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The effect of fluids flushed in pediatric cardiac catheterization procedures on lung ultrasound score

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ABSTRACT

Background: Intravascular catheters used during cardiac catheterization require frequent flushing with heparinized solutions. Fluid overload is more common in pediatric patients with congenital heart diseases. This study aimed to determine the safe volume of fluids that can be used without congestion using the lung ultrasound score.

Methodology: A total of 42 patients aged from 1 month to 6 years undergoing diagnostic cardiac procedures were included in this study. The total volume of infused fluids, the volume of fluids used for flushing intravascular sheaths and catheters, the lung ultrasound score, and $PaCO_2$ and PaO_2 /FiO_2 ratio were documented.

Results: There was a very strong positive relationship between the total fluid volume infused in ml/kg and the difference in the lung ultrasound score before and after fluid infusion (r = 0.841, P < 0.001). There was a very weak positive relationship between the total fluid volume infused in ml/kg and the difference in $PaCO_2$ before and after fluid infusion (r = 0.217, P = 0.167). There was a weak negative relationship between the total fluid volume infused in ml/kg and the change in the PaO_2 /FiO_2 ratio (r = −0.21, P = 0.182).

Conclusion: A fluid flush volume of >11.3 ml/kg has a high probability of inducing volume load in pediatric patients undergoing cardiac catheterization. A flushing volume of 3.478 ml/kg affects the lung ultrasound score. Hence, we recommend reducing the volume of intravenous fluids if higher volumes are required for flushing.

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1. Introduction

During the catheterization procedure, operators must flush the intravascular sheaths and catheters with heparinized solutions frequently so they will remain patent. There are no protocols or recommendations concerning the type and amount of fluids used, which increases the risk of fluid overload [1].

Several studies have investigated various aspects of heparinized and nonheparinized flushes. One aspect is the advantage of heparinized vs. saline flush in preventing thrombotic complications; another aspect is the effect of heparin use on the probability of inducing bleeding. Ishii et al. compared thrombotic complications between heparinized vs. saline flush [2]. Grady et al. examined the subsequent bleeding tendency resulting from the heparin flush [3].

To our knowledge, no study has investigated the effect of such practice on the volume status of patients undergoing cardiac catheterization.

Pediatric patients are more liable to fluid overload due to their smaller weights than adult patients. The risk increases in pediatric patients with congenital heart diseases due to lower tolerability and reserve capacity; some of them may already have a degree of heart failure. Fluid overload increases the incidence of morbidity and mortality in such patients [4,5].

Fluid overload is the most common cause of postoperative acute kidney failure in pediatric patients undergoing cardiac surgeries [6,7]. Fluid overload is also associated with a longer duration of mechanical ventilation after cardiac surgeries in pediatrics as it increases the incidence of chest wall edema and pleural effusion [8].

Lung ultrasound plays a significant role in diagnosing fluid overload through the detection of increased lung water content, where the presence of more than three "B lines" within the same lung field is generally associated with a reduction in PaO_2/FiO_2 ratio [9].

We conducted this study to determine the fluids required for flushing during pediatric cardiac catheterization (in ml/kg) and evaluate its effect on total lung water volume and PaO_2/FiO_2 ratio.

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2. Patients and methods

2.1. Study population and randomization

This prospective observational study was conducted at Abo El Reesh Pediatric Hospital, Faculty of Medicine, Cairo University.

After obtaining approval from the local ethics committee, 42 patients were recruited from February 2020 till January 2021. The patients' guardians provided informed consent. The study included pediatric patients aged from 1 month to 6 years who were undergoing diagnostic cardiac catheterization procedures. Exclusion criteria were patients aged <1 month and >6 years who underwent preoperative mechanical ventilation or had heart failure or oligemic lung diseases.

2.2. Methods

The patients' parents provided their medical histories. We examined each patient and performed all routine investigations with parents' informed consent. Patients were allowed to continue clear fluids up to 2 hours before the operation.

All patients underwent standard monitoring (electrocardiography, pulse oximetry, end-tidal CO_2, and noninvasive arterial blood pressure). They were subjected to inhalational induction using 4% sevoflurane in 100% oxygen, followed by a peripheral intravenous cannula placement. Oral endotracheal intubation was facilitated by IV administration of fentanyl (1–2 µg/kg) and atracurium (0.5 mg/kg).

