longer submersion duration, a lower PCIS, higher NLR and Lac levels, and more severe chest imaging abnormalities; were more likely to develop concomitant infection and MODS; and had higher requirements for IMV, longer PICU stays, and a greater in-hospital mortality rate. Previous pediatric drowning studies gradually moved beyond simple epidemiologic description toward more detailed evaluations of lung injury, respiratory complications, and clinical outcomes, yet most focused on drowning-associated lung injury, radiographic abnormalities, or overall hospitalization outcomes rather than ARDS as a rigorously defined severe respiratory endpoint [11, 19–22]. Accordingly, the main value of the present study lies in extending the existing pediatric drowning literature by specifically targeting ARDS and identifying early clinical signals that may support front-load risk stratification in the emergency department and PICU.

In the present cohort, children with ARDS had a longer submersion duration, a higher proportion of seawater drownings, more frequent irregular breathing, and worse treatment and prognostic indicators; however, the multivariate analysis showed that submersion duration, rather than water type, was independently associated with ARDS. This distinction is important. Earlier clinical observations and traditional pathophysiological concepts suggested divergent systemic effects of freshwater and seawater aspiration. Freshwater aspiration was historically linked to hemodilution, electrolyte disturbance, erythrocyte injury, and even severe coagulation disorders including

disseminated intravascular coagulation in extreme cases, whereas seawater, owing to its hyperosmolarity and high salt content, has long been considered more likely to aggravate alveolar fluid shifts, pulmonary edema, and acute lung injury [23, 24].

Experimental studies supported the ability of seawater exposure to induce marked alveolar–capillary barrier injury and surfactant dysfunction [24]. However, more recent reviews and systematic evaluations emphasized that, regardless of water type, severe drowning-related lung injury ultimately converges on common downstream pathways including surfactant inactivation, alveolar–capillary barrier disruption, atelectatic change, pulmonary edema, and ventilation–perfusion mismatch [8, 9]. Our findings are consistent with this more contemporary view: seawater drowning was associated with ARDS in the univariable analysis but lost significance after the adjustment for submersion duration and overall critical illness severity, whereas a submersion duration ≥ 5 min remained stable in the final model. This suggests that time spent underwater better captures the true pathophysiological burden relevant to ARDS than water type. The higher frequency of irregular breathing in the ARDS group is also biologically plausible. Early irregular breathing post-drowning likely reflects severe hypoxemia, an unstable respiratory drive, central suppression, and an evolving airway and parenchymal injury. Thus, it should be understood as an early severe clinical phenotype rather than a non-specific respiratory symptom. Although this variable did not remain in the final model, its predictive information was likely absorbed by more integrated indicators such as PCIS, Lac level, and imaging findings. Importantly, the children with ARDS in our cohort also required mechanical ventilation more often, stayed longer in the PICU, and had a higher mortality rate, further indicating that post-drowning ARDS is not merely an imaging or oxygenation abnormality but rather a marker of a more complex, resource-intensive, and prognostically unfavorable disease trajectory.

A lower PCIS score, among the most clinically distinctive findings in this study, deserves particular emphasis. PCIS is a pediatric critical illness scoring tool developed and widely used in China for the rapid bedside assessment of overall disease severity. Its major strengths include its relative simplicity, reliance on objective physiological variables, low resource demand, and strong practicality in emergency and PICU settings. Previous studies demonstrated that PCIS can discriminate between different levels of critical illness severity and has prognostic value in severe hand-foot-and-mouth disease, pediatric sepsis, and other PICU scenarios, with lower scores indicating more severe organ dysfunction and a higher risk of death [25–27]. When applied to post-drowning ARDS, its role becomes particularly understandable, as drowning does not cause an isolated single-organ injury; rather, it is a complex syndrome characterized by hypoxemia, acidosis, impaired perfusion, and multisystem compensatory failure. PCIS is well-suited to capture this global critical illness state, which also helps explain why it performed more robustly than the GCS in the final model. In this context, the value of PCIS does not lie in being “an ARDS-specific predictor” but rather in signaling that the child is already on a trajectory of severe hypoxic, hemodynamic, and multiorgan deterioration before ARDS is fully established. From this perspective, emphasizing PCIS in the early stratification of post-drowning ARDS is not only clinically useful, but it also highlights the translational value of a locally developed pediatric critical care tool in Chinese clinical research.

