

# Comparative efficacy of finger versus forehead Plethysmographic Variability Index monitoring in pediatric surgical patients

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## Abstract

**Introduction:** The Plethysmographic Variability Index can be measured by both finger and forehead probes. Vasoconstriction may jeopardize the reliability of finger PVI measurements in pediatric patients undergoing surgery. However, forehead vasculature exhibits more marked resistance to alterations in the vasomotor tonus.

**Objective:** Our aim was to compare the Plethysmographic Variability Index measured via finger or forehead probes in mechanically ventilated pediatric surgery patients in terms of their ability to predict fluid responsiveness as well as to determine the best cut-off values for these two measurements.

**Materials and Methods:** A total of 50 pediatric patients undergoing minor elective surgery were included after provision of parental consent and ethics committee approval. Perfusion index measured at the finger or forehead and Plethysmographic Variability Index monitoring comprised the primary assessments. Hemodynamic parameters monitored included perfusion index, Plethysmographic Variability Index, and cardiac output. A  $\geq 15\%$  increase in cardiac output following passive leg raise maneuver was considered to show fluid responsiveness. Two groups were defined based on fluid responsiveness: Group R (responsive) and Group NR (non-responsive). Student's *t*-test, Mann-Whitney U test, DeLong test, and ROC were used for statistical analysis.

**Results:** The area under curve for finger and forehead Plethysmographic Variability Index prior to passive leg raise maneuver were 0.699 ( $p = .011$ ) and 0.847 ( $p < .001$ ), respectively. The sensitivity for finger and forehead measurements at a cut-off value of  $\leq 14\%$  was 92.9% and 96.4%, and 45.4% and 72.7%, respectively.

**Conclusion:** Although forehead and finger Plethysmographic Variability Index monitoring were similarly sensitive in predicting fluid responsiveness in pediatric surgical patients, the former method provided higher specificity. The best cut-off value for PVI measurements with forehead and finger probes was found to be 14%.

## KEYWORDS

fluid responsiveness, pediatric, PI, PVI, USCOM

## 1 | INTRODUCTION

The objectives of perioperative fluid management include ensuring adequate and reliable tissue oxygenation via blood circulation and maintaining effective cardiac output to meet metabolic requirements. Studies have shown that in adult patients, individualized and targeted fluid management strategies optimizing perioperative cardiac output may reduce morbidity, mortality, and the length of hospital stay.<sup>1-4</sup>

A multitude of studies have reported on the use of cardiopulmonary interactions in assessing the fluid responsiveness in patients under mechanical ventilation.<sup>5</sup> Dynamic parameters obtained through continuous monitoring are known to provide a more efficient method to assess fluid responsiveness as compared with the parameters obtained through measurements at single time-points.<sup>6</sup> As compared with other dynamic measurement techniques, Plethysmographic Variability Index (PVI) has been shown to provide a non-invasive means for predicting intravascular volume status. Its advantages include the ease of use, no requirement for interventional procedures, and provision of numerical data.<sup>7</sup> The reliability of PVI measurements is adversely affected by hypothermia, circulatory failure, vasopressor use, vasoconstriction, and stimulation of the sympathetic nervous system. A reliable PVI measurement requires a perfusion index (PI) value of greater than 0.5. Previous studies have suggested that the forehead vasculature is more resistant to alterations in vasomotor tonus, as compared with finger vasculature.<sup>2,3</sup>

Based on these data, we aimed to compare the efficacy of PVI measured at the finger or forehead in predicting the fluid responsiveness in pediatric surgical patients under mechanical ventilation and to determine the best cut-off value for these two measurements. Passive leg raise maneuvers were used to assess the fluid responsiveness.

## 2 | METHODS

The study protocol was approved by the Ethics Committee (date, January 3, 2020; no, 09.2020.132) and registered the [clinicaltrials.gov](https://clinicaltrials.gov) (NCT04835610). The study was registered after completing data acquisition.

A total of 50 pediatric patients aged between 5 and 12 years with an ASA of I or II who were scheduled to have elective minor surgery (expected bleeding <500 ml) under general anesthesia were included in this study after written approval from the parents or legal guardians. Exclusion criteria included the presence of cardiopulmonary diseases, spontaneous respiratory effort, Allen test positivity, peripheral vascular insufficiency, use of vasopressor agents, anemia, or hypothermia.

