Assessing Passive Leg Raise Test in Pediatric Shock Using Electrical Cardiometry

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Abstract

Passive leg raise (PLR) is widely used to incite an autobolus to assess fluid responsiveness in adults; however, there is a paucity of studies exploring its utility in children. Our study aimed to analyze the efficacy of PLR in determining fluid responsiveness in children presenting with shock using electrical cardiometry. Patients in the age group of 0 to 20 years who presented in shock to our children's hospital emergency department were evaluated. Multiple hemodynamic metrics including, heart rate, systolic/diastolic blood pressure, cardiac output (CO), stroke index, stroke volume (SV), flow time corrected (FTC), and left ventricular ejection time (LVET) were recorded using the noninvasive ICON device and compared at baseline and post-PLR. A total of 68 patients had pre- and post-PLR data available for review between June and July 2022. Median age was 7 years (54% male); most common etiology was hypovolemic (67.6%) shock. Following PLR, there was no significant change in most hemodynamic parameters, including SV and CO; however, there was a significant difference in FTC (301 [pre-PLR] vs. 307 [post-PLR], $p = 0.016$) (ms) and LVET (232 [pre-PLR] vs. 234 [post-PLR], $p = 0.014$) (ms). A significantly higher proportion of children diagnosed with septic shock demonstrated fluid responsiveness ($\Delta SV \geq 10\%$ from baseline) compared with those with hypovolemic shock ($p = 0.036$). This study demonstrated no identifiable fluid responsiveness ($\Delta SV \geq 10\%$ from baseline) following PLR; however, a significantly higher proportion of children suffering from septic shock demonstrated fluid responsiveness compared with those with hypovolemic shock. Larger studies are needed to further assess the utility of PLR, as well as other modalities, in determining fluid responsiveness in children.

Keywords

- passive leg raise
- fluid responsiveness
- hemodynamic monitoring
- NICOM
- emergency department

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Introduction

Shock is a significant contributor to morbidity and mortality in pediatric patients.[1,2] Sepsis continues to be the most common etiology, with a global incidence of approximately 1.2 million cases/year;[3] however, other shock subtypes include hypovolemic, cardiogenic, and neurogenic. Early identification and expeditious fluid resuscitation are crucial to restoring intravascular volume and ensuring tissue perfusion.[1,4–6]

Intravenous fluid resuscitation involves the administration of an initial fluid bolus of 10 to 20 mL/kg of isotonic saline (0.9%) with subsequent repeat boluses until hemodynamic parameters are normalized.[7,8] However, well-studied adverse effects of liberal fluid administration, including pulmonary edema, respiratory failure, abdominal compartment syndrome, and even mortality,[9–12] have prompted judicious goal-directed resuscitation protocols in emergency and intensive care settings.[3,13] Furthermore, targeted efforts to assess which patients truly benefit from fluid resuscitation are increasingly prioritized. This determination is known as "fluid responsiveness" and is broadly defined as a 10 to 15% increase in either stroke volume (SV) or cardiac output (CO) following crystalloid fluid bolus.[14–16]

Passive leg raise (PLR) is a bedside maneuver in which the patient's lower extremities are raised to 45 degrees, to simulate administration of an "auto-bolus." Essentially, this maneuver is thought to facilitate rapid venous return from the lower extremities and augment preload,[17] manifested in both subjective and objective clinical parameters. Previous studies validating the utility of PLR in critically ill adults are robust;[18–20] however, existing literature in the pediatric population is scarce, particularly in the setting of noninvasive CO monitoring.

Recently, there have been advances in such noninvasive monitoring, especially related to the devices which integrate electrical cardiometry (EC), also known as bioimpedance. These devices assess changes in the cardiac cycle by means of red blood cell orientation within the thoracic aorta. In doing so, indices of hemodynamic function such as SV and CO (among others) can be estimated while minimizing the risk associated with more invasive monitoring modalities.[21,22] EC has shown increasing promise in its accuracy and reliability in both critically ill and perioperative populations.[23–25]

Though previously our team had explored the use of EC in determining hemodynamic changes following fluid bolus in children with shock,[16] we wanted to assess PLR using EC in the pediatric cohort. Thus, our study aimed to assess fluid responsiveness following PLR in children presenting with shock to our emergency department (ED) using EC.

