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Weight variability at pediatric intensive care unit admission and adverse outcomes in critically ill children

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Background: Body weight can fluctuate during critical illness due to factors such as fluid shifts, nutritional status, the type of acute illness, and underlying comorbidities. We investigated the association between acute body weight variability (WV) and clinical outcomes in critically ill pediatric patients.

Methods: We retrospectively analyzed data from patients aged 1 month to 18 years who were admitted to the pediatric intensive care unit (PICU) of a university-affiliated tertiary hospital between August 2017 and July 2021. WV was defined as the percentage difference between the measured body weight at PICU admission and the usual body weight, obtained either from recent hospital records or caregiver reports. Associations between WV and clinical outcomes, including PICU mortality and ventilator-free days (VFDs), were assessed.

Results: Of the 926 patients, 74 (8.0%) died. Median WV was significantly higher in non-survivors than in survivors (8.7% vs. 0.0%, P<0.001). Increased WV was independently associated with higher mortality (hazard ratio [HR], 1.102; 95% CI, 1.073–1.131) and fewer VFDs (odds ratio [OR], 0.599; 95% CI, 0.524–0.684). Combining WV with Pediatric Index of Mortality 3 score significantly improved mortality prediction over either parameter alone (area under the curve, 0.888; P=0.047).

Conclusions: Higher WV at PICU admission is independently associated with adverse clinical outcomes, including increased mortality and fewer VFDs. WV could complement existing mortality prediction models in pediatric critical care.

Key Words: critical illness; mortality; pediatric intensive care unit; prognosis; weight variability

Original Article

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INTRODUCTION

Accurate mortality prediction in the pediatric intensive care unit (PICU) supports assessments of disease severity, guides clinical decision-making, and informs evaluations of novel

therapies, interventions, and health policy outcomes [1]. The Pediatric Index of Mortality 3 (PIM 3) score, a widely used and validated mortality prediction model, estimates risk using physiological data collected during the first hour of PICU admission, in conjunction with diagnostic risk stratification [2,3].

Nutritional status plays a critical role in the outcomes of children in PICUs because both malnutrition and obesity are associated with increased morbidity and mortality rates [4]. However, static, single-point anthropometric measures such as body weight or the body mass index (BMI) offer limited insight into a child's nutritional status [5]. Chronic comorbidities and metabolic imbalances frequently obscure the true physiological reserve, making isolated measurements unreliable [6,7].

Body weight in the acute phase of a critical illness is strongly influenced by fluid status, such as edema or fluid overload, and that limits its reliability as a standalone indicator of nutritional status. Nevertheless, acute weight changes could reflect physiological instability, including both nutritional deficits and dynamic shifts in volume status, and might therefore carry independent prognostic significance [8]. Although several nutritional screening tools for critically ill children have been proposed [9], no universally accepted standard currently exists.

Therefore, we hypothesized that acute weight changes at PICU admission, regardless of the patient's underlying cause of admission, might correlate with poor clinical outcomes. In this study, we evaluated whether early weight variability (WV), potentially reflecting fluid shifts or nutritional instability, can serve as a prognostic marker in pediatric patients who are critically ill.

KEY MESSAGES

- Higher weight variability (WV) at pediatric intensive care unit admission is independently associated with increased mortality and fewer ventilator-free days in critically ill children.
- Incorporating WV with existing severity scores (e.g., PIM 3) enhances risk stratification.
- WV is a feasible and pragmatic indicator that is especially useful in resource-limited settings that lack comprehensive nutritional assessment tools.

MATERIALS AND METHODS

This study was approved by the Institutional Review Board of the Severance Hospital, Seoul, Korea (No. 4-2021-1041). This study was conducted in accordance with the principles of the Declaration of Helsinki and reporting guidelines. The requirement for informed consent was waived because this study was retrospective.