### 2.1 | Anesthesia management

Routine pre-medication with midazolam was given to all patients. Peripheral oxygen saturation (SpO<sub>2</sub>), electrocardiography (ECG), and non-invasive blood pressure were monitored at the operation theater. Additionally, PI and PVI monitoring were performed using

### What is already known

- Plethysmographic Variability Index is a non-invasive and dynamic hemodynamic assessment tool used in fluid management that reflects the preload changes due to cardiopulmonary interactions.
- Despite the presence of a variety of tools utilized to monitor fluid status of patients, their utility in pediatric patients is limited.

### What this article adds

- Plethysmographic Variability Index allows continuous and non-invasive monitoring of fluid status in pediatric patients under mechanical ventilation. Plethysmographic Variability Index monitoring via forehead probes were found to be more reliable than that performed via finger probes.

M-LNCS™ Red TFA-1 forehead probes and M-LNSC™ Pdtx finger probes compatible with a Masimo device.

Anesthesia was induced with 2–3 mg/kg propofol and 1 mcg/kg remifentanyl in those with previously established venous line, while in others 8% sevoflurane (6 L/min) in 80% oxygen and 20% nitrogen protoxide mixture were administered using face masks. Muscular relaxation was achieved with 0.6 mg/kg of rocuronium bromide. Endotracheal intubation was performed to maintain airway continuity. Anesthesia was maintained at 1 MAC sevoflurane and 0.25 mcg/kg/min remifentanyl infusion. As in the other routine procedures, patients were ventilated to achieve normocapnia using auto-flow mode at 5 cmH<sub>2</sub>O PEEP, 8–10 ml/kg tidal volume, and respiration frequency of 10–18 per minute.

### 2.2 | Assessment methods and data collection

A 5-min time interval was allowed to achieve hemodynamic and respiratory stability following endotracheal intubation, after which heart rate, SPO<sub>2</sub>, MAP (mean arterial pressure), PI, PVI, and CO with USCOM were assessed according to the following scheme:

1. Five minutes after the patient was in half-sitting position at 45 degrees.
2. One minute after PLR at 45 degrees following achievement of supine position.
3. Five minutes after restoration of the original body position.

A ≥ 15% increase in CO after PLR was considered fluid responsiveness, while the absence of this increase was considered as non-responsiveness, hence two groups were defined: Group R (responsive) and Group NR (non-responsive). No fluid was given from anesthesia induction until the completion of assessments. The

ultrasonic cardiac output monitor (USCOM) (Pty Ltd, Coffs Harbor) is a non-invasive monitoring device allowing bedside CO measurements. In multiple studies, USCOM have been shown to provide reliable and accurate CO measurements in pediatric patients, with additional piece of evidence from animal studies.<sup>8-11</sup> Alterations in cardiac output with passive leg raising provide a sensitive means for detecting fluid deficit in patients with spontaneous respiration or under mechanical ventilation.<sup>12</sup> In pediatric patients over 5 years of age, the measurement of CO alterations with PLR is known to predict fluid responsiveness.<sup>13,14</sup> Thus, USCOM has been approved for use in pediatric patients by the Food and Drug Administration (FDA), based on its reliability and practicability.<sup>9,15</sup>

### 2.3 | Statistical analysis

Statistical analysis was performed R vers. 2.15.3 software (R Core team, 2013). The study data were reported with mean, standard deviation, median, first quartile, third quartile, frequency, percentage, minimum, and maximum. Quantitative data with normal distribution were compared with independent groups t-test, while those without normal distribution were compared with Mann-Whitney U test. The diagnostic screening tests [sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV)] as well as a receiver operating characteristic (ROC) analysis were utilized for predicting cut-off values. ROC areas under curve (AUC) were compared with De Long method. Statistical significance was assessed at a *p* value of <.05.

For sample size calculations, data from a similar study were taken into consideration where a reduction in crystalloid infusion volume of 452 ml (1815 ml vs. 1363 ml) was considered significant, with patients receiving fluid replacement, under the guidance of ROC AUC differences of PVI of  $0.836 \pm 0.077$  and PVI of  $0.906 \pm 0.666$  for predicting fluid responsiveness.<sup>16</sup> Accordingly, the minimum sample size required was 38 (*n* = 19 in each group) at an alpha and beta error probability of 0.05 and 0.20, respectively. Based on possible drop-outs, a total of 50 patients were planned for inclusion.

## 3 | RESULTS

A total of 50 pediatric patients aged between 5 and 12 years with an ASA of I or II and undergoing minor surgical procedures were included. Overall, 44% patients (*n* = 22) were fluid responsive, and 56% (*n* = 28) were non-responsive. Table 1 shows the patient data.

HR and MAP before, during and after PLR did not differ significantly between fluid responsive and non-responsive patients (*p* > .05). (Table 2).