Mechanical ventilation was maintained with an inspired oxygen fraction (FiO_2) of 50%, a PEEP of 5 cmH_2O, an I:E ratio of 1:2, a peak inspiratory pressure set to deliver a tidal volume of 5–8 ml/kg (maintaining PCO_2 at 30–40 mmHg), and a respiratory rate of 15–35 cycles per minute according to the end-tidal CO_2.

After inducing anesthesia and before starting the procedure, we performed a lung ultrasound examination using a curved transducer with low frequency (2–5 MHz) and was evaluated for the presence of B lines. Arterial blood gas samples were aspirated simultaneously.

The operators inserted the intravascular sheaths (femoral artery and vein cannulation with the suitable sheath size for age) and introduced different catheters through the sheaths to perform the procedure. The catheters and sheaths must be frequently flushed with heparinized solutions to maintain patency. The volume of fluids used for flushing was calculated and correlated to the lung ultrasound score.

After the end of the procedure, both arterial blood gases and lung ultrasound examinations were repeated, provided that no complications such as spells and hypertensive crises occurred.

Maintenance requirements of intravenous fluids were administered by a crystalloid solution (lactated Ringer's solution) calculated using the "4:2:1 rule," i.e., 4 ml/kg/h for the first 10 kg weight, 2 ml/kg/h for the second 10 kg weight, and 1 ml/kg/h for each remaining kilogram.

2.2.1. Lung ultrasound score

The used ultrasound device was SonoSite USS-JCH1F -00880 and we used the curved ultrasound probe (8.5) MHz

The lung ultrasound score (LUS) was obtained by scanning the 12-rib interspaces, where each hemithorax was divided into six areas.The areas are split into upper and base areas bounded by anterior and posterior axillary lines. Each scanning site yielded a score, and four ultrasound aeration patterns were defined as follows:

Normal aeration (N):	Line sliding sign associated with respiratory movement.
Moderate loss of lung aeration (B1 lines):	A clear number of multiple visible B lines with horizontal spacing between adjacent B lines ≤7 mm.
Severe loss of lung aeration (B2 lines):	Multiple fused B lines with difficulty to count with horizontal spacing between adjacent B lines ≤3 mm.
White lung or pulmonary consolidation (C):	Hyperechoic lung tissue, accompanied by dynamic air bronchogram.

The LUS was determined based on the following four lung ultrasonographs: N = 0, B = 1, B2 = 2, and C = 3. We examined 12 lung areas and determined the final LUS of the patient by adding each regional ultrasound score (ranging from 0 to 36).

2.3. Statistical analysis

2.3.1. Sample size

Based on a previous study [10], the sample size was calculated using B lines' preoperative LUS as the primary outcome. The median (range) of the LUS of B lines was 14 (2–26) in the intervention group; assuming that a difference of 20% will be clinically significant between two dependent mean values, with a correlation of 0.5 between groups, a power of 0.8, and an alpha error of 0.05. A minimum sample size of 39 patients was calculated for the matched pairs. A 10% increase compensated for possible dropouts; therefore, 43 patients were required. The sample size calculation was done using the G*Power 3 software.

2.3.2. Statistical analysis

The Statistical Package for Social Sciences (SPSS 21) software was used for statistical analysis. Numerical variables were first tested for normality using Shapiro's test and then analyzed using an unpaired *t*-test. Pearson's test was used for correlation. A P value of <0.05 was considered statistically significant.

MedCalc software determined the cut-off level of fluids' flush at which the volume load was observed. Lung ultrasound was the classification variable for the presence or absence of volume load through an interactive dot diagram.

3. Results

A total of 60 patients were screened for eligibility, and 18 were excluded as they did not meet the inclusion criteria. The remaining 42 patients were available for the final analysis.

Demographic data consisted of age, weight, gender, and the total volume of fluids used for flushing the sheaths and catheters. The calculated mean age of the included patients was 4.3 years with a standard deviation of 2.1. The mean weight of the patients was 18.1 kg with a standard deviation of 7.8. The number of male patients in this study was 29, representing 69% of the included patients. The mean volume of fluids used for flushing was 9.9 ml/kg with a standard deviation of 8.1 (Table 1).