Methods

This study was approved by the Driscoll Children's Hospital Institutional Review Board (IRB) with a waiver of informed consent (22.016). A single-blinded, prospective observational study was performed, examining pediatric patients, ages 0 to 21 years, who presented with the diagnosis of shock to The Driscoll Children's Hospital ED from June 1, 2022 to October 31, 2022. This institution is a 191-bed pediatric tertiary care center serving the greater South Texas area, including Corpus Christi, Rio Grande Valley, Victoria and Laredo.

Inclusion Criteria

Inclusion criteria were as follows.

1. Children between 0 and 21 years who presented to the Driscoll Children's Hospital ED from June 1, 2022 to October 31, 2022 and deemed to require a resuscitative fluid bolus. Indications for fluid bolus are based on the institutional best practice alert (BPA) (components of this BPA: tachycardia, hypotension, fussiness, fever, delayed capillary refill, low blood pressure, dry mucosa, poor skin turgor, lethargy, poor color, poor pulse volume, and elevated lactate.)
2. Children who had pre-PLR and post-PLR hemodynamic data available for analysis before any fluid bolus offered by the clinical team.

Exclusion Criteria

Exclusion criteria were as follows.

(1) Premature babies.
(2) Children with pre-existing cardiac diseases.
(3) Children with nonavailability of hemodynamic data around PLR.

The ICON® noninvasive hemodynamic monitor, approved by the FDA for use in adult, pediatric, and neonatal patients was utilized to obtain both baseline hemodynamic data, before any therapy was administered, and postintervention hemodynamic following the 5-minute PLR maneuver (►**Fig. 1**). To avoid any error with PLR and to have consistent approach with PLR, we trained our investigators on PLR using a mannequin and only two investigators (A.P. and S.C.) who had rigorous training in PLR conducted the PLR test in study subjects. The ICON® monitor is an FDA-approved noninvasive CO device that delivers real-time hemodynamic measurements by analyzing time-dependent changes in blood conductivity within the aorta and throughout the cardiac cycle.[26,27] To obtain hemodynamic readings, four adhesive skin sensors were placed on the left side of the patient (►**Fig. 2A**) which connected to the stand-alone, battery-operated device (►**Fig. 2B**).

Patient-specific information was collected, including gender, age, clinical or laboratory evaluation findings, organ system involved, and etiology of shock. Next, using an automated blood pressure cuff, systolic blood pressure and diastolic blood pressure were calculated. Using the ICON® monitor, pre-PLR and post-PLR values were obtained for the following hemodynamic parameters: heart rate (HR), mean arterial pressure (MAP), cardiac output (CO), cardiac index (CI), stroke index (SI), stroke volume (SV), stroke volume variation (SVV), flow time corrected (FTC), thoracic fluid content (TFC), left ventricular ejection time (LVET), systemic vascular resistance (SVR), systemic vascular resistance index (SVRI), index of contractility (ICON), systolic time ratio (STR),

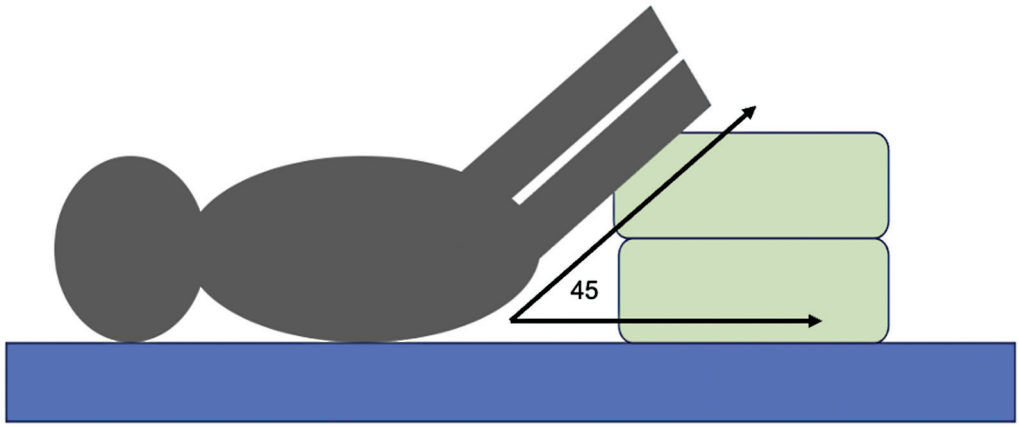

Fig. 1 Depiction of passive leg raise (PLR) maneuver, with legs appropriately raised from the supine position to 45 degrees.