Patients with fluid responsiveness had significantly higher CO during PLR (*p* < .001), suggesting that these patients are sensitive to increased pre-load. On the contrary, detection of similar CO before and after PLR in the two study groups show that assessment of fluid status with PLR maneuver and USCOM is a reproducible test (*p* > .05).

Finger PVI during and after PLR were statistically comparable (*p* < .05) in the study groups, while fluid responsive patients had higher finger PVI before PLR as compared with non-responsive subjects (*p* = .016).

Fluid responsive patients had significantly higher forehead PVI before, during, and after PLR (*p* < .001, =.004, and <.001, respectively), suggesting that forehead PVI can discriminate between fluid responsive and non-responsive patients irrespective of the position. (Table 3).

Receiver operating characteristic analysis was also performed to test the utility of finger PVI, forehead PVI, and PI values in terms of predicting fluid responsiveness. Accordingly, the AUC for finger PVI before PLR was 0.699 (95% CI: 0.553, 0.820; *p* = .001) (Figure 1.L). The sensitivity, specificity, PPV, and NPV for this measurement at a cut-off value of ≤14 were 92.9%, 45.4%, 68.4%, and 83.3%, respectively (Table 4). The AUC for finger PVI after PLR was 0.677 (95% CI: 0.530, 0.802; *p* = .024). The sensitivity, specificity, PPV, and NPV for this measurement at a cut-off value of ≤14 were 82.1%, 31.8%, 60.5%, and 58.3%, respectively.

The AUC for forehead PVI before PLR was 0.847 (95% CI: 0.724, 0.971; *p* < .001) (Figure 1.R). The sensitivity, specificity, PPV, and NPV for this measurement at a cut-off value of ≤14 were 96.4%, 72.7%, 81.8%, and 94.1%, respectively. The AUC for forehead PVI after PLR was 0.826 (95% CI: 0.709, 0.944; *p* < .001). The sensitivity, specificity, PPV, and NPV for this measurement at a cut-off value of ≤13 were 96.4%, 50%, 71.1%, and 91.7%, respectively.

To compare the relative superiority of finger and forehead PVI in predicting fluid responsiveness, areas under ROC curves were compared using the De Long method. The area determined for forehead PVI before PLR was significantly higher as compared with area determined for finger PVI before and after PLR (*p* = .002, =.011, respectively). AUCs for forehead PVI before and after PLR as well as AUCs for finger PVI before and after PLR were statistically

TABLE 1 Demographical data

	Group R ( <i>n</i> = 22)	Group NR ( <i>n</i> = 28)	
	Mean ± SD	Mean ± SD	<i>p</i> -Value
Age (years)	8.68 ± 2.75	7.75 ± 2.24	.193 <sup>a</sup>
Weight (kg)	28.86 ± 9.27	24.54 ± 7.12	>.05
Body temperature (C°)	36.19 ± 0.21	36.14 ± 0.24	>.05
	<i>n</i> (%)	<i>n</i> (%)	<i>p</i> -Value
Sex			
Female	6 (42.9)	8 (57.1)	.919 <sup>b</sup>
Male	16 (44.4)	20 (55.6)	
ASA			
1	20 (45.5)	24 (54.5)	.683 <sup>c</sup>
2	2 (33.3)	4 (66.7)	

Note: Statistical analysis – <sup>a</sup>Independent samples t-test, <sup>b</sup>Pearson's chi square test, <sup>c</sup>Fisher's exact test.

TABLE 2 Data before, during, and after PLR based on fluid response

		Group R (n = 22)	Group NR (n = 28)	Difference (95% CI)	p-Value <sup>a</sup>
		Mean ± SD	Mean ± SD		
HR (beat/min)	Before PLR	113.23 ± 19.03	113.68 ± 15.31	0.99 (0.91–1.08)	.926
	During PLR	98.32 ± 16.86	97.46 ± 14.5	1.00 (0.91–1.10)	.848
	After PLR	108.73 ± 17.77	107.14 ± 15.06	1.00 (0.91–1.10)	.734
MAP (mmHg)	Before PLR	70.27 ± 13.68	68.43 ± 6.7	1.02 (0.93–1.12)	.566
	During PLR	67.14 ± 12.87	69.36 ± 7.05	0.96 (0.88–1.05)	.472
	After PLR	67.91 ± 14.64	65.64 ± 6.97	1.03 (0.93–1.14)	.509
SPO <sub>2</sub> (%)	Before PLR	99.50 ± 0.8	99.71 ± 0.53	0.99 (0.99–1.00)	.264
	During PLR	99.68 ± 0.65	99.75 ± 0.44	0.99 (0.99–1.00)	.660
	After PLR	99.64 ± 0.73	99.71 ± 0.46	0.99 (0.99–1.00)	.646
CO (ml/dk)	Before PLR	3.18 ± 0.66	3.20 ± 1.13	0.99 (0.84–1.17)	.933
	During PLR	4.17 ± 0.98	3.10 ± 1.00	1.34 (1.15–1.58)	<.001*
	After PLR	3.17 ± 0.82	2.94 ± 1.02	1.07 (0.90–1.28)	.395

Note: Statistical analysis - <sup>a</sup>Independent samples t-test; \**p* < .05.