Study Design and Data Collection

We conducted a retrospective observational study using data extracted from the electronic medical records of a tertiary university-affiliated hospital. The data of patients aged 1 month to 18 years who were admitted to the PICU between August 2017 and July 2021 were screened for inclusion in this study. Patients admitted for short-term observations without major medical interventions and those with PICU lengths of stay <3 days were excluded from the analysis. The following demographic and anthropometric data were collected for the eligible study population at the time of PICU admission: age, sex, height, body weight, and BMI. Additional clinical information (the primary reason for PICU admission, presence of comorbidities, PIM 3 score, duration of mechanical ventilation, and PICU mortality) was also obtained.

Variable Definitions

WV at PICU admission was calculated using the following formula:

$$\text{WV}\ (\%) = \left| \frac{\text{Usual body weight} - \text{body weight at PICU admission}}{\text{Usual body weight}} \right| \text{x}100$$

The usual body weight was primarily obtained from nutritional support team consultation records at PICU admission, which were based on caregiver-reported values documented by dietitians during structured interviews. These values represented the most recent weight, within 1–3 months prior to admission, and were reported to assess acute changes in body weight. If caregiver-reported data were unavailable, we used weights documented in the electronic health records within 1 month prior to admission [10,11]. Nutritional status at the time of PICU admission was categorized according to anthropometric z-scores as follows: normal, z-score > –1; mild malnutrition, z-score between –2 and –1; moderate malnutrition, z-score between –3 and –2; and severe malnutrition, z-score

≤ –3. Z-scores were calculated based on the 2017 Korean National Growth Charts for children and adolescents [12]. For patients <2 years old, height-for-weight z-scores were used [13,14]. For those aged ≥ 2 years old, BMI-for-age z-scores were used [13,15].

The primary outcome was mortality in the PICU. The secondary outcomes were the duration of mechanical ventilation, ventilator-free days (VFDs) at day 28, and length of PICU stay. VFDs were calculated for survivors by subtracting the number of days on mechanical ventilation from 28. A VFD value of zero was assigned to patients who died in the PICU or required mechanical ventilation for ≥28 days [16]. The durations of mechanical ventilation and PICU stay were analyzed only among survivors.

Statistical Analysis

Categorical variables are presented as counts and percentages. Continuous variables were tested for normality using the Kolmogorov-Smirnov test and are reported as medians with interquartile ranges (IQRs). A Cox proportional hazards regression model was used to analyze survival outcomes, with adjustments for age, sex, comorbidities, and the PIM 3 score. Multivariable regression analyses were performed to evaluate the correlation between WV and the secondary outcomes. The predictive performance of WV for PICU mortality was assessed using a receiver operating characteristic (ROC) curve analysis, and area under the curve (AUC) values were compared using DeLong's test. Kaplan-Meier survival curves were constructed based on dichotomized WV (high and low), with the optimal cutoff point derived from the ROC analysis.

RESULTS

Characteristics of the Study Population

During the study period, 1,170 pediatric patients were screened, and 926 met the inclusion criteria (Figure 1). Of those 926 patients, 74 (8.0%) were non-survivors. The demographic and clinical characteristics of the study population are summarized in Table 1. No significant differences in sex or anthropometric z-scores for height-for-weight or BMI were observed between survivors and non-survivors. However, non-survivors were significantly older than survivors.

Neurological disorders were the most prevalent comorbidity, affecting 33.3% of patients, followed by pulmonary disorders at 30.8%. Pulmonary disorders were the most common reason for PICU admission, accounting for 40.1% of cases. A significant difference in survival was observed based on nutritional status (P=0.006); however, no consistent trend or dose–response relationship was identified between the severity of malnutrition and mortality.

Association between WV and Clinical Outcomes

Median WV was significantly higher in non-survivors than in survivors (8.7% [IQR, 3.7–12.2] vs. 0.0% [IQR, 0.0–3.6]; P <0.001) (Table 1). After adjustment for potential confounders (age, sex, PIM 3 score, and comorbidities), the multivariable Cox proportional hazards analysis revealed that WV was independently associated with an increased risk of PICU mortality. In particular, each 1% increase in WV was associated with a 10.2% increase in the mortality risk (hazard ratio [HR], 1.102; 95% confidence interval [CI], 1.073–1.131; P<0.001) (Figure 2). In a multivariable logistic regression analysis adjusting for the same confounders, WV was also independently associated with mortality. The predicted probability of mortality increased steeply as WV exceeded 10%, suggesting that higher degrees of acute weight fluctuation strongly reflect adverse clinical outcomes (Supplementary Figure 1).

