Monitoring the correlation between passive leg-raising maneuver and fluid challenge in pediatric cardiac surgery patients using impedance cardiography

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Aim
The aim of the study was to highlight the effectiveness of passive leg-raising maneuver as a predictor of fluid responsiveness in pediatric patients following cardiac surgery and to determine the parameter that we can depend on to assess its responsiveness.

Patients and methods
This prospective randomized study was performed in the ICU. Forty pediatric patients aged 2–7 years with a noncyanotic cardiac defect scheduled for elective corrective cardiac surgery under cardiopulmonary bypass (CPB) support were included if they needed fluid challenge (FC) in the early postoperative period (10 ml/kg normal saline infusion).
Hemodynamic parameters [heart rate, mean blood pressure, stroke volume (SV), and cardiac index (CI)] were assessed at baseline, after passive leg raising (PLR), at baseline again, and after FC.

Statistical analysis
A comparison of pre-PLR and post-PLR hemodynamic parameters and those before and after FC was made using the paired Student's *t*-test, whereas a comparison after passive leg raising (PLR) and FC was made using the unpaired Student's *t*-test. The hemodynamic parameters after PLR and its relation to the responses to fluid administration were analyzed using diagnostic validity tests and the χ^2-test.

Results
The increase in SV and CI with PLR is significantly correlated with the response to fluid administration. An increase in CI by 10% or more due to PLR predicted preload-dependent status with a sensitivity of 65% and a specificity of 75%, whereas an increase in SV by more than 10% due to PLR predicted preload-dependent status with a sensitivity of 42.1% and a specificity of 85.7%.

Conclusion
The PLR maneuver is a reliable noninvasive method that can predict volume responsiveness in post-cardiac-surgery pediatric patients. Both SV and CI can be used as predictors of fluid responsiveness, although CI is a more accurate.

Keywords:
fluid responsiveness, impedance cardiography, passive leg raising, pediatric cardiac surgery

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Introduction

In critically ill patients, fluid volume replacement is often necessary to optimize the cardiovascular function, thus maintaining adequate cardiac preload and output, which will guarantee enough oxygen delivery to tissues, which is essential in the management of critically ill patients [1].

It is quite a challenge to predict the patients who will respond to fluid administration by a significant increase in cardiac output, particularly because excessive fluid administration may be risky in critically ill patients, especially in pediatric patients who recently underwent cardiac surgery [2,3].

The usual clinical and hemodynamic parameters are not necessarily reliable indexes of the adequacy of the cardiac preload. Fluid challenge (FC) with invasive measurement of cardiac output remains a widely used test to detect cardiac preload dependence [4].

Passive leg raising (PLR) is a noninvasive reversible maneuver that mimics rapid fluid loading by causing rapid autotransfusion of a significant volume of blood by shifting venous blood from the legs toward the intrathoracic compartment, thereby increasing right and left ventricular preloads. Eventually, the increase in left cardiac preload increases the stroke volume

(SV) and cardiac output depending upon the degree of preload reserve of the left ventricle. Thus, when SV increases with PLR, it should increase with rapid fluid loading as well [5].

As a clinical application of this simple physiological concept, several studies reported that the increase in cardiac output induced by the PLR test enables the prediction of fluid responsiveness. These findings have contributed to establishing PLR as a reliable and easy way of predicting fluid responsiveness at the bedside [6]. The advantage of PLR is that the increase in cardiac preload induced by PLR is totally reversed once the legs are returned to the initial horizontal position [4]. Our study may be a leading one on the use of PLR as a predictor of fluid responsiveness in pediatric patients after cardiac surgery.

The purpose of our study was to predict whether the hemodynamic effect of PLR could predict the hemodynamic response to subsequent FC in post-cardiac-surgery noncyanotic pediatric patients and also to determine the parameters that we can depend upon to assess passive leg-raising responsiveness in these patients.