A white-out appearance on chest radiography was independently associated with post-drowning ARDS and showed the largest effect size in the final model. However, it must be emphasized that the presence of a white-out appearance is not synonymous with ARDS. ARDS remains a syndromic diagnosis requiring acute onset, impaired oxygenation, imaging evidence of pulmonary parenchymal injury, and a clinical context consistent with non-cardiogenic pulmonary edema; white-out is merely one extreme imaging phenotype within this spectrum. The strong early warning value in our study is likely derived from the fact that it reflects severe alveolar filling, diffuse pulmonary consolidation, marked loss of aerated lung volume, and advanced alveolar–capillary barrier injury already present at the time of admission. Previous pediatric drowning imaging studies demonstrated that the presence of early chest radiographic

abnormalities is associated with more severe clinical status, greater need for hospitalization or intensive care, and a more complicated hospital course [10, 12]. Thus, in the present context, a white-out appearance should be understood as an early severe lung injury phenotype and high-risk warning signal rather than radiographic surrogate for ARDS itself. This interpretation is also consistent with the progression of drowning-related lung injuries. Fluid aspiration, surfactant washout, alveolar edema, atelectasis, and inflammatory exudation drive the lung from a potentially reversible injury toward diffuse alveolar damage, while the white-out appearance represents the imaging concentration of this process. Therefore, children presenting with a white-out appearance warrant more intensive oxygenation surveillance, repeat imaging when indicated, and earlier consideration of escalated respiratory support, even if their initial vital signs appear temporarily acceptable.

This study had several strengths. First, it focused specifically on post-drowning ARDS, a clearly defined and clinically important severe outcome, rather than on broader constructs such as lung injury or radiographic abnormalities. Second, the study included patients from two regional centers in Hainan with substantial experience with pediatric drowning rescue and covered nearly a decade of time, thereby providing a reasonable sample base and regional relevance. Third, variable selection was not performed mechanically by entering all significant univariable factors but instead incorporated LASSO, a collinearity assessment, a correlation analysis, and clinical judgment, which improved model stability and interpretability.

The study also had several limitations. As it was retrospective in design, exposure information such as submersion duration was inevitably subject to recall bias. In addition, Hainan has distinctive island- and tourism-related exposure characteristics, including a relatively high proportion of seawater drownings; therefore, caution is needed when extrapolating these findings to other regions. The variables retained in this study are better understood as early clinical factors independently associated with ARDS rather than as strictly causal upstream determinants. Finally, although concomitant infections were more frequent in the ARDS group, we did not further analyze the pathogen distribution, infection timing, or appropriateness of antimicrobial therapy. Overall, our findings suggest that post-drowning ARDS is a severe composite outcome with both pulmonary injury and systemic critical illness features; moreover, variables such as submersion duration, PCIS, and a white-out appearance may help clinicians identify high-risk children before ARDS becomes fully established [14, 19, 28].

Conclusions

In conclusion, post-drowning ARDS is common in children and associated with more severe systemic pathophysiological disturbances and poorer short-term outcomes. A submersion duration ≥ 5 min, lower PCIS, higher NLR, elevated Lac level, and white-out appearance on chest radiography were independently associated with ARDS and may serve as clinically useful markers for the early identification of high-risk children. Further validation in larger multicenter cohorts is warranted, as are efforts to develop more practical early stratification and intervention pathways based on these initial clinical features.