Statistically significant changes occurred in the LUS, PCO_2, and P/F ratio before and after the procedure, which were most probably related to the usage of fluids for flushing the sheaths and catheters. The mean values of the LUS were 6.9 with a standard deviation of 4.4 before the procedure and 10.5 with a standard deviation of 5.1 after the procedure ($P \leq 0.001$) (Table 2, Figures 1 and 2). The mean $PaCO_2$ values were 33 with a standard deviation of 5.3 before flushing and 37 with a standard deviation of 6.1 after flushing ($P < 0.001$) (Table 2, Figure 3). The mean P/F ratios were 353 with a standard deviation of 131 before flushing and 308 with a standard deviation of 126 after flushing, which also indicated a high statistical significance ($P < 0.001$) (Table 2, Figure 4).

There was a very strong positive relationship between the total fluid volume infused in ml/kg and the difference in the LUS before and after fluid infusion, with a Pearson's correlation coefficient (r) of 0.841 and a P value of <0.001 (Figure 5). There was a very weak positive relationship between the total fluid volume infused in ml/kg and the difference in $PaCO_2$ before and after fluid infusion, with a Pearson's correlation coefficient (r) of 0.217 and a P value of 0.167 (Figure 6).

There was a weak negative relationship between the total fluid volume infused in ml/kg and the difference in P/F ratio before and after fluid infusion, with a Pearson's correlation coefficient (r) of −0.21 and a P value of 0.182 (Figure 7).

An interactive dot diagram indicated the fluid level (ml/kg) that best determines the presence of volume load based on LUS changes. The volume of fluids used for flushing that increased the LUS was 3.478 ml/kg (Figure 8). The total volume of infused fluids (intravenous fluids and fluids used for flushing) that increased the LUS was 11.3 ml/kg (Figure 9).

Table 1. Demographic data. Data are expressed as mean (SD) and number (percent), as appropriate.

Age (years)	4.3 (2)
Weight (kg)	18.1 (7.8)
Male sex no. (%)	29 (69)
Total amount of fluids infused (ml/kg)	9.9 (8.1)

Table 2. Lung ultrasound score, $PaCO_2$, and PF ratio before and after the procedure. Data are expressed as mean (SD).

	Before flushing	After flushing	P value
Lung ultrasound score	6.9 (4.4)	10.5 (5.1)	<0.001*
$PaCO_2$ (mmHg)	33 (5.3)	37 (6.1)	<0.001*
P/F ratio	353 (131)	308 (126)	<0.001*

$P \leq 0.05$ is considered to be statistically significant

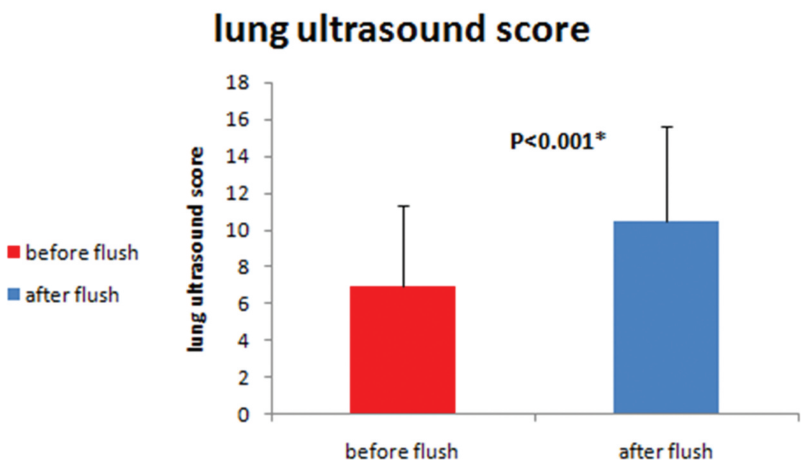

Figure 1. Lung ultrasound score after flushing was higher, with $P < 0.001$.