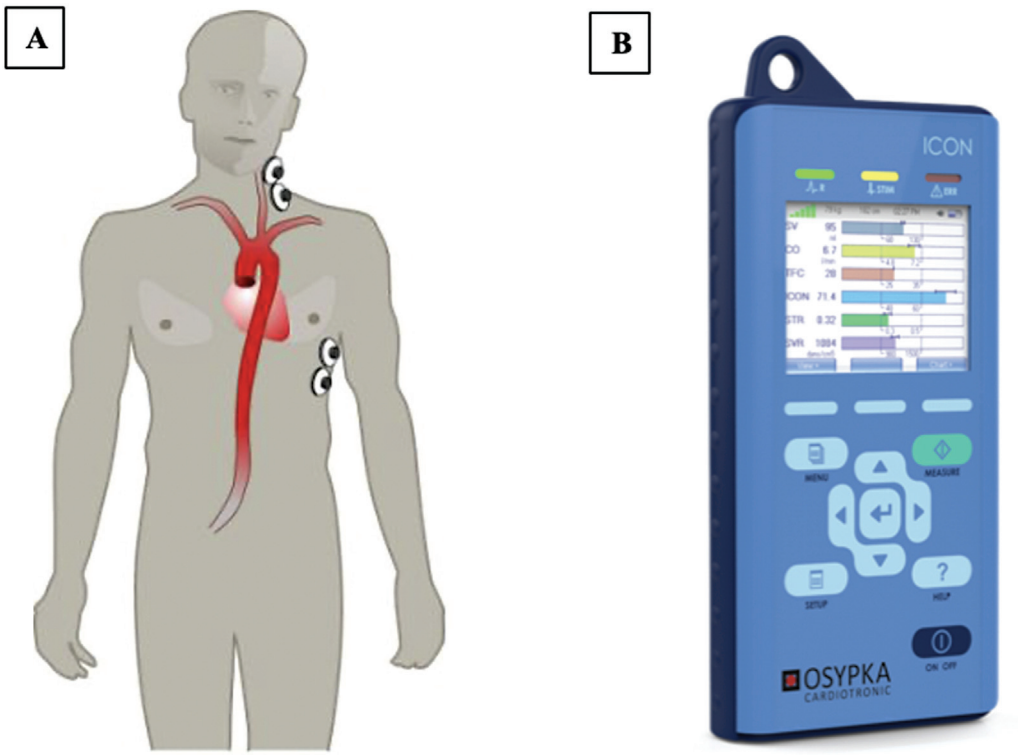

Fig. 2 (**A**) Adhesive skin sensors applied to the left side of the patient, along the ipsilateral carotid artery and in line with the cardiac apex. (**B**) Handheld, battery-operated ICON device with 3.5 high-resolution screen. Adopted from ICON user manual with due permission from Markus Osypka, Osypka Medical Inc., Germany.

pre-ejection period (PEP), variation of index of contractility (VIC), and heart rate variability (HRV). Only patients who had complete sets of ICON® derived data were included for analysis. Patients were grouped into the septic shock category based on IV antibiotics and IV fluid bolus order placed in ED and patients with only IV fluid bolus ordered were grouped into the hypovolemic shock category.

The pre-PLR and post-PLR parameters were compared using the paired *t*-test with confidence levels set at 95%. Next, stratification by key demographics (age >10 or <10, gender, and etiology of shock) was used, and chi-square test was performed to detect differences in fluid responsiveness.

Results

During the study period, a total of 18,393 patients were evaluated in our ED and 152 had fluid bolus ordered for sepsis alert and/or management of shock during the study period. Of these, 68 children met all inclusion criteria and, thus, were included for final analysis (►**Fig. 3**). The median (interquartile range) age was 90 (48, 180) months, with a male/female ratio of 1:1.2. Distribution of shock etiologies included hypovolemic (67.6%) and septic shock (32.4%), most commonly gastrointestinal (42.7%) or respiratory (22.1%) in origin. Vomiting (47%), fever (42.4%), tachycardia (42.4%),