Abbreviations

ARDS, acute respiratory distress syndrome

BE, base excess

CRP, C-reactive protein

CRT, capillary refill time

GCS, Glasgow Coma Scale

Hb, hemoglobin

IMV, invasive mechanical ventilation

Lac, lactate

LASSO, least absolute shrinkage and selection operator

MODS, multiple organ dysfunction syndrome

NLR, neutrophil-to-lymphocyte ratio

PALICC-2, Pediatric Acute Lung Injury Consensus Conference-2

PCIS, Pediatric Critical Illness Score

PICUs, pediatric intensive care units

Plt, platelet

VIF, variance inflation factor

WBC, white blood cell

Declarations

Ethics approval and consent to participate

The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of Sanya Maternal and Child Hospital (No.SYFYIRB2025113).Due to the design of retrospective observation study, informed consent was waived.

Consent for publication

not applicable

Availability of data and materials

Data supporting reported results are available by contacting the corresponding author.

Competing interests

The authors declare that they have no conflict of interest.

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not applicable

Authors' contributions

Conceptualization, Feng Jiang.; Methodology, Hongdie Chen; Formal Analysis, Hongdie Chen; Investigation, Boyi Lin & Yuanlu Chen;Data Curation, Hongdie Chen & Boyi Lin; Writing - Original Draft Preparation, Feng Jiang & Hongdie Chen;Supervision, Zefu Chen & Shufan Wu.