Patients and methods

After obtaining the approval of the local ethics committee and written informed consent had been obtained from parents of the children, this prospective randomized study was performed in the ICU between April 2014 and November 2014. Forty pediatric patients aged 2–7 years with a noncyanotic cardiac defect scheduled for elective corrective cardiac surgery performed with CPB support were included.

Patients who needed FC in the early postoperative period were included in the study. FC was given if one or more of the following occurred: a decrease in mean blood pressure (MBP) by more than 10% from baseline; an increase in heart rate (HR) by more than 10% from baseline; or urine output less than 0.5 ml/kg/h after exclusion of other possible causes such as pain, awareness, kinked, or displaced urinary catheter.

Exclusion criteria included patients in shock who required urgent resuscitation or contraindications to leg elevation and fluid bolus, such as cardiomyopathy, lung edema, increased intracranial pressure, or lower-extremity fractures. Also, patients undergoing emergency surgery or redo surgery were not included in the study.

General anesthesia and postoperative management followed institutional standards. During the postoperative period, all patients were admitted to the ICU, intubated, and ventilated (pressure-controlled regimen) with standard settings to achieve normocapnia. The FiO_2 was 0.4, with baseline postive end expiratory pressure (PEEP) 3 cmH_2O. All patients were sedated and paralyzed with continuous infusion of midazolam at 0.5 μg/kg/h and atracurium at 5–9 μg/kg/min to prevent any spontaneous breathing trials. All patients were subjected to impedance cardiography (the electrical cardiometry monitor AESCULON, Osypka Medical GmbH, Grossbeerenstrasse 184, D-12277 Berlin, Germany) to monitor SV and cardiac index (CI) continuously.

Clinical data, including age, sex, height, weight, body surface area, type of operation, and dose of inotropic drugs, were recorded at the time of entry. Measurements of hemodynamic parameters, including HR, MBP, SV, and CI, were monitored and recorded during the study. SV and CI were noninvasively monitored using impedance cardiography (the electrical cardiometry monitor AESCULON).

All measurements were taken within 2 h of arrival at the ICU. During the study period, the patients remained supine and doses of midazolam, atracurium, vasoactive agents, and ventilator settings were unchanged.

SV, CI, mean arterial blood pressure (MABP), and HR were recorded four times.

At T1, the patient was in the supine position, with the head raised 45°; at T2, the lower extremities were raised 45° with the help of an assistant, and after 5 min the four hemodynamic parameters were measured again; at T3 the patient was placed back in the initial position for 10 min and the hemodynamic parameters were again measured. At T4, a bolus of intravenous FC was given to the patient using 10 ml/kg of 0.9% NaCl and the four hemodynamic parameters were measured immediately after the challenge.

The patients were categorized as responders if the CI increased by more than 10% following the FC or leg raising.

The primary endpoint of our study was to predict whether PLR could predict the hemodynamic response to subsequent FC in pediatric patients following cardiac surgery. The secondary endpoint was to determine which parameter we can depend upon for assessment of passive leg-raising responsiveness in pediatric patients following cardiac surgery.

Statistical methods

Data were expressed as mean ± SD for quantitative parametric measures in addition to both number and percentage for categorized data. IBM SPSS statistics (version 22.0, 2013; IBM Corp., USA) was used for data analysis.

On the basis of a pilot study in our ICU, it was determined that a sample size of 39 achieves 80% power to detect to detect a 40% in patients who will respond to PLR using a two-sided binomial test with a significance level less than 0.05. Forty patients were included to replace any missing data. PASS 11 (Kaysville, Utah) was used for sample size calculation.

The comparison between pre-PLR and post-PLR hemodynamic parameters and those before and after FC was made using the paired Student's *t*-test, whereas the comparison after FLR and FC was made using the unpaired Student's *t*-test. The hemodynamic parameters after PLR and its relation to the responses to fluid administration were analyzed using diagnostic validity tests (including sensitivity, specificity, predictive value for a negative test, predictive value for a positive test, and efficacy) and the χ^2-test. The *P* of error at 0.05 was considered significant, and those at 0.01 and 0.001 were considered highly significant.