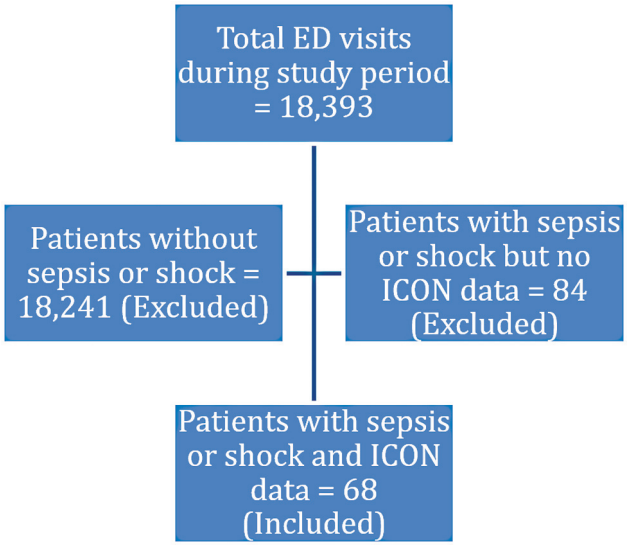

Fig. 3 Flow diagram explaining total ED visits and number of patients excluded as well as the final number of patients included in final analysis.

and fatigue/lethargy (21.2%) were among the most predominant clinical exam findings upon evaluation. Full details of patient demographics, diagnoses, and presenting symptoms can be viewed in ►**Table 1**.

At the end of the 5-minute PLR maneuver, significant decreases in ΔHR (−2 [−1, −2]; $p = 0.0086$) (bpm) and ΔSTR (−0.02 [−0.0025, −0.04]; $p = 0.035$) were observed. Additionally, significant increases in ΔFTC [2.5 (26, 0); $p = 0.046$] (ms) and ΔLVET (2.5 [25.25, 6.5]; $p = 0.0064$) (ms) were noted. However, no significant changes were appreciated in SV or CO and all other noninvasively obtained hemodynamic metrics (see ►**Table 2**).

A statistically significant proportion of children under 10 years showed responsiveness to PLR in our study (see ►**Table 3**). When stratifying by the type of shock, a significantly higher proportion of children suffering from septic shock demonstrated fluid responsiveness (ΔSV ≥10% from baseline) when compared with those with hypovolemic shock (chi square = 4.39, $p = 0.036$). There was no significant difference identified by patient gender (see ►**Table 3**).

Table 1 Patient demographics, clinical factors, and diagnoses (IQR—interquartile range).

Patient demographics	*n* (%) or median (IQR)
Age (median [IQR])	90 mo (48, 180)
Gender	
Male	31 (45.6)
Female	37 (54.4)
Etiology of Shock	***n* (%)**
Hypovolemic	46 (67.6)
Septic	22 (32.4)
Organ system involved	**(%)**
Gastrointestinal	42.7%
Respiratory	22.1%
Neurological	14.7%
Genitourinary	8.8%
Hematology/Oncology	7.4%
Endocrine/Metabolic	4.4%
Clinical/Laboratory evaluation finding	***n* (%)**
General	
Fever	28 (41.2)
Fatigue/lethargy	14 (20.6)
Fussiness	6 (8.8)
Cardiovascular	
Tachycardia (based on age)	29 (42.6)
Lactate (>2/mmol/L)	7 (10.3)
Hypotension	3 (4.4)
Capillary refill (>3 s)	1 (1.5)
Weak pulse	0 (0)
Gastrointestinal	
Vomiting	31 (45.6)
Diarrhea	12 (17.6)
Skin/Appearance	
Dry mucosa	12 (17.6)
Poor color	10 (14.7)
Poor skin turgor	0 (0)

Discussion

This is the first study to evaluate the implication of PLR as an assessment of pediatric fluid responsiveness in the ED, particularly in the setting of noninvasive CO monitoring. Though PLR demonstrated significant changes in preload (ΔHR, ΔSTR, ΔFTC, and ΔLVET), following PLR in our pediatric cohort, it failed to demonstrate fluid responsiveness as defined by ΔSV ≥10% from the baseline.[28,29] In short, our findings indicate that the utility of PLR in guiding fluid therapy in pediatric shock may be limited. It is likely that PLR at 45 degrees for 5 minutes may not generate an adequate auto-bolus in children.