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Figures

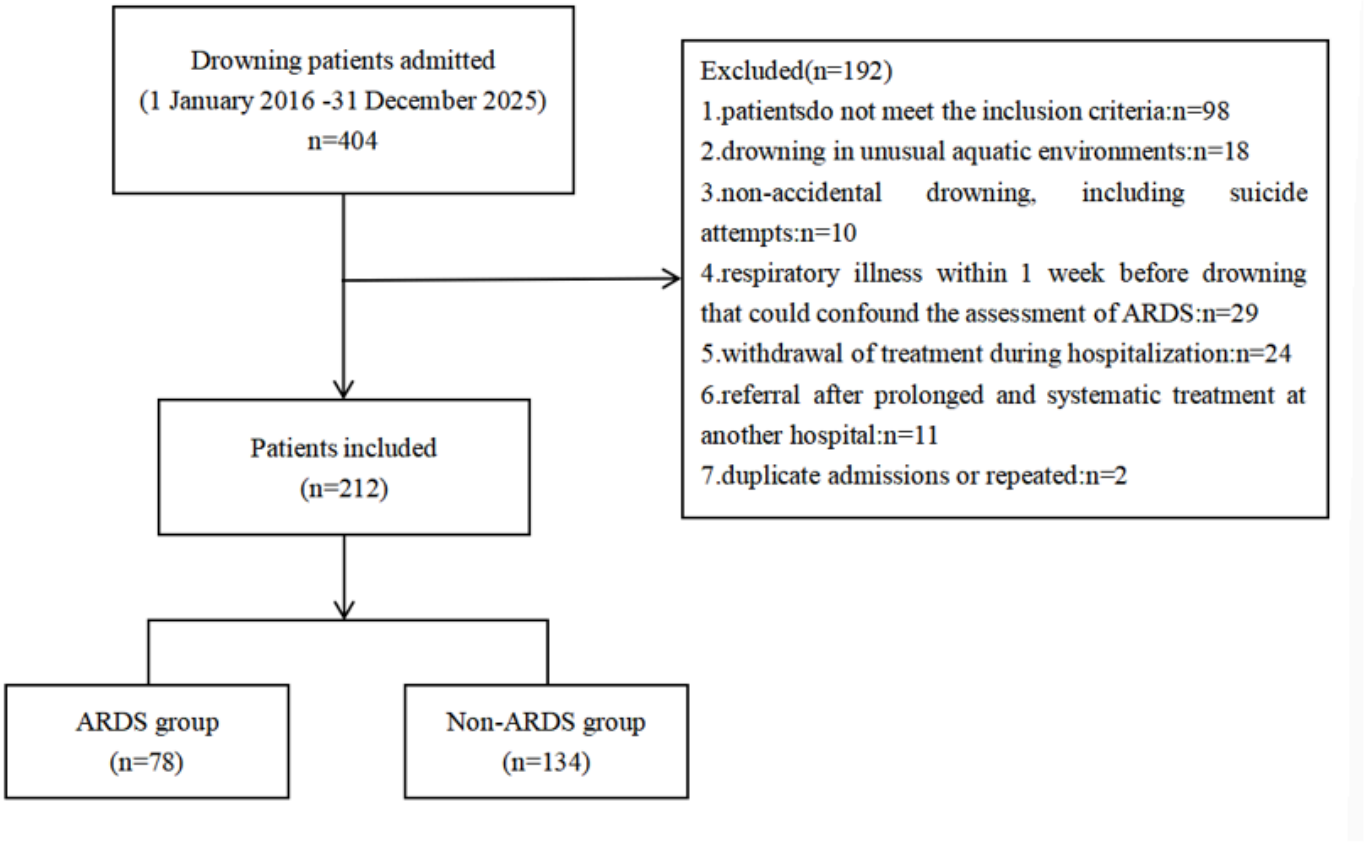


Figure 1

Flowchart of patient exclusion criteria

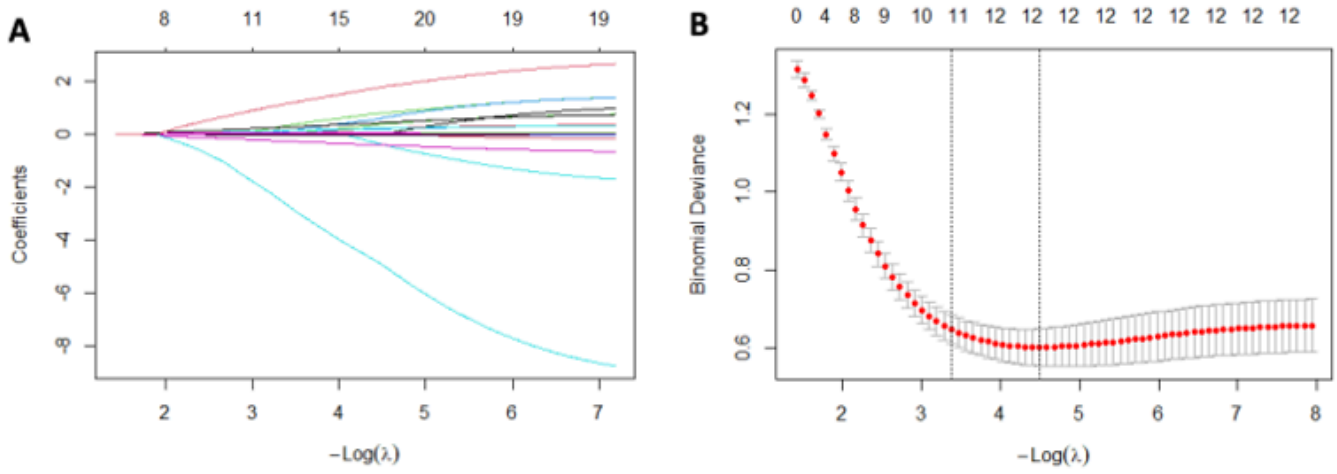


Figure 2

Feature selection of candidate predictors for ARDS after drowning using LASSO regression.(A) Coefficient profiles of candidate variables during LASSO regularization. Each curve represents the regression coefficient trajectory of an individual variable as the penalty parameter λ changes. The vertical axis shows coefficient values, the lower

horizontal axis shows −log(λ), and the upper horizontal axis indicates the number of non-zero coefficients retained in the model.(B) Optimal λ selection by 10-fold cross-validation based on binomial deviance. Red dots indicate the mean cross-validated binomial deviance, and grey bars represent standard errors. The vertical dashed lines indicate the λ values selected according to the minimum criterion and the 1-SE criterion, respectively.