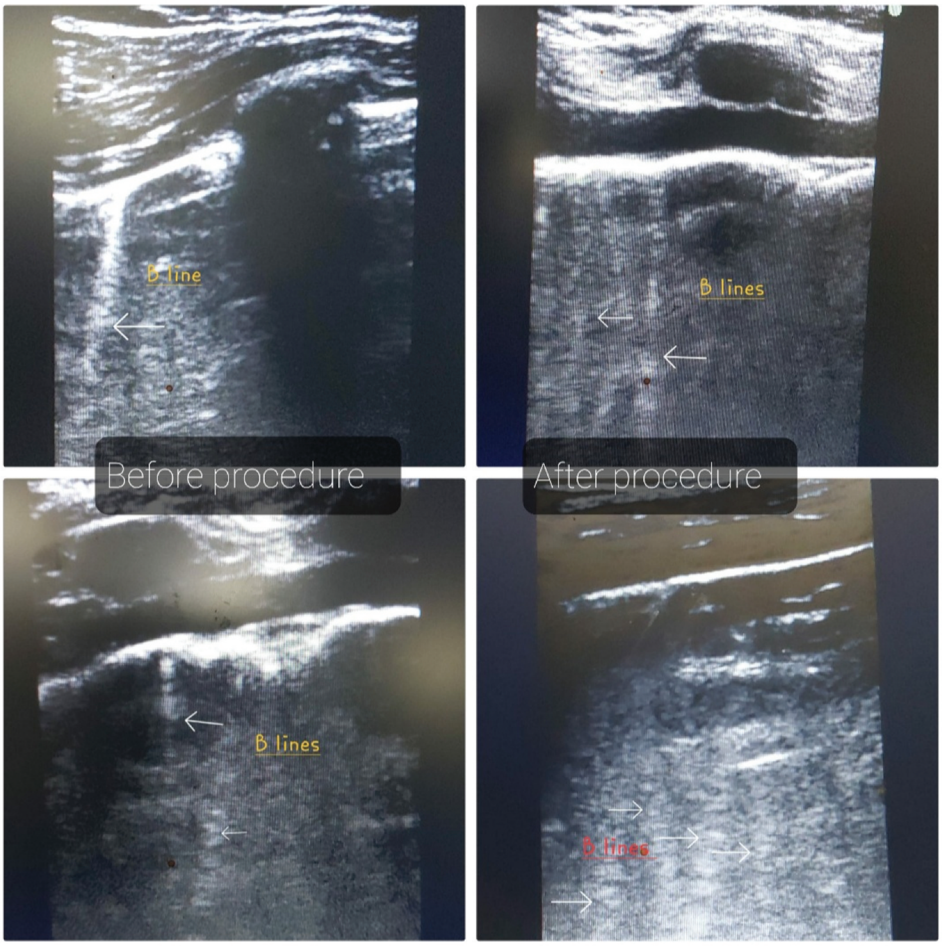

Figure 2. Examples of ultrasound images before and after the procedure and flushing by fluids.

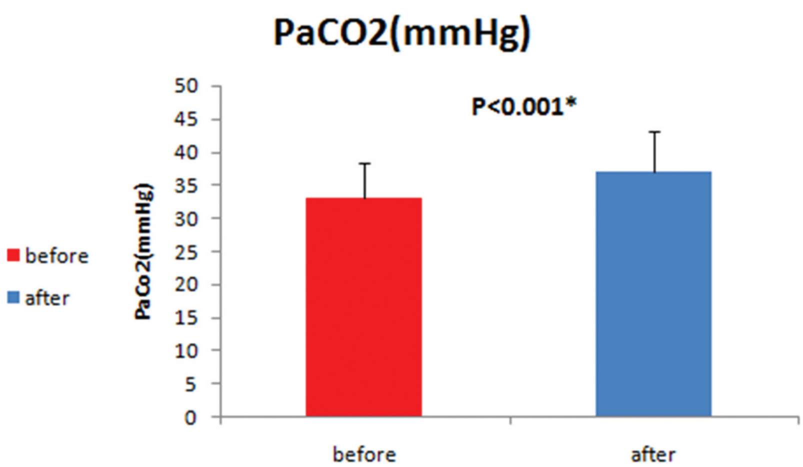

Figure 3. $PaCO_2$ after flushing was higher, with $P < 0.001$.

4. Discussion

This study determined the fluids used for flushing during pediatric cardiac catheterization procedures and evaluated its effect on the total lung water volume (detected by lung ultrasound) and PaO_2/FiO_2 ratio.

As mentioned earlier, there are scarce data regarding the effect of saline or heparinized saline flush on the volemic status during pediatric cardiac catheterization.