Results

During the study period, 40 patients were included (25 boys and 15 girls); the mean age of patients was 4.86 years. The average body surface area of the patients was 0.83 ± 0.26 m^2. The diagnoses of the children were atrial septal defect (*n* = 12, 30%), ventricular septal defect (*n* = 13, 32.5%), common atrioventricular canal (*n* = 8, 20%), and subaortic membrane (*n* = 7, 17.5%) (Table 1).

The only parameter that showed significant changes after PLR was CI (*P*<0.001), but after we conducted the FC significant changes were found in HR (*P* = 0.006), SV (*P*<0.001), and CI (*P*<0.001), as shown in Tables 2 and 3. There was no significant difference between pre-PLR and pre-FC values with respect to any of the measured hemodynamic parameters (*P* > 0.05).

Among those patients with decreased HR after FC (20 patients), only seven patients had the same response after PLR (35%) and 13 (65%) patients showed no decrease in HR after PLR, which indicates that there was no significant correlation between FC and PLR on the basis of HR, as shown in Table 4.

As regards MBP, among those patients with increased MBP after FC (20 patients), only four (20%) patients had the same response after PLR and 16 (80%) patients

Table 1 Study population characteristics

Characteristics	Values
Age (years)	4.86 + 1.31
Sex (male/female)	25 (62.5)/15 (37.5)
BSA (m^2)	0.83 ± 0.26
Diagnosis	
ASD	12 (30)
VSD	13 (32.5)
Common atrioventricular canal	8 (20)
Subaortic membrane	7 (17.5)

Values are expressed as mean ± SD or *n* [%]; ASD, atrial septal defect; BSA, body surface area; VSD, ventricular septal defect.

Table 2 Comparison between pre-passive leg raising and post-passive leg raising values as regards heart rate, mean blood pressure, stroke volume, and cardiac index

Variables	Before PLR	After PLR	*P* value
HR (beats/min)	132.3 ± 50	130.9 ± 46	0.4
MBP (mmHg)	60.6 ± 5.72	59.2 ± 13.56	0.522
SV (ml/beat)	18.627 ± 23.8	18.648 ± 17.5	0.242
CI (l/m/m^2)	3.297 ± 2.155	3.465 ± 1.86	<0.001

Values are expressed as mean ± SD; CI, cardiac index; HR, heart rate; MBP, mean blood pressure; PLR, passive leg raising; SV, stroke volume; *P* < 0.05 is considered statistically significant.

Table 3 Comparison between pre-fluid challenge and post-fluid challenge values as regards heart rate, mean blood pressure, stroke volume, and cardiac index

Variables	Before FC	After FC	*P* value
HR (beats/min)	129.15 ± 47	127.05 ± 45.5	0.006
MBP (mmHg)	59.8 ± 14.65	60.2 ± 12.65	0.634
SV (ml/beat)	18.658 ± 25	20.391 ± 21.55	<0.001
CI (l/m/m^2)	3.076 ± 1.92	3.623 ± 2.66	<0.001

Values are expressed as mean ± SD; CI, cardiac index; FC, fluid challenge; HR, heart rate; MBP, mean blood pressure; SV, stroke volume; *P*<0.05 is considered statistically significant.

Table 4 Correlation between fluid challenge and passive leg raising using heart rate, mean blood pressure, stroke volume, and cardiac index

Response to PLR	Response to FC		*P* value
	Yes	No	
Decrease in HR			
Yes	7 (35)	6 (30)	0.736
No	13 (65)	14 (70)	
Increase in MBP			
Yes	4 (20)	2 (10)	0.376
No	16 (80)	18 (90)	
Increase in SV			
Yes	8 (42.1)	3 (14.3)	0.049
No	11 (57.9)	18 (85.7)	
Increase in CI			
Yes	13 (65)	3 (15)	0.001
No	7 (35)	17 (85)	

Values are expressed as *n* [%]; CI, cardiac index; FC, fluid challenge; HR, heart rate; MBP, mean blood pressure; PLR, passive leg raising; SV, stroke volume; *P*<0.05 is considered statistically significant.

showed no increase in MBP after PLR, which indicates that there was no significant correlation between FC and PLR on the basis of MBP, as shown in Table 4.