Among the secondary outcomes (Table 2), WV was significantly associated with fewer VFDs at day 28 (adjusted odds ratio [OR], 0.599; 95% CI, 0.524–0.684; P<0.001). Spline-based

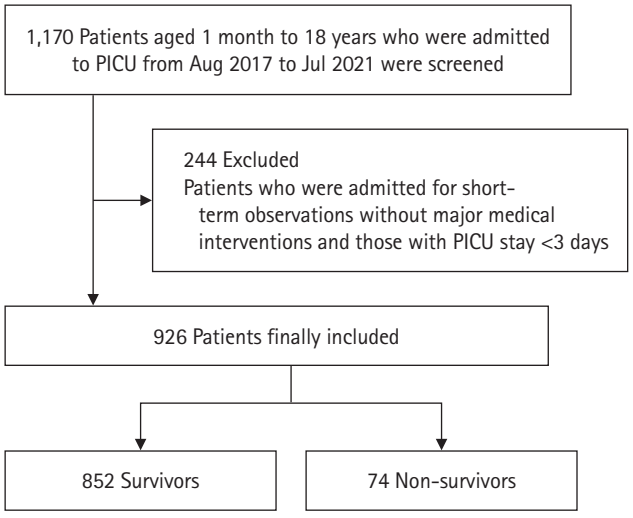

Figure 1. Study flowchart. PICU: pediatric intensive care unit.

Table 1. Baseline characteristics of the study population

Variable	Total patients (n=926)	Survivor (n=852)	Non-survivor (n=74)	P-value
Age (yr)	4.0 (1.1 to 9.6)	3.7 (1.1 to 9.4)	5.7 (1.3 to 14.2)	0.027
Sex (male)	509 (55.5)	468 (54.9)	41 (55.4)	>0.999
Comorbidity				-
Pulmonological disorder	285 (30.8)	276 (32.4)	9 (12.2)	
Infectious disease	65 (7.0)	55 (6.5)	10 (13.5)	
Neurological disorder	308 (33.3)	297 (34.9)	11 (14.9)	
Gastrointestinal disorder	91 (9.8)	81 (9.5)	10 (13.5)	
Hemato-oncological disorder	95 (10.3)	66 (7.7)	29 (39.2)	
Renal disorder	40 (4.3)	35 (4.1)	5 (6.8)	
Cardiac disease	14 (1.5)	14 (1.6)	0	
Trauma	28 (3.0)	28 (3.3)	0	
Cause of PICU admission				-
Pulmonological disorder	371 (40.1)	360 (42.3)	11 (14.9)	
Infectious disease	68 (7.3)	59 (6.9)	9 (12.2)	
Neurological disorder	108 (11.7)	106 (12.4)	2 (2.7)	
Gastrointestinal disorder	39 (4.2)	32 (3.8)	7 (9.5)	
Hemato-oncological disorder	74 (8.0)	48 (5.6)	26 (35.1)	
Renal disorder	39 (4.2)	36 (4.2)	3 (4.1)	
Cardiac disease	8 (0.9)	8 (0.9)	0	
Trauma	13 (1.4)	13 (1.5)	0	
Postoperative	161 (17.4)	156 (18.3)	5 (6.8)	
Post-resuscitation care	45 (4.9)	34 (4.0)	11 (14.9)	
PIM 3	3.3 (0.8–7.3)	2.9 (0.8–6.2)	18.4 (5.3–53.4)	<0.001
Height-for-weight or BMI[a] (z-score)	–0.3 (–1.6 to 1.0)	–0.3 (–1.6 to 1.0)	–0.4 (–2.0 to 1.3)	0.818
Nutritional status[b]				0.006
Normal	592 (63.9)	546 (64.1)	46 (62.2)	
Mild malnutrition	155 (16.7)	145 (17.0)	10 (13.5)	
Moderate malnutrition	71 (7.7)	58 (6.8)	13 (17.6)	
Severe malnutrition	108 (11.7)	103 (12.1)	5 (6.8)	
Weight variability[c]	0.8 (0.0 to 4.3)	0.0 (0.0 to 3.6)	8.7 (3.7 to 12.2)	<0.001