Our study involved 42 pediatric patients aged from 1 month to 6 years undergoing diagnostic cardiac catheterization procedures. We observed a strong positive relationship between the total amount of fluids infused and the LUS before and after fluid infusion. There was a weak positive relationship between the total fluid volume infused and the difference between the decrease in P/F ratio and the increase in $PaCO_2$ before and after fluid infusion.

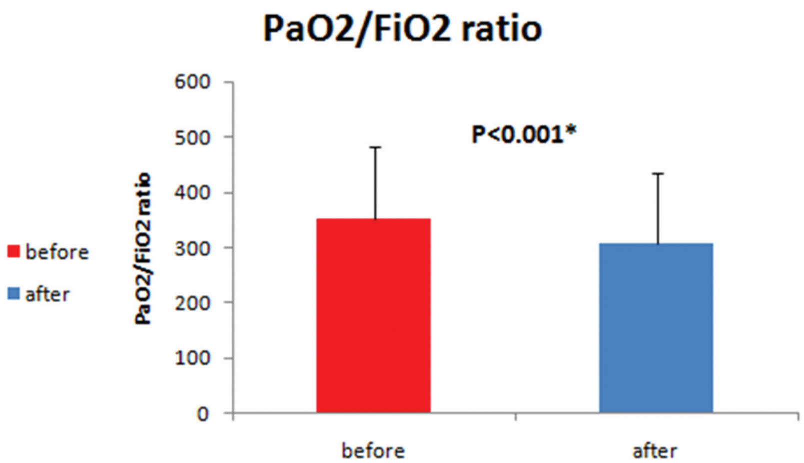

Figure 4. P/F ratio after flushing was less, with P < 0.001.

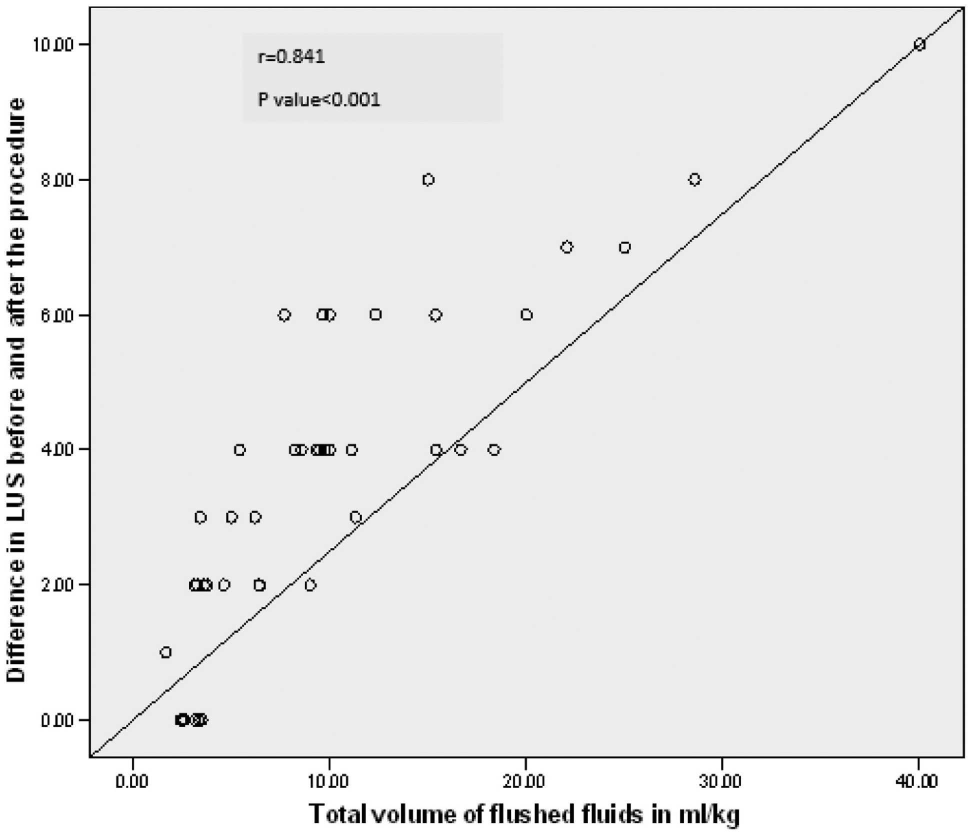

Figure 5. The correlation between the total fluid volume infused and the difference in LUS (lung ultrasound score) before and after fluid infusion.