As regards SV, among those patients with increased SV after FC (19 patients), only eight (42.1%) patients had the same response after PLR and 11 (57.9%) patients showed no increase in SV after PLR, which indicates that there was significant correlation between FC and PLR on using SV, as shown in Table 4.

CI also showed significant correlation between FC and PLR, as shown in Table 4. Among those patients with increased CI after FC (20 patients), 13 (65%) patients had the same response after PLR and seven (35%) patients showed no increase in CI after PLR, whereas among patients who showed no increase in CI after FC (20 patients), only three patients showed increased CI after PLR and 17 (85%) patients showed no response.

A patient was categorized as a responder if there was an increase in CI of 10% or more after FC. Twenty patients were categorized as responders, with a CI increase of 10% or more after receiving intravenous fluid with 10 ml/kg of normal saline. The sensitivity of CI using the PLR maneuver was 65%, with a specificity of 85%, efficacy of 75.0%, positive predictive value of 81.3%, and negative predictive value of 70.8%, whereas sensitivity of SV using the PLR maneuver was 42.1%, with a specificity of 85.7%, efficacy of 65.0%, positive predictive value of 72.7%, and negative predictive value of 62.1%, as shown in Table 5. The only hemodynamic parameter that showed a quite high sensitivity to FC after PLR was CI.

Discussion

This study showed that the PLR maneuver can be used as a noninvasive reversible predictor of the responses to fluid administration in post-cardiac-surgery pediatric patients. It also clarified that both SV and CI can be used as hemodynamic parameters for assessing the responsiveness of PLR. However, the study showed that CI had a higher sensitivity and efficiency than SV.

Table 5 Accuracy of hemodynamic parameter changes in passive leg raising to predict fluid responsiveness

Items	Specificity (%)	Sensitivity (%)	Negative predictive value	Positive predictive value	Efficacy (%)
HR	70.0	35.0	51.9	53.8	52.5
MBP	90.0	20.0	52.9	66.7	55.0
SV	85.7	42.1	62.1	72.7	65.0
CI	85.0	65.0	70.8	81.3	75.0

CI, cardiac index; HR, heart rate; MBP, mean blood pressure; SV, stroke volume.

In this study, the PLR maneuver has been chosen as a noninvasive method for predicting fluid responsiveness in post-cardiac-surgery pediatric patients by virtue of the fact that the changes in CI during PLR are temporary and reversible as the CI returns to its original value within 7–10 min after the legs are repositioned, thus avoiding the detrimental effects of unnecessary fluid administration [5,7,8].

On comparing the hemodynamic parameters before and after FC, it was found that MABP did not show a significant change, which was also observed following PLR. This can be attributed to sympathetically mediated arterial autoregulation, where the arterial tone changes with changes in cardiac output to maintain constant MABP. Therefore, MABP cannot be relied upon as an indicator of fluid responsiveness [9–11].

Although the HR changed significantly following FC, it did not show a significant change after PLR. This may be because the volume of autotransfused fluid following PLR in pediatric patients is likely to be less than the volume of FC administered (10 ml/kg), and thus it cannot be used for assessing the responsiveness of PLR to fluid administration; in addition, many factors may affect HR, especially in pediatric patients [12–16].

SV also did not show a significant change after PLR, despite a significant change after FC; again, this may be due to the smaller autotransfused blood volume following PLR in pediatric patients. Therefore, the increase in SV after PLR is not as high as the increase resulting from FC [12]. However, by comparing SV after both PLR and FC, there was a significant correlation between FC and PLR, with a sensitivity of 42.2%, and thus it can be used for assessing the responsiveness of PLR to fluid administration.