Abbreviations: CO, cardiac output; HR, heart rate; MAP, mean arterial pressure.

TABLE 3 Plethysmographic data before, during, and after PLR

		Group R (n = 22)	Group NR (n = 28)	Difference (95% CI)	p-Value <sup>a</sup>
		Mean ± SD	Mean ± SD		
Finger PVI (%)	Before PLR	13.55 ± 7.07	9.18 ± 4.36	1.47 (1.09–1.96)	.016*
	During PLR	9.73 ± 8.51	6.96 ± 3	1.39 (0.85–2.01)	.116
	After PLR	13.18 ± 7.76	9.54 ± 5.07	1.38 (0.86–2.11)	.051
Finger PI (%)	Before PLR	3.77 ± 1.74	4.29 ± 2.06	0.87 (0.66–1.12)	.352
	During PLR	4.68 ± 2.18	5.33 ± 2.21	0.87 (0.67–1.12)	.307
	After PLR	3.42 ± 1.62	4.11 ± 1.86	0.83 (0.63–1.08)	.174
Forehead PVI (%)	Before PLR	16.45 ± 6.65	8.61 ± 2.99	1.91 (1.52–2.36)	<.001*
	During PLR	10.5 ± 4.17	7.39 ± 2.25	1.42 (1.14–1.73)	.004**
	After PLR	14.86 ± 6.47	8.75 ± 3.19	1.69 (1.33–2.13)	<.001*
Forehead PI (%)	Before PLR	0.59 ± 0.38	0.72 ± 0.6	0.81 (0.53–1.28)	.338
	During PLR	0.76 ± 0.55	0.85 ± 0.77	0.89 (0.55–1.47)	.613
	After PLR	0.53 ± 0.27	0.98 ± 1.24	0.54 (0.33–1.06)	.071

Note: <sup>a</sup>Independent samples t-test; \**p* < .05; \*\**p* < .01.

Abbreviations: PI, perfusion index; PVI, Plethysmographic Variability Index.

comparable (*p* > .05), suggesting the reliability and reproducibility of our measurements.

## 4 | DISCUSSION

The present study compared the effectiveness of forehead PVI and finger PVI monitoring in the prediction of fluid responsiveness in mechanically ventilated pediatric surgical patients. Although both measurements were highly sensitive, the specificity of forehead PVI was significantly higher as compared with finger PVI (72.7% vs. 45.4%), suggesting that data obtained using forehead probes for

predicting the fluid responsiveness among pediatric surgery patients may provide a more effective and reliable measurement.

Plethysmographic Variability Index monitoring is routinely performed using finger probes. However, in recent years, probes allowing measurements at forehead or ear have been developed. Our literature search suggested that studies examining the comparative efficacy of these two probes were mainly limited to adult patients,<sup>16,17</sup> while data on PVI in pediatric patients were limited to studies using fingers as the sole monitoring site.<sup>18,19</sup> Thus, we designed this study involving pediatric surgical patients who are known to have more rapid and deeper vasomotor tonus alterations as compared with adults due to several different mechanisms.<sup>20</sup>