The cut-off value for the total infused fluids (including intravenously administered fluids) was 11.3 ml/kg, whereas the cut-off value for the volume of fluids used for flushing the sheaths and catheters was 3.478 ml/kg.

Many studies were done to assess the association between fluid overload and postoperative morbidity and mortality in pediatric patients after cardiac surgery. They all used cumulative fluid overload in the first postoperative days and found its association with a higher incidence of acute kidney injury [6,11], prolonged mechanical ventilation [5,8], morbidity, and mortality [4]. All these studies used cumulative fluid balance over a few days but no studies were done to assess the intraoperative fluid balance on the outcome.

The importance of the intraoperative assessment of fluid intake in our study is that the diagnostic catheters are simple procedures with a short postoperative stay period and early resumption of oral feeding.

In a study conducted in 2005 on 20 adult patients undergoing cardiac surgery, Agricola E et al. found a correlation between the number of B lines observed by lung ultrasound and lung water quantified using

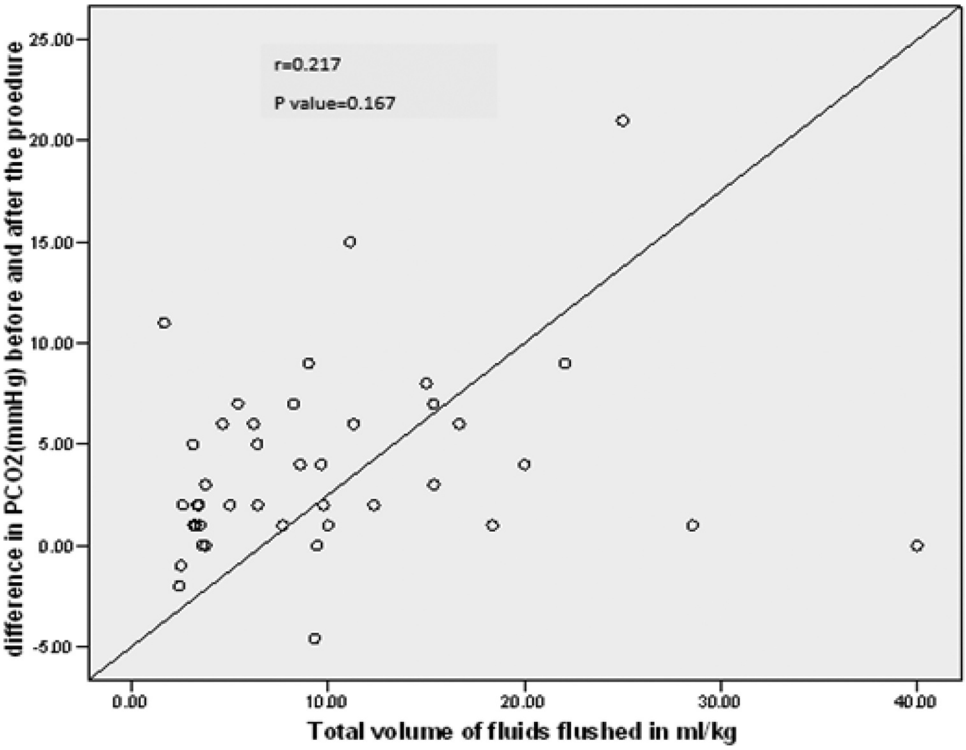

Figure 6. The correlation between the total amount of fluids infused and the difference in PCO_2 before and after fluid infusion.