In contrast to HR and SV, CI showed a significant change after both PLR and FC. Moreover, on comparing CI after both PLR and FC, a significant correlation was found between PLR and FC, with a sensitivity of 65%, and thus it is considered a good parameter in assessing the responsiveness of PLR to fluid administration in pediatric patients after cardiac surgery.

Therefore, we concluded that either SV or CI can be used as a predictor of fluid responsiveness. But still, the change in CI is a much more accurate parameter for determining the response to fluid administration because of its higher sensitivity.

Similar results were obtained in a study by Lukito *et al.* [12] conducted on pediatric ICU patients. This study showed that the CI changed significantly after both PLR and FC, whereas SV changed significantly only after FC. Caille *et al.* [16] found that the increase in SV after PLR was not significantly as high as the increase after FC. Lukito *et al.* [12] proposed an explanation for these results; they suggested that the effect of FC was higher because of some residual fluid from PLR, as the wash-out time after PLR was not maximal yet, thus making the increase in SV and CI following PLR lower compared with that after FC.

In contrast to our study, other studies [13,14,17–19] reported that the changes in SV induced by PLR are an accurate and interchangeable index for predicting fluid responsiveness – for example, in the study by Dong *et al.* [17] in nonintubated critically ill patients and that by Préau *et al.* [14] in nonintubated septic shock patients. Guint *et al.* [19] also stated that PLR significantly increases both SV and cardiac output (COP) and those changes in SV after PLR can predict fluid responsiveness in venovenous extracorporial membrane oxygenator (ECMO) patients. These differences in results may be due to the different types of patients selected, as most of these studies were conducted on adult patients with different pathologies.

Some studies that were also conducted on pediatric patients attributed the difference in results between adults and pediatric patients to the leg-length to body-length ratio, which is lower in children compared with adults [12,20]. Lukito *et al.* [12] assumed that the shorter leg length in pediatric patients might result in a decreased effect of autotransfusion when compared with fluid administration. Therefore, the change in SV after PLR may not be enough to show statistically significant differences.

In our study, we performed the PLR maneuver while the patient was in the 45° semirecumbent position instead of the supine position as this is believed to add blood from the splanchnic venous reservoir. Jabot *et al.* [7] concluded that the 45° semirecumbent position induces a larger increase in cardiac preload than the supine position and may be preferred for predicting fluid responsiveness. This was also ascertained by Monnet and Teboul [21]. Therefore, this method is considered the standard.

It is also worth mentioning that correct monitoring of a PLR effect requires a device that allows continuous monitoring. This was achieved in our study as SV and CI were continuously monitored using impedance cardiography (the electrical cardiometry monitor AESCULON), which is not available in every ICU.

Impedance cardiography has the merit of being simple, noninvasive, continuous, and cost-effective, with good correlation with other clinical measures of cardiac function [22].

Conclusion

The passive leg-raising maneuver is a reliable noninvasive method that can predict volume responsiveness in post-cardiac-surgery pediatric patients.

The increase in SV and CI with PLR is significantly correlated with the response to fluid administration. Therefore, either SV or CI can be used as a predictor of fluid responsiveness. Nevertheless, the increase in CI is a much more accurate parameter for assessing the response to fluid administration.

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Conflicts of interest
There are no conflicts of interest.