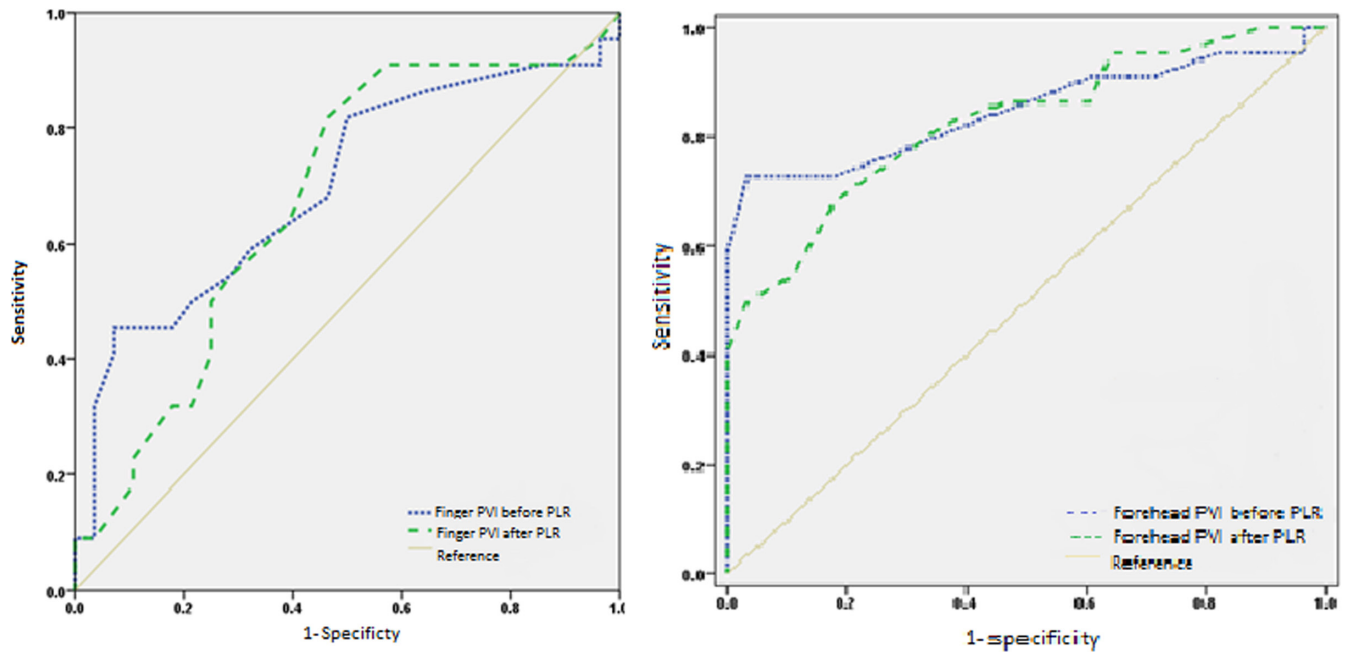


FIGURE 1 Left Panel ROC curves for finger PVI before and after PLR in the prediction of fluid responsiveness. Right Panel ROC curves for forehead PVI before and after PLR in the prediction of fluid responsiveness.

TABLE 4 Utility of forehead and finger PVI values for the assessment of fluid responsiveness

		AuROC (95% CI)	p-Value	Cut-off value	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)
Finger PVI	Before PLR	0.699 (0.553–0.820)	.011*	≤14	92.9 (76.5–99.1)	45.4 (24.4–67.8)	68.4 (51.3–82.5)	83.3 (51.6–97.9)
	After PLR	0.677 (0.530–0.802)	.024*	≤14	82.1 (63.1–93.9)	31.8 (13.9–54.9)	60.5 (43.4–76.0)	58.3 (27.7–84.8)
Finger PI	Before PLR	0.588 (0.440–0.726)	.286	>3.3	71.4 (51.3–86.8)	50 (28.2–71.8)	64.5 (45.4–80.8)	57.9 (33.5–79.7)
	After PLR	0.657 (0.499–0.816)	.051	>3.2	71.4 (51.3–86.8)	63.6 (40.7–82.8)	71.4 (51.3–86.8)	63.6 (40.7–82.8)
Forehead PVI	Before PLR	0.847 (0.724–0.971)	<.001**	≤14	96.4 (81.7–99.9)	72.7 (49.8–89.3)	81.8 (64.5–93.0)	94.1 (71.3–99.9)
	After PLR	0.826 (0.709–0.944)	<.001**	≤13	96.4 (81.7–99.9)	50 (28.2–71.8)	71.1 (54.1–84.6)	91.7 (61.5–99.8)
Forehead PI	Before PLR	0.640 (0.473–0.808)	.099	>0.45	78.6 (59.0–91.7)	59.1 (36.4–79.3)	71 (52.0–85.8)	68.4 (43.4–87.4)
	After PLR	0.674 (0.516–0.832)	.031*	>0.44	82.1 (63.1–93.9)	59.1 (36.4–79.3)	71.9 (53.3–86.3)	72.2 (46.5–90.3)

Abbreviations: AuROC, area under receiver operating characteristic; CI, confidence interval; NPV, negative predictive value; PPV, positive predictive value.

\* $p < .05$ ; \*\* $p < .001$ .