Values are presented as median (interquartile range) or number (%).
PICU: pediatric intensive care unit; PIM 3: pediatric index of mortality 3; BMI: body mass index.
a) Z-scores have been calculated using height-for-weight for children <2 years old and BMI-for-age for those aged ≥2 years old; b) Nutritional status has been categorized as follows: normal, z-score > –1; mild malnutrition, z-score between –2 and –1; moderate malnutrition, z-score between –3 and –2; and severe malnutrition, z-score ≤–3; c) Weight variability at PICU admission was calculated using the following formula: weight variability (%)=|(usual body weight-body weight at PICU admission)/(usual body weight)|×100.

Cox models further demonstrated a progressive decline in the hazard of ventilator liberation with increasing WV in the overall cohort after adjustment for age, sex, PIM 3, and comorbidities (Figure 3). In contrast, when analysis was limited to survivors, WV was not significantly associated with the duration of mechanical ventilation or PICU stay.

The ROC analysis demonstrated that WV had good predictive performance for PICU mortality, with an AUC of 0.836, comparable to the PIM 3 score (AUC=0.804, P=0.414) (Supplementary Figure 2). When WV and the PIM 3 score were combined in the model, the AUC increased to 0.888, indicating improved predictive accuracy. Based on the optimal cutoff value of 3.741% for WV, patients in the high WV group had significantly lower survival and a lower probability of ventilator liberation than those in the low WV group (Figures 4 and 5).

Direction of WV and Clinical Outcomes

When patients were stratified by the direction of WV, those

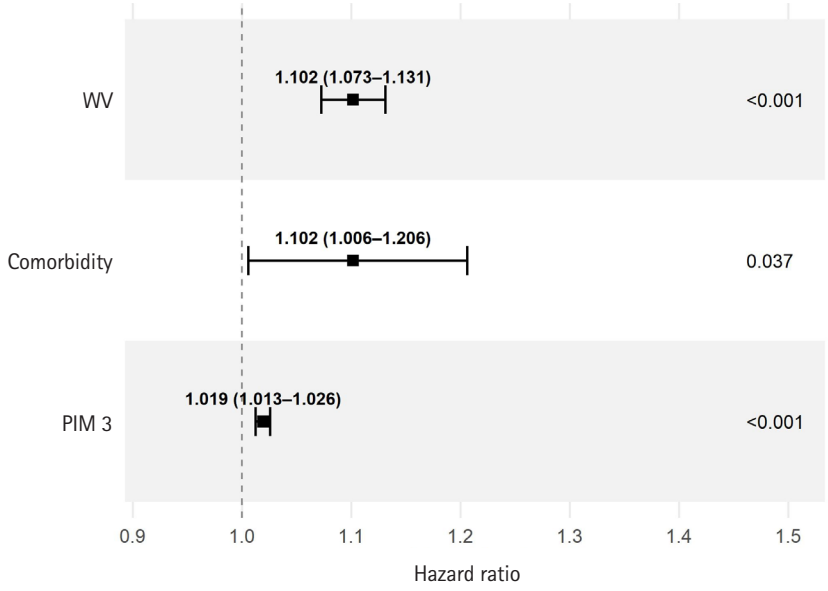

Figure 2. Multivariable Cox regression analysis of the association between weight variability and pediatric intensive care unit (PICU) mortality. Weight variability (WV) is independently associated with an increased risk of PICU mortality, with a hazard ratio of 1.102 (95% CI, 1.073–1.131). The model has been adjusted for age, sex, comorbidities, and the Pediatric Index of Mortality 3 (PIM 3) score. Values are presented as hazard ratio (95% CI).

Table 2. Multivariable regression analysis examining the correlation between weight variability and clinical outcomes

	Adjusted OR	95% CI	P-value
All patients admitted to PICU (n=926)			
PICU mortality	1.269	1.197–1.345	<0.001
VFD at day 28	0.599	0.524–0.684	<0.001
Survivor (n=852)			
Duration of mechanical ventilation	0.958	0.644–1.426	0.833
Length of PICU stay	0.973	0.647–1.461	0.894

OR: odds ratio; PICU: pediatric intensive care unit; VFD: ventilator-free day.