References

1 Benington S, Ferris P, Nirmalan M. Emerging trends in minimally invasive haemodynamic monitoring and optimization of fluid therapy. Eur J Anaesthesiol 2009; 26:893–905.
2 Vincent JL, Sakr Y, Sprung CL, Ranieri VM, Reinhart K, Gerlach H, *et al.* Sepsis Occurrence in Acutely Ill Patient Investigators Sepsis in European intensive care units: results of the SOAP study. Crit Care Med 2006; 34:344–353.
3 Boyd JH, Forbes J, Nakada TA, Walley KR, Russell JA. Fluid resuscitation in septic shock. A positive fluid balance and elevated central venous pressure are associated with increased mortality. Crit Care Med 2011; 39:259–265.
4 Monnet X, Teboul JL. Assessment of volume responsiveness during mechanical ventilation: recent advances. Crit Care 2013; 17:217.
5 Monnet X, Rienzo M, Osman D, Anguel N, Richard C, Pinsky MR, *et al.* Passive leg raising predicts fluid responsiveness in the critically ill. Crit Care Med 2006; 34:1402–1407.
6 Antonelli M, Levy M, Andrews PJ, Chastre J, Hudson LD, Manthous C, *et al.* Hemodynamic monitoring in shock and implications for management. International Consensus Conference, Paris, France, 27–28 April 2006. Intensive Care Med 2007; 33:575–590.
7 Jabot J, Teboul JL, Richard C, Monnet X. Passive leg raising for predicting fluid responsiveness: importance of the postural change. Intensive Care Med 2009; 35:85–90.
8 Monnet X, Jabot J, Maizel J, Richard C, Teboul JL Norepinephrine increases cardiac preload and reduces preload dependency assessed by passive leg raising in septic shock patients. Crit Care Med 2011; 39:689–694.
9 Vincent JL, Weil MH. Fluid challenge revisited. Crit Care Med 2006; 34:1333–1337.
10 Monnet X, Letierce A, Hamzaoui O, Chemla D, Anquel N, Osman D, *et al.* Arterial pressure allows monitoring the changes in cardiac output induced by volume expansion but not by norepinephrine. Crit Care Med 2011; 39:1394–1399.
11 Pierrakos C, Velissaris D, Scolletta S, Heenen S, De Backer D, Vincent JL. Can changes in arterial pressure be used to detect changes in cardiac index during fluid challenge in patients with septic shock? Intensive Care Med 2012; 38:422–428.
12 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; 13:155–160.
13 Maizel J, Airapetian N, Lorne E, Tribouilloy C, Massy Z, Slama M. Diagnosis of central hypovolemia by using passive leg raising. Intensive Care Med 2007; 33:1133–1138.

14 Préau S, Saulnier F, Dewavrin F, Durocher A, Chagnon JL. Passive leg raising is predictive of fluid responsiveness in spontaneously breathing patients with severe sepsis or acute pancreatitis. Crit Care Med 2010; 38:819–825.

15 Kyriakides ZS, Koukoulas A, Paraskevaidis IA, Chrysos D, Tsiapras D, Galiotos C, *et al*. Does passive leg raising increase cardiac performance? A study using Doppler echocardiography. Int J Cardiol 1994; 44:288–293.

16 Caille V, Jabot J, Belliard G, Charron C, Jardin F, Vieillard-Baron A. Hemodynamic effects of passive leg raising: an echocardiographic study in patients with shock. Intensive Care Med 2008; 34:1239–1245.

17 Dong ZZ, Fang Q, Zheng X, Shi H. Passive leg raising as an indicator of fluid responsiveness in patients with severe sepsis. World J Emerg Med2012; 3:191–196.

18 Lamia B, Ochagavia A, Monnet X, Chemla D, Richard C, Teboul JL. Echocardiographic prediction of volume responsiveness in critically ill patients with spontaneously breathing activity. Intensive Care Med 2007; 33:1125–1132.

19 Guint PG, Zogheib E, Detave M, Moubarak M, Hubert V, Badoux L, *et al*. Passive leg raising can predict fluid responsiveness in patients placed on venovenous extracorporeal membrane oxygenation. Crit Care 2011; 15:216.

20 Fredriks AM, van Buuren S, van Heel WJ, Dijkman-Neerincx RHM, Verloove-Vanhorick SP, Wit JM. Nationwide age references for sitting height, leg length, and sitting height/height ratio, and their diagnostic value for disproportionate growth disorders. Arch Dis Child 2005; 90:807–812.

21 Monnet X, Teboul JL. Passive leg raising: five rules, not a drop of fluid! Crit Care 2015; 19:18.

22 Van De Water MJ, Miller WT, Vogel LR, Mount EB, Dalton LM. Impedance cardiography: the next vital sign technology? Chest 2003; 123:2028–2033.