As the ED is the gateway for initial patient evaluation and management, studies in this care setting are increasingly important within the realm of shock. This current endeavor follows a recent study from our institution by Awadhare et al that evaluated a fluid bolus challenge in tandem with the same ICON® monitor.[16] Aside from identifying significant changes in TFC, STR, MAP, and SVR, our prior study concluded that a 15% change in the ICON had strong predictive value in fluid responsiveness.[16] The differing findings in the current study highlight potential incongruences between observed volume expansion provided by the PLR maneuver compared with a physical fluid bolus. While the PLR is a transient challenge and does not confer an additional risk of fluid

Table 2 Comparative analysis of hemodynamic parameters before and after passive leg raise

Parameter	Pre-PLR (range)	Post-PLR (range)	Δ Median (IQR)	*p*-Value
HR (bpm)	110.5 (84.5,142.6)	108.5 (83.5, 139.8)	−1.4 (−7.5, 1.4)	**0.009**[a]
SBP (mm Hg)	111.5 (100.8, 121)	107 (100, 119)	−1 (−6.7, 3.3)	0.061
DBP (mm Hg)	67 (60, 75)	69 (57.8, 73.3)	−1.6 (−7.9, 5.8)	0.125
MAP (mm Hg)	82 (73, 91)	82.5 (72, 89.3)	−1.9 (−6.6, 3)	0.092
SV (mL)	39 (20.9,65.3)	40.5 (21, 63.3)	1.6 (−6.4, 9.5)	0.530
SI (BSA)	33.5 (24.8, 46)	34.5 (27, 45.3)	0.8 (−6.5, 8.7)	0.062
CO (L/min)	3.9 (2.7, 5.5)	3.8 (2.7, 5.6)	−0.4 (−7, 10.1)	0.967
CI (BSA)	3.7 (2.6, 4.5)	3.8 (2.6, 4.7)	0 (−6.5, 10.5)	0.297
SVV (%)	14.5 (9.8, 20.3)	13 (9.8, 21)	−12.9 (−35.9, 22.5)	0.341
FTC (ms)	305 (256.5, 318.3)	307.5 (282.5, 318.3)	0.5 (−1.6, 3.8)	**0.046**[a]
TFC	24 (18, 29)	24 (19, 29.3)	0 (−3.8, 4.4)	0.182
SVR (dyn. s/cm^5)	1,806.5 (1161.5, 2354.8)	1,704 (1116, 2517.3)	−0.8 (−14, 10.1)	0.109
SVRI (BSA)	1,876.5 (1487.3, 2589.3)	1,790 (1362.8, 2470.8)	−0.5 (−14, 7.5)	0.138
STR	0.4 (0.4, 0.5)	0.4 (0.4, 0.5)	−2.5 (−9.7, 3.5)	**0.035**[a]
ICON	63.8 (45.1, 99.1)	62.7 (46.6, 98.7)	1.7 (−11.3, 10.7)	0.556
LVET (ms)	233 (163.8, 263.3)	235.5 (189, 269.8)	1.9 (−2.7, 7.8)	**0.006**[a]
VIC (%)	20.5 (13.3, 30.3)	16.5 (9.8, 29)	−12.1 (−50, 28.6)	0.597
PEP (ms)	94.5 (77.5, 113.3)	91 (80.8, 113)	1.1 (−7.1, 5.6)	0.624
HRV (ms)	23.5 (10.3, 45.3)	20 (12.8, 46.8)	−9.8 (−33.1, 46.7)	0.562

Abbreviations: CI, cardiac index; CO, cardiac output; DBP, diastolic blood pressure; FTC, flow time corrected; HR, heart rate; HRV, heart rate variability; ICON, index of contractility; LVET, left ventricular ejection time; MAP, mean arterial pressure; PEP, pre-ejection period; SBP, systolic blood pressure; STR, systolic time ratio; SV, stroke volume; SVV, stroke volume variation; SVR, systemic vascular resistance; SVRI, systemic vascular resistance index; TFC, thoracic fluid content; IQR, interquartile range; PLR, passive leg raise; VIC, variation of index of contractility.
[a]*p*-Value <0.05, statistically significant.

overload in and of itself, the reservoir of blood volume returned from the lower extremities is known to be less robust in children due to a smaller body size and instead is confined primarily to the torso and upper extremities.[30] This auto-bolus may have further been limited by the increase in SVR induced by early shock. The findings comparing children with septic versus hypovolemic shock are interesting. It may be that patients with hypovolemic shock have an absolute volume deficit such that peripheral vascular volume cannot be transferred to the central circulation, while patients with septic shock may exhibit vasoplegia with peripheral vascular fluid that is transferrable to the central circulation. Further studies are needed to assess PLR in the pediatric septic cohort. Additionally, the physical maneuver is highly subject to human error—the extent and precise angle of leg elevation may vary each time.