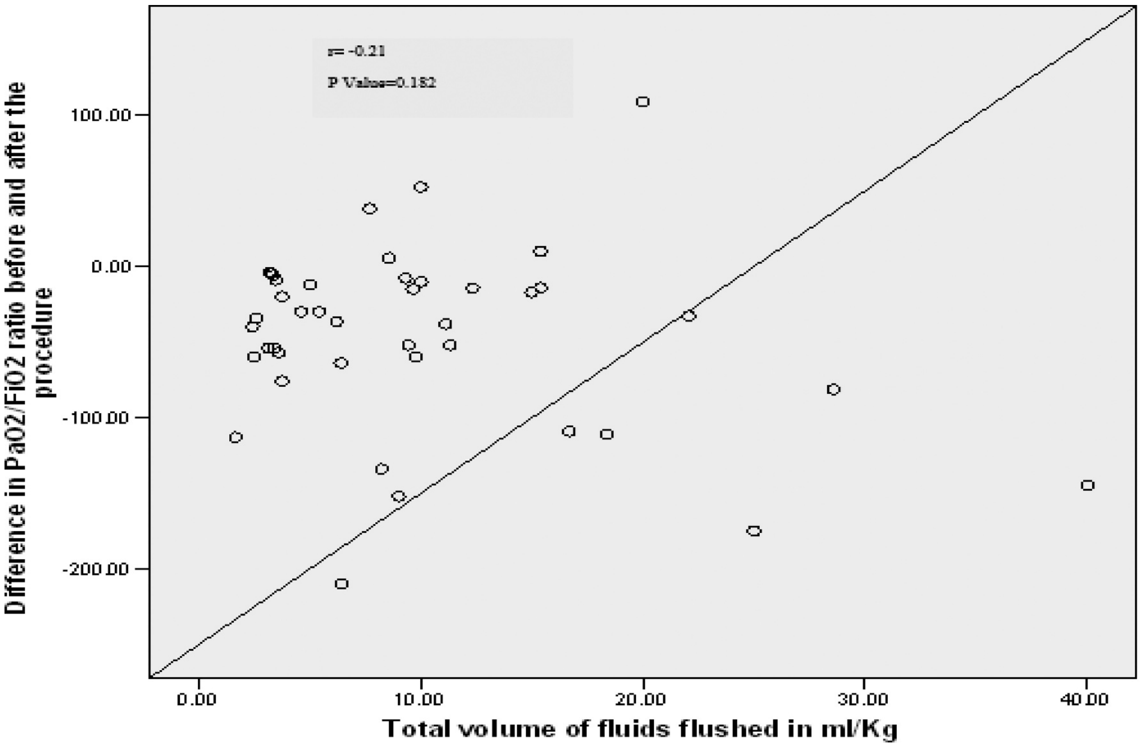

Figure 7. Correlation between the total fluid volume infused and the difference in P/F ratio before and after fluid infusion.

the indicator dilution approach. Before, directly after, and 24 h after the cardiac surgery, the patients were tested. The echo comet score and chest radiography showed a strong positive linear correlation [12].

The authors concluded that the existence and number of comet tail images provide accurate information on interstitial pulmonary edema and that lung ultrasound was a simple bedside diagnostic method for evaluating cardiac function and pulmonary edema. Their findings support our study findings, suggesting that ultrasound can be a diagnostic method to detect lung water [12].

Di Biase et al. concluded that irrigation of conventional catheters resulted in volume load following the catheter ablation of atrial fibrillation [13].

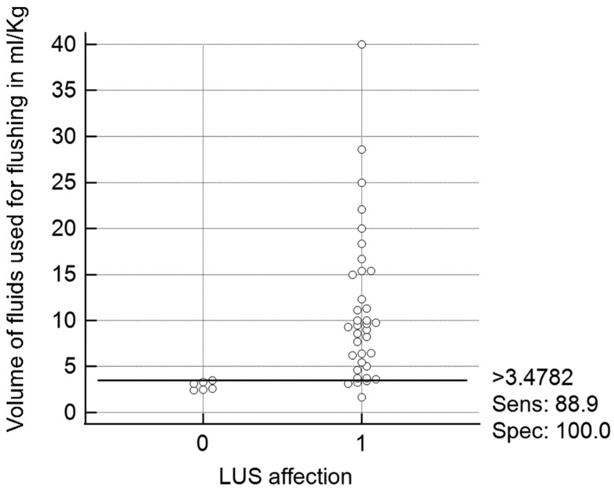

Figure 8. Interactive dot diagram showing the cut-off level of fluids' flush at which the volume load is observed.