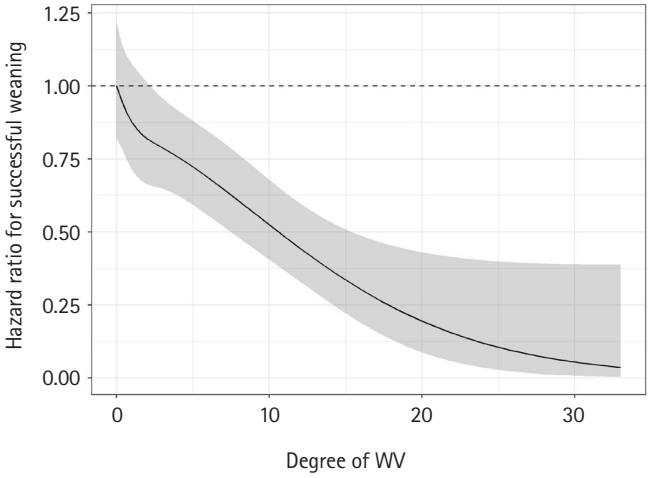

Figure 3. Association between weight variability (WV) and the probability of ventilator liberation. In a restricted cubic spline-based Cox proportional hazards model adjusted for age, sex, Pediatric Index of Mortality 3 (PIM 3) score, and comorbidities, increasing weight variability was associated with a progressive decline in the hazard of ventilator liberation in the overall cohort. The shaded area represents the 95% CI.

with weight loss had significantly higher mortality (14.5% vs. 6.3%), greater need for mechanical ventilation, fewer VFDs, higher PIM 3 scores, and more frequent continuous renal replacement therapy use than patients without weight loss (Supplementary Table 1). They also exhibited a higher prevalence of hemato-oncological disorders and more severe malnutrition, suggesting that weight loss reflects nutritional compromise and more severe illness, whereas weight gain is more likely attributable to fluid overload or edema.

Further stratification confirmed that both weight loss and weight gain correlated significantly with PICU mortality (Supplementary Figure 3). Within the weight-loss sub-cohort, hemato-oncological disorders were the most common underlying condition in non-survivors, with mortality reaching 56.0%, compared with 26.8% in the weight-gain sub-cohort (P=0.035).

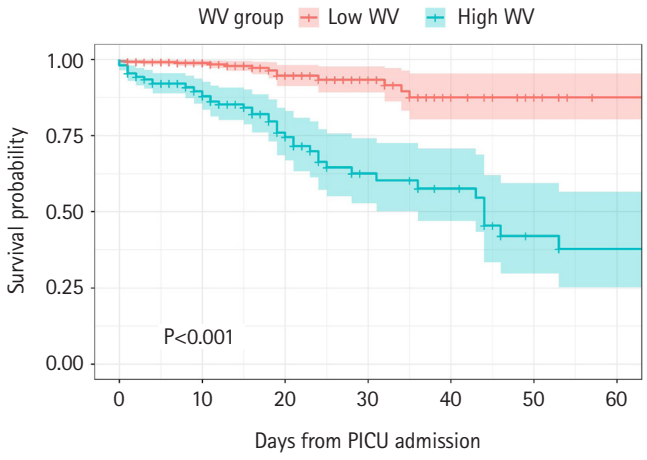

Figure 4. Kaplan-Meier survival curves according to weight variability (WV). Patients were divided into two cohorts based on the optimal cutoff value for WV (3.741%) determined in a receiver operating characteristic curve analysis. The high WV group (≥3.741%) had a significantly lower cumulative survival probability during the pediatric intensive care unit (PICU) stay than the low WV group (<3.741%) (log-rank test, P<0.001).