Although studies investigating the PVI cut-off values for forehead probes among adults are scarce in number, those using finger probes reported cut-off values ranging between 12% and 19%.<sup>7,19–22</sup> In Desgrandes et al.'s study, the reported cut-off values for PVI to predict fluid responsiveness in adult patients was 12% for finger and 15% for forehead probes.<sup>16</sup> On the contrary, in Fischer et al. study, the cut-offs for PVI were 19% and 12% for finger and forehead probes, respectively.<sup>17</sup> Among our pediatric patients, the cut-off for PVI for forehead and finger probe measurements was 14%. A ROC AUC analysis based on this cut-off value showed that both methods had high sensitivity in predicting fluid responsiveness (96.4% for finger and 92.9% for forehead probes). However, monitoring performed using forehead probes were associated with higher specificity (72.7% vs. 45.4%). The reported sensitivity and specificity for forehead probes among adult patients are 88–89%

and 78%, respectively.<sup>16,17</sup> The AUC for PVI prior to PLR in our study was 0.847, which is very close to the figure reported by Desgrandes et al. (0.906).<sup>16</sup> Therefore, the sensitivity and specificity of forehead probes in pediatric patients appear to be akin to previous observations among adult patients.

Although the sensitivity of finger PVI was similar to the adult data, the specificity was lower. For instance, as compared with a specificity of 100% reported by Cannesson et al.<sup>7</sup> the specificity for a PVI cut-off of 14% in our study was 45.4 (AuROC 0.6999). In our study, the collateral circulation of the hand was assessed in all patients with Allen's test, and the third finger was chosen for probe placement, as it is known to have the highest local perfusion.<sup>23</sup> However, it was possible that the finger probe might not have responded adequately or might have responded with delay to alterations in perfusion, due to the immaturity of the collateral circulation

in pediatric patients. This may represent a potential explanation for low specificity of finger PVI.

The observed superiority of forehead PVI in predicting fluid responsiveness may be associated with the effect vessel caliber and pulse pressure on PI. Reduction in systemic vascular resistance due to anesthetic agents is not equally distributed throughout the body. For instance, vascular structures of the head have been reported to be less prone to the effects of the sympathetic nervous system as compared to extremities.<sup>2,3</sup> As compared with the fingers, head and ear regions have been found to have lower PI variation coefficients, and despite this, PVI values were higher.<sup>16</sup> It has been suggested the PI variations in fingers may be more related to the vasomotor tonus than to the volume status of the individual.<sup>16</sup>

Higher specificity of the forehead probes as compared to finger probes in pediatric surgical patients may be explained in several ways. Mechanical ventilation has an impact on the power of photo-plethysmographic signals, which play a primary role in PI measurements.<sup>24</sup> Signals at the head region are stronger than the signals at the extremities.<sup>24</sup> Although PI values at the forehead are lower, the effect of ventilation on signals is more pronounced when compared to the finger, possibly due to higher blood flow and shorter measurement distance in the head region as compared with the extremities in pediatric patients. In contrast with the finger probes, the measurements performed by forehead probes are based on infrared light reflection, rather than the light absorbed by erythrocytes loaded with oxyhemoglobin. Measurements based on trans-reflection and absorption react similarly to hemodynamic change.<sup>25</sup> However, it is possible that the former method may provide more sensitive measurements than the latter. Another potential explanation for the more reliable measurements by the forehead probes may be related with the prevention of pulsations in the venous circulation. External compression may influence photo-plethysmographic measurements. In Teng et al.'s study, compression was found to be associated with an initial increase in AC/DC ratio, followed by a decrease.<sup>26</sup> However, oxyhemoglobin in the venous blood may also contribute to these measurements as a result of inadequate compression. In a method aiming to assess the beat-to-beat variations, the focus of the measurement consists of the alterations in arterial pulsation. In our study, the probes were externally fixed with plaster and a partial compression was applied while performing measurements with forehead probes. The plaster not only prevents the effect of the external light beams on photo-plethysmographic signals, but also prevents venous circulation due to the partial pressure.<sup>27</sup>

Obligatory monitoring such as near infrared spectroscopy (NIRS) and bispectral index (BIS) requires too many sensor attachment sides on the forehead of critically ill surgical children. In this patient population, there will be no place for a third sensor. In this situation, placement of the BIS sensor across the nasal bridge may be an alternative. This alternative positioning in adults is suggested by Nelson P et al, nevertheless it is not validated in pediatric patients, yet.<sup>28</sup> For the time being, lack of sufficient space stands as a limitation of the forehead PVI monitoring in pediatric patients. This could force

the anesthetists to choose the monitoring device that most meets their need.