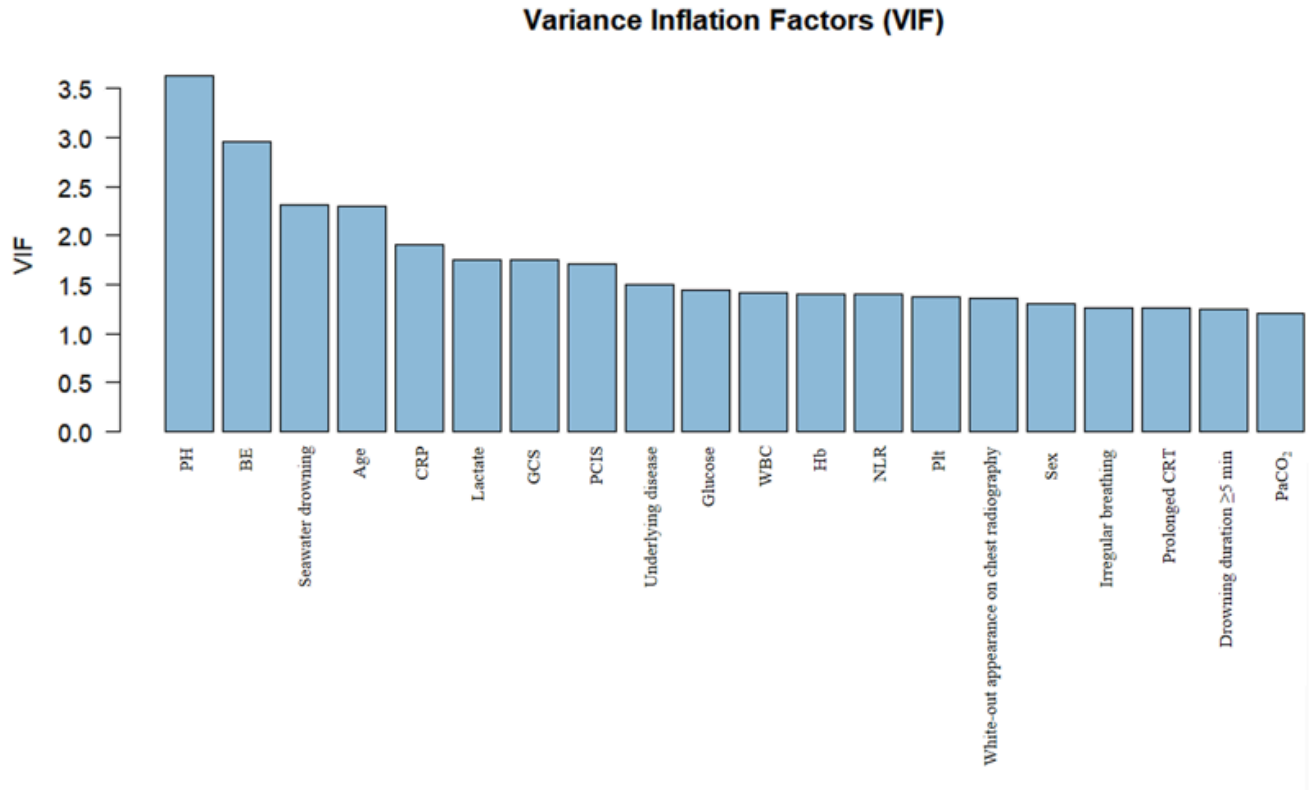


Figure 3

Variance inflation factor (VIF) analysis for candidate predictors of ARDS after drowning.The bar plot shows the VIF value of each candidate variable included in the screening process. The vertical axis represents the VIF value, and the horizontal axis represents the corresponding variables. All candidate variables had VIF values < 5, suggesting the absence of apparent multicollinearity.