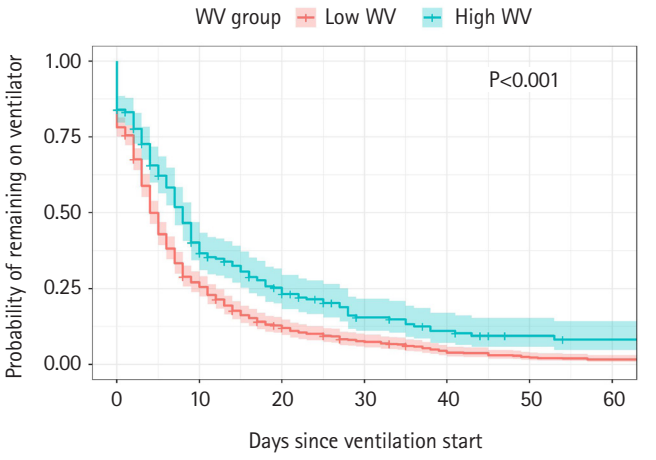

Figure 5. Kaplan-Meier curves for ventilator liberation according to weight variability (WV). Kaplan-Meier curves comparing the high and low WV groups for time from pediatric intensive care unit admission to successful ventilator liberation. Deaths and patients remaining on mechanical ventilation beyond 60 days were censored. The high WV group demonstrated a significantly lower probability of ventilator liberation over time (log-rank test, P<0.001).

Those findings suggest that critically ill children with hemato-oncological disease face particularly heightened vulnerability to weight loss-associated deterioration.

Consistently, a spline-based logistic regression demonstrated a U-shaped association between directional WV and PICU mortality, indicating that both marked weight loss and marked weight gain were associated with an increased risk of death in the PICU, and minimal WV was associated with the lowest mortality risk (Supplementary Figure 4). The spline term for directional WV was statistically significant (estimated degrees of freedom=3.9, χ^2=28.4, P<0.001).

DISCUSSION

This study is the first to investigate the association between acute WV and clinical outcomes in critically ill children admitted to the PICU. A key novelty of our work lies in the emphasis on the magnitude of WV over time, rather than static anthropometric measurements at admission. High WV, regardless of baseline BMI or the direction of weight change (gain or loss) was significantly associated with increased PICU mortality and fewer VFDs. Incorporating WV into clinical risk assessment could thus enhance the predictive accuracy of existing mortality models in the PICU population.

Nutritional status plays an important role in predicting outcomes in critically ill patients, and the BMI is commonly used as a standard indicator of malnutrition [17]. However, prior research examining the association between BMI and ICU outcomes has produced inconsistent findings. Some studies reported no association [7,18], and others identified a significant relationship between low BMI and increased mortality in both ICU and hospital settings [19-21]. In this study, no clear relationship was observed between a low BMI and PICU mortality. When malnutrition was stratified by severity, mild-to-moderate malnutrition was associated with increased mortality. However, paradoxically, patients with severe malnutrition demonstrated relatively low mortality rates. This observation could be explained by the fact that many children in the lowest BMI category had chronically low body weight due to pre-existing comorbidities and were in a stable metabolic state. In such cases, a single BMI measurement might not accurately reflect the patient's current physiological condition or acute deterioration. Therefore, we focused on acute weight changes rather than baseline nutritional status. Our findings revealed that acute weight loss, even in the absence of underweight status, was more strongly associated with adverse outcomes than a chronically low BMI.

Acute weight loss has been shown to cause a reduction in

lean body mass [22], which can negatively affect immune function and a patient's overall prognosis [23]. Although chronic malnutrition can influence long-term outcomes, clinicians should interpret nutritional indices such as BMI with caution, particularly in patients with complex comorbidities. Dynamic indicators, including WV, might provide a more responsive and clinically relevant indicator of physiological instability in the acute-care setting.

Both negative WV, reflecting acute weight loss, and positive WV, reflecting acute weight gain, were significantly associated with adverse outcomes in critically ill pediatric patients. This finding aligns with those of previous studies in adult ICU populations that demonstrated a positive correlation between increases in body weight and mortality [24]. Although the so-called "obesity paradox," in which individuals who are overweight or mildly obese exhibit lower mortality rates than lighter patients during critical illness [25], has been described in adults, weight gain in the acute phase is more likely to reflect fluid accumulation than an increase in nutritional reserve. In our study, the association followed a U-shaped pattern: mortality was lowest near zero variability, and both weight loss and gain carried excess risk, albeit through different mechanisms—catabolism versus fluid overload.

