Dynamic parameters for fluid responsiveness in mechanically ventilated children: A systematic review

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Objective: Fluid administration is the initial step of treatment of unstable pediatric patients. Evaluation of fluid responsiveness is crucial in mechanically ventilated children to avoid fluid overload, which increases mortality. We aim to review and compare the diagnostic performance of dynamically hemodynamic parameters for predicting fluid responsiveness in mechanically ventilated children.

Design: A systematic review was performed using four electronic databases, including PubMed, EMBASE, Scopus, and Central, for published articles from 1 January 2010 to 31 December 2020. Studies were included if they described diagnostic performance of dynamic parameters after fluid challenge was performed in mechanically ventilated children.

Settings: Pediatric intensive and cardiac intensive care unit, and operative room.

Patients: Children aged 1 month to 18 years old who were under mechanical ventilation and required an intravenous fluid challenge.

Measurements and Main Results: Twenty-seven studies were included in the systematic review, which included 1,005 participants and 1,138 fluid challenges. Respiratory variation in aortic peak velocity was reliable among dynamic parameters for predicting fluid responsiveness in mechanically ventilated children. All studies of respiratory variation in aortic peak velocity showed that the area under the receiver operating characteristic curve ranged from 0.71 to 1.00, and the cutoff value for determining fluid responsiveness ranged from 7% to 20%. Dynamic parameters based on arterial blood pressure (pulse pressure variation and stroke volume variation) were also used in children undergoing congenital heart surgery. The plethysmography variability index was used in children undergoing neurological and general surgery, including the pediatric intensive care patients.

Conclusions: The respiratory variation in aortic peak velocity exhibited a promising diagnostic performance across all populations in predicting fluid responsiveness in mechanically ventilated children.
responsiveness in mechanically ventilated children. High sensitivity is advantageous in non-cardiac surgical patients and the pediatric intensive care unit because early fluid resuscitation improves survival in these patients. Furthermore, high specificity is beneficial in congenital heart surgery because fluid overload is particularly detrimental in this group of patients.

**Systematic Review Registration:** [https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=206400](https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=206400)

**KEYWORDS**
fluid therapy, cardiac output, predict, pediatric, hemodynamic

**Introduction**

Fluid administration is the first line of treatment for critically ill children who are admitted to the pediatric intensive care unit (PICU) with unstable hemodynamics. However, only 40% to 69% of these children show a response to fluid administration (1). Fluid responsiveness is defined as an increase in cardiac output of more than 10% to 15% after an intravenous fluid challenge (1–3). Early administration of fluid in patients who are responsive improves survival. However, fluid administration to those who are unresponsive may cause fluid overload, leading to longer ventilator days and higher morbidity and mortality rates (4–6).

Many hemodynamic parameters have been used to predict fluid responsiveness in critically ill children. These parameters can be divided into static and dynamic parameters ([Supplementary Table S1](#)). Static parameters are measured at a specific time point during observation. Dynamic parameters are measured by monitoring changes in physiological responses based on cardiopulmonary interaction (e.g., variability change in preload during mechanical ventilation). Most studies have suggested that dynamic parameters are more accurate than static parameters for predicting fluid responsiveness (1, 7–9).

Dynamic parameters can be measured in an invasive or non-invasive manner. Ultrasonic cardiac output monitoring and electrical cardiometry are non-invasive methods that are commonly used to assess dynamic parameters in the intensive care unit (ICU) setting.

Previous studies of dynamic parameters were conducted in different circumstances and populations (10–36). To date, there are no standard parameters that can be used across all critically ill children, especially in mechanically ventilated children, who are prone to fluid overload. This systematic review aimed to compare the diagnostic performance of dynamic parameters for predicting fluid responsiveness in mechanically ventilated children.