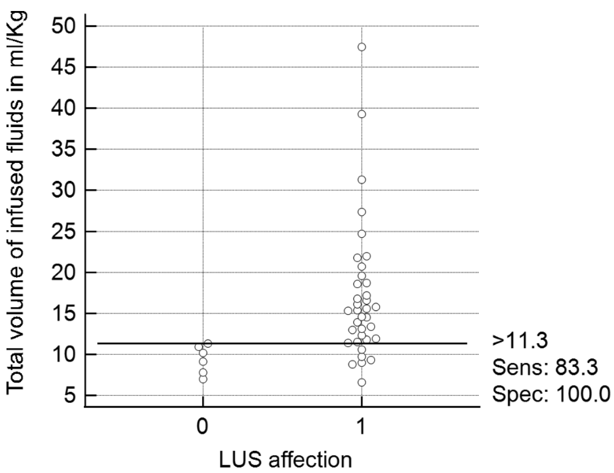

Figure 9. Interactive dot diagram showing the cut-off level of fluids' infusion (intravenous fluids and fluids used for flushing) at which the volume load is observed.

Another study was conducted on 300 patients within 48 h of admission to emergency medicine units by Volpicelli G et al. With a sensitivity of 85.7% and an accuracy of 97.7%. They concluded that comet tail artifact B lines are an accurate sign of alveolar interstitial syndrome [14].

Their result is different from our study in targeting adult patients and aiming primarily to diagnose alveolar interstitial syndrome as a part of diseases affecting the lung interstitium.

In a 2017 study, Osman A et al. used lung and diaphragmatic ultrasounds to evaluate the success of extubation in adult mechanically ventilated ICU patients. They mostly depended on evaluating three parameters by ultrasound (diaphragmatic excursion, diaphragmatic thickness fraction, and LUS). They found that both LUS and diaphragmatic ultrasound have a high predictive value to evaluate the outcome of the weaning process [15].

This is consistent with our study regarding the use of lung ultrasound in detecting lung status.

Consistent with our study, Adi Ciumanghel et al. reported in 2018 that there was a difference in the number of B lines in 45 patients with acute kidney injury admitted to the ICU [20 patients with respiratory dysfunction (PaO_2/FiO_2 300) and 25 patients without respiratory dysfunction (PaO_2/FiO_2 = 300)]. They found a negative linear correlation between the baseline B-line score and PaO_2/FiO_2 ratio, where B lines >17 can predict PaO_2/FiO_2 ratio <300, with 76% sensitivity and 65% specificity [16].

Consistent with our results, Bilotta et al. conducted a study in 2013 to demonstrate the effectiveness of lung ultrasound in estimating the PaO_2/FiO_2 ratio and estimate its diagnostic sensitivity compared with chest X-ray and thoracic computed tomography (CT). Based on the findings, the number of B lines used to evaluate lung water content showed a linear relationship with the PaO2/FiO2 ratio (with statistical significance). When thoracic CT was used as a reference technique, lung ultrasound showed a diagnostic accuracy similar to that of a chest radiograph (99% vs. 96%) [9].

Philipp Enghard et al. conducted a study on 50 ventilated intensive care patients, measuring lung ultrasound and transpulmonary thermodilution. They used an ultrasound score to evaluate pulmonary overhydration based on the number of single and confluent B lines per intercostal space [17].

According to their findings, lung water assessment by ultrasound using a simplified protocol (four-region protocol) demonstrated excellent association with extravascular lung water index across a wide range of lung hydration grades and ventilator environments. Chest radiography and extravascular lung water index showed a less reliable correlation. According to that study, lung ultrasound is a valuable, noninvasive method for predicting hydration status in mechanically ventilated patients [17].

Finally, yet importantly, we determined that a fluid flush volume of >11.3 ml/kg has a high probability of inducing volume load in pediatric patients undergoing cardiac catheterization. A flushing volume of 3.478 ml/kg affects the LUS. We recommend reducing the volume of intravenous fluids if higher volumes are required for flushing. A larger sample size would be useful to establish this volume as a practice guideline.

5. Conclusion

Lung ultrasound plays a significant role in diagnosing fluid overload by detecting increased lung water content (by fluids flushed in pediatric cardiac catheterization procedures). The increased numbers of B lines within the same lung field is generally associated with a reduction in PaO_2/FiO_2 ratio and an increase in $PaCO_2$.

The clinical implication is to develop a useful protocol for the volume of fluids used in flushing during pediatric cardiac catheterization procedures guided by the LUS.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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