In fluid responsive group, we observed a slight and statistically not significant decrease in MAP. The basic physiologic response to PLR is an increase in CO together with an increase in MAP. We concluded that this response may not be obvious in all children because of the physiologic characteristics of the pediatric population.

In prolonged surgical procedures, pediatric patients are more predisposed to heat loss than adult patients. Since hypothermia may be associated with vasoconstriction, it may reduce the reliability of photo-plethysmographic measurements. In our study, all patients had normothermia, which precluded the evaluation of the effect of hypothermia on forehead PVI measurements.

## 4.1 | Limitations

Children aged between 5 and 12 years were included in this study. Therefore, our results cannot be generalized to younger children. On the contrary, a narrower age range could have provided more reliable results due to more homogeneous sample characteristics. Measurement of CO with invasive methods could have allowed more precise measurements of volume status. However, although USCOM is non-invasive, its efficacy in CO measurements in pediatric patients has already been established.<sup>8,9,15</sup> Also, fluid infusion could have been used instead of the PLR maneuver in the detection of fluid responsiveness. However, this was an ethical issue. Our study was based on the exclusive use of non-invasive methods. The Allen's test was used to assess the collateral perfusion of the hand. This may be a relatively weak test to assess the hand circulation, but the study population consisted of otherwise healthy children estimated to have normal hand perfusion. We have chosen the third finger anyway. Another limitation was related to the fact that the values obtained were pertained to the pre-surgery period. The effect of the type and duration of surgery on measurements remained unknown.

In conclusion, PVI based on the use of forehead probes provided similar sensitivity, but superior specificity as compared to finger probes in pediatric surgical patients. The cut-off value for PVI for both measurement sites was 14%. Our results suggested that use of forehead probes for PVI monitoring may represent a viable alternative to the use of finger probes.

## CONFLICT OF INTEREST

None to declare.

## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from corresponding author upon reasonable request.