Table 3 Assessment of fluid responsiveness during PLR for age, gender, and type of shock

Parameter	ΔSV (≥10% from baseline)	*p*-Value
Age		**0.002**[a]
<10 y ($n=38$)	15 (39.5%)	
>10 y ($n=30$)	2 (6.7%)	
Gender		0.67
Male ($n=31$)	7 (22.6%)	
Female ($n=37$)	10 (27%)	
Type of shock		**0.036**[a]
Hypovolemic ($n=46$)	8 (17.4%)	
Septic ($n=22$)	9 (41%)	

Abbreviations: PLR, passive leg raise; SV, stroke volume.
[a]Significant at the α level of 0.05. Bold font shows the the statistically significant values.

Conclusions drawn from published pediatric data are highly variable without consensus.[30–33] The only existing study to investigate PLR using NICOM was centered around the comparison of its utility in patients older than or younger than 5 years.[30] These authors reported an increase of CI by 7.5% after PLR to be a good predictor of fluid responsiveness index only in patients older than 5 years old. While this study was the first of its kind nearly a decade prior, it had notable drawbacks including a small sample size of only 40 patients as well as the inclusion of trauma patients who may have introduced additional variation in the form of multisystem injury. Two other studies[31,32] used transthoracic echocardiography with Doppler to demonstrate a SV increase of 10% and an increase in CI by 8.7 to 10% after PLR in children under the age of 5 years were predictive of fluid responsiveness. The final study[33] investigated mechanically ventilated patients following cardiac

surgery using bedside ultrasound and verified the predictive value of ΔSV. It is important to note that these studies were all conducted in the pediatric intensive care unit and, thus, explored a vastly different and likely variable patient cohort. Conversely, our pediatric ED patients were assessed while they were not exposed to interventions such as inotropes and/or ventilator support which could potentially impact their hemodynamic status.

Nonetheless, the benefits of early but judicious fluid administration continue to underscore the importance of assessing fluid responsiveness; thus, additional studies are warranted. While our results demonstrate that PLR may not be the best mechanism to determine such responsiveness in pediatric patients in shock, certain opportunities for expansion in future studies may be worth discussing in further detail. Aside from potentially insufficient auto-bolus, another factor particularly in children is that pain (both somatic and visceral) with the physical PLR maneuver can cause more profound adrenergic stimulation and result in an erroneous interpretation of hemodynamic parameters.[19,31] To maximize test reliability and reduce patient discomfort, future studies integrating the PLR may instead be performed by adjusting the bed and not by manual leg raising. Additionally, as hemodynamic changes incited by PLR are notably transient, and best detected 1 minute after initiating PLR, variation in the timing of post-PLR metrics could be pursued to discern an optimal interval for measuring meaningful changes in hemodynamic response. Finally, though the poor performance of PLR in this study may invalidate its use in the ED, especially considering that the time required to initiate and perform the maneuver is not insignificant, future investigative directions may explore other methods of predicting fluid responsiveness in this setting.

This study is not without limitations. Our sample size, although larger than that of other similar pediatric literature in this realm, is still relatively underpowered. Given that the study was essentially negative, we propose a multicenter study to capture a larger sample size to definitively evaluate whether or not PLR represents a clinically relevant procedure to help assess volume status among critically ill children. Next, the diagnosis of shock was based upon an institutional BPA, which may vary from other institutions' fluid bolus triggers, limiting the generalizability of results. Additionally, patients in this study were likely demonstrating elements of early or compensated shock at the time of their evaluation and may not have been ill enough to elicit physiologic changes from PLR.

Conclusion

In our cohort of pediatric patients presenting to the ED in shock, PLR did not demonstrate significant fluid responsiveness as defined by improvement in SV $\geq$10% from the baseline. In the future, larger, multicenter studies should focus on assessing PLR for fluid responsiveness in children with decompensated shock.

Previous Presentation
The abstract was presented as a podium presentation at the 2023 Critical Care Congress: Annual Meeting in San Francisco, CA (January 21–24, 2023).

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Conflict of Interest
None declared.

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