In critically ill patients, aggressive fluid resuscitation is often needed to maintain hemodynamic stability, particularly in the early stages of shock or organ dysfunction. Thus, increased fluid administration that leads to measurable weight gain could serve as an indirect marker of illness severity [8], and fluid overload is well established to be harmful in intensive care settings [26,27]. Excess fluid must be eliminated via renal excretion, which assumes preserved cardiac and renal function. In patients with impaired renal function, the inability to adequately remove retained fluid can contribute to worsened outcomes because acute kidney injury is strongly associated with increased mortality in the ICU [28].

High WV has been identified as a poor prognostic factor in various adult populations [29]. Studies have shown that large fluctuations in body weight are associated with increased risk of cardiovascular events and all-cause mortality during follow-up in patients with coronary artery disease [30]. Additionally, weight fluctuations are related to a higher incidence of atrial fibrillation in patients with diabetes [31]. Our findings contribute to this growing body of evidence, confirming that high WV is significantly associated with PICU mortality and a reduced probability of successful ventilator liberation.

Furthermore, in pediatric patients with hematologic or oncologic diseases, acute weight loss was significantly associated with increased mortality. This suggests that this subgroup has heightened vulnerability, likely due to limited physiological reserve and impaired tolerance to acute catabolic stress. These findings highlight the need for heightened vigilance and individualized monitoring of body weight trends in this high-risk population.

In the management of critically ill children, avoiding abrupt weight changes after admission could play an important therapeutic role, and peri-admission weight changes might serve as valuable prognostic indicators. WV appears to complement conventional predictors and might provide additional prognostic value beyond established severity scoring systems such as the PIM 3 and the Pediatric Risk of Mortality scores, which do not currently incorporate weight change as a parameter.

Importantly, in this study, WV was simple to measure, did not require specialized equipment or time-consuming assessments, and demonstrated strong associations with both mortality and VFDs. In resource-limited settings, in which comprehensive nutritional assessments for every patient in the PICU might not be feasible, WV could serve as a practical, surrogate marker for risk stratification and early clinical decision-making.

Nonetheless, our findings should be interpreted with caution because this study has several limitations. Usual body weight was primarily derived from caregiver-reported values documented by dietitians at PICU admission, and only when such data were unavailable was weight information extracted from electronic health records within the preceding month. Caregiver-reported weights are inherently vulnerable to recall bias and measurement inconsistency, and the lack of systematic distinction between reported and measured values might have introduced misclassification. Nevertheless, this reflects the practical constraints of real-world pediatric critical care, in which caregiver-reported weights are often the most readily available information, and meaningful associations with outcomes were still identified in this study [32]. Additionally, we did not observe a significant association between WV and either the length of PICU stay or duration of mechanical ventilation among survivors. This might be due to the relatively small degree of weight fluctuation in the surviving patients.

Therefore, in survivors, WV alone might not be sufficient, and additional clinical or laboratory markers could be necessary to better characterize recovery and risk profiles.

In conclusion, this study identified WV as a simple, feasible, and reliable parameter associated with PICU mortality and VFDs. This association remained robust after adjusting for major demographic and clinical confounders. Notably, weight change exceeding 3.7% was particularly predictive of adverse outcomes. Given its ease of measurement and clinical relevance, WV at admission could serve as a valuable adjunct to existing PICU mortality prediction models, particularly in resource-limited settings or when comprehensive nutritional assessments are not readily available.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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AUTHOR CONTRIBUTIONS

Conceptualization: JHJ, MHS, SYK. Methodology: YHK, MP, HMK. Formal analysis: JHJ, YHK, MP, HMK. Data curation: JHJ, MJK, SYK. Funding acquisition: MJK, SYK. Writing – original draft: JHJ. Writing – review & editing: KWK, MHS, SYK. All authors read and agreed to the published version of the manuscript.

SUPPLEMENTARY MATERIALS

Supplementary materials can be found via https://doi.org/10.4266/acc.001550.

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