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## REFERENCES

- Monnet X, Guérin L, Jozwiak M, et al. Pleth variability index is a weak predictor of fluid responsiveness in patients receiving norepinephrine. *Br J Anaesth*. 2013;110(2):207-213. doi:10.1093/bja/aes373
- Hertzman AB, Roth LW. The absence of vasoconstrictor reflexes in the forehead circulation. Effects of cold. *Am J Physiol-Legacy Content*. 1942;136(4):692-697. doi:10.1152/ajplegacy.1942.136.4
- Awad AA, Ghobashy MA, Ouda W, Stout RG, Silverman DG, Shelley KH. Different responses of ear and finger pulse oximeter wave form to cold pressor test. *Anesth Analg*. 2001;92(6):1483-1486. doi:10.1097/00000539-200106000-00026
- Venn R, Steele A, Richardson P, Poloniecki J, Grounds M, Newman P. Randomized controlled trial to investigate influence of the fluid challenge on duration of hospital stay and perioperative morbidity in patients with hip fractures. *Br J Anaesth*. 2002;88(1):65-71. doi:10.1093/bja/88.1.65
- Marik PE, Cavallazzi R, Vasu T, Hirani A. Dynamic changes in arterial waveform derived variables and fluid responsiveness in mechanically ventilated patients: a systematic review of the literature. *Crit Care Med*. 2009;37(9):2642-2647. doi:10.1097/CCM.0b013e3181a590da
- Singh S, Kuschner WG, Lighthall G. Perioperative intravascular fluid assessment and monitoring: a narrative review of established and emerging techniques. *Anesthesiol Res Pract*. 2011;2011:231493. doi:10.1155/2011/231493
- Cannesson M, Desebbe O, Rosamel P, et al. Pleth variability index to monitor the respiratory variations in the pulse oximeter plethysmographic waveform amplitude and predict fluid responsiveness in the operating theatre. *Br J Anaesth*. 2008;101(2):200-206. doi:10.1093/bja/aen133
- Dhanani S, Barrowman NJ, Ward RE, Murto KT. Intra- and inter-observer reliability using a noninvasive ultrasound cardiac output monitor in healthy anesthetized children. *Paediatr Anaesth*. 2011;21(8):858-864. doi:10.1111/j.1460-9592.2010.03480.x
- Stewart GM, Nguyen HB, Kim TY, Jauregui J, Hayes SR, Corbett S. Inter-rater reliability for noninvasive measurement of cardiac function in children. *Pediatr Emerg Care*. 2008;24(7):433-437. doi:10.1097/PEC.0b013e31817de143
- Jain S, Allins A, Salim A, Vafa A, Wilson MT, Margulies DR. Noninvasive doppler ultrasonography for assessing cardiac function: can it replace the swan-Ganz catheter? *Am J Surg*. 2008;196(6):961-968. doi:10.1016/j.amjsurg.2008.07.039
- Phillips R, Paradis M, Evans N, Southwell D, Burstow D, West M. Cardiac output measurement in preterm neonates: validation of USCOM against echocardiography. *Crit Care*. 2006;10(Suppl 1):P343. doi:10.1186/cc4690
- Monnet X, Rienzo M, Osman D, et al. Passive leg raising predicts fluid responsiveness in the critically ill. *Crit Care Med*. 2006;34(5):1402-1407. doi:10.1097/01.CCM.0000215453.11735.06
- Lu GP, Yan G, Chen Y, Lu ZJ, Zhang LE, Kisson N. The passive leg raise test to predict fluid responsiveness in children--preliminary observations. *Indian J Pediatr*. 2015;82(1):5-12. doi:10.1007/s12098-013-1303-5
- Lukito V, Djer MM, Pudjiadi AH, Munasir Z. The role of passive leg raising to predict fluid responsiveness in pediatric intensive care unit patients. *Pediatr Crit Care Med*. 2012;13(3):e155-e160. doi:10.1097/PCC.0b013e3182388ab3
- Beltramo F, Menteeer J, Razavi A, et al. Validation of an ultrasound cardiac output monitor as a bedside tool for pediatric patients. *Pediatr Cardiol*. 2016;37(1):177-183. doi:10.1007/s00246-015-1261-y
- Desgranges FP, Desebbe O, Ghazouani A, et al. Influence of the site of measurement on the ability of plethysmographic variability index to predict fluid responsiveness. *Br J Anaesth*. 2011;107(3):329-335. doi:10.1093/bja/aer165
- Fischer MO, Pellissier A, Saplacan V, Gérard JL, Hanouz JL, Fellahi JL. Cephalic versus digital plethysmographic variability index measurement: a comparative pilot study in cardiac surgery patients. *J Cardiothorac Vasc Anesth*. 2014;28(6):1510-1515. doi:10.1053/j.jvca.2014.05.003
- Renner J, Broch O, Gruenewald M, et al. Non-invasive prediction of fluid responsiveness in infants using pleth variability index. *Anaesthesia*. 2011;66(7):582-589. doi:10.1111/j.1365-2044.2011.06715.x
- Desgranges FP, Evain JN, de Souza P, et al. Does the plethysmographic variability index predict fluid responsiveness in mechanically ventilated children? A meta-analysis. *Br J Anaesth*. 2016;117(3):409-410. doi:10.1093/bja/aew245
- Mecham N. Early recognition and treatment of shock in pediatric patient. *J Trauma Nurs*. 2006;13(1):17-21. doi:10.1097/00043860-200601000-00005
- Broch O, Bein B, Gruenewald M, et al. Accuracy of the pleth variability index to mEPredict fluid responsiveness depends on the perfusion index. *Acta Anaesthesiol Scand*. 2011;55(6):686-693. doi:10.1111/j.1399-6576.2011.02435.x
- Bailey CR, M.B. B.S, F.R.C.A. Different responses of ear and finger pulse oximeter wave form to cold pressor test. *Surv of Anesthesiol*. 2002;46(3):173.
- Basaranoglu G, Bakan M, Umutoglu T, Zengin SU, Iidin K, Salihoglu Z. Comparison of SpO2 values from different fingers of the hands. *Springerplus*. 2015;4:561. Published 2015 Sep 29. doi:10.1186/s40064-015-1360-5
- Shelley KH, Jablonka DH, Awad AA, Stout RG, Rezkanna H, Silverman DG. What is the best site for measuring the effect of ventilation on the pulse oximeter waveform? *Anesth Analg*. 2006;103(2):372-377.
- Reisner A, Shaltis PA, McCombie D, Asada HH. Utility of the photoplethysmogram in circulatory monitoring. *Anesthesiology*. 2008;108(5):950-958.
- Teng XF, Zhang YT. The effect of contacting force on photoplethysmographic signals. *Physiol Meas*. 2004;25(5):1323-1335.
- Galla TJ, Hellekes D, Feller AM. Differentiation between arterial and venous vessel occlusion by simultaneous measurement with laser doppler flowmetry and photoplethysmography. *J Reconstr Microsurg*. 1999;15(1):67-72.
- Nelson P, Nelson JA, Chen AJ, Kofke WA. An alternative position for the BIS-vista montage in frontal approach neurosurgical cases. *J Neurosurg Anesthesiol*. 2013;25(2):135-142. doi:10.1097/ANA.0b013e31826ca3a0

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