**Materials and methods**

This study followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) reporting guideline (37). The protocol was registered and approved by the international prospective register of systematic reviews PROSPERO (CRD42020206400) on 1 October 2020. Inclusion criteria included the following: (i) children aged 1 month to 18 years old who were under mechanical ventilation and required an intravenous fluid challenge; (ii) diagnostic accuracy studies of dynamic parameters for predicting fluid responsiveness compared with the gold standard definition of fluid responsiveness (10%–15% increase in cardiac output after a fluid challenge as measured by the pressure recording analytic method, an echocardiogram, or non-invasive cardiac output monitoring), and the measurements needed to be performed before and after a fluid challenge; and (iii) the diagnostic performance included the cutoff value, sensitivity, specificity, and area under the receiver operating characteristic (ROC) curve. Meta-analyses, systematic reviews, narrative reviews, clinical practice guidelines, conference proceedings, case series and case reports with a sample size < 10, and non-English articles were excluded.

**Outcome**

The primary outcome was to study the diagnostic performance of dynamic hemodynamic parameters, including sensitivity, specificity, and the area under ROC curve, for the prediction of fluid responsiveness in mechanically ventilated children. The secondary outcome was to identify the reliable dynamic parameters among mechanically ventilated children in different clinical circumstances.

**Search strategy**

A systematic review was performed using four electronic databases, including PubMed, EMBASE, Scopus, and Central, for published articles from 1 January 2010 to 31 December 2020. The last search was conducted on 15 January 2021. The search terms were fluid, volume, response, challenge, bolus, and guided. These words were combined with the medical subject heading (MeSH) terms hemodynamics, hemodynamic monitoring, fluid therapy, cardiac output, infant, child, adolescent, and pediatrics. An additional search for potentially
eligible articles was carried out using references of selected retrieved articles.

**Study selection and risk of bias assessment**

Two authors (P.Y. and W.K.) independently reviewed abstracts of the retrieved articles for their eligibility. Articles that clearly did not fulfill the inclusion criteria were excluded at this stage. The remaining articles underwent a full-text review for final determination of their eligibility. Any disagreements were resolved by conference with a third author (R.L.). The risk of bias was assessed using the Quality Assessment of Studies of Diagnostic Accuracy tool (38, 39), which is composed of the following 4 domains: patient selection, index test, reference standard, and flow-timing, while the applicability concern was assessed through 3 domains: patient selection, index test, and reference standard. The risk of bias and applicability concern was judged as “low”, “high”, or “unclear.” If a study was judged as “low” in all domains relating to bias or applicability, then the overall judgment of a “low risk of bias” was assigned for that study. If a study was judged as “high” in one or more domains, it was judged as a “high risk of bias”. The term “unclear” was assigned only when there was missing data that could not be retrieved.

**Data extraction and data synthesis**

Two authors (P.Y. and R.L.) independently extracted data from the included articles using a standardized data extraction form derived from the Cochrane Public Health Group Data Extraction and Assessment Template. We contacted the corresponding author of the included articles for missing data. However, only 2 of 10 corresponding authors replied. Those missing data were labeled as not reported.

The following data were collected for systematic review: sample size, age, specific circumstance of participants, definition and percentage of fluid responsiveness, cutoff value, and diagnostic performance of dynamic parameters.

**Results**

The identification and selection of studies are shown in Figure 1. A total of 27 studies were included in the final systematic review (10–36), which comprised 1,005 participants and 1,138 intravenous fluid challenges. A total of 77% (21/27) of studies were published after the last systematic review (1). Twenty-five studies were conducted as prospective observational cohorts (10–16, 18–36), and only 1 study was retrospective cohort study (17). There were 4 major groups of patients in different clinical settings as follows: (i) the congenital heart surgery group in 14 studies; (ii) the general surgery group in 5 studies; (iii) the neurological surgery group in 4 studies; and (iv) the general PICU group in 4 studies.

Among the subgroups of participants, different fluid types and volumes were administered. Patients with congenital heart surgery mostly received colloid or blood components; only 2 of 14 studies used isotonic crystalloids. The other 3 groups of participants mostly received crystalloids with larger bolus volumes.

**Table 1** shows the diagnostic performance of dynamic parameters compared with the gold standard measurement of fluid responsiveness. The gold standard measurement was an increase in cardiac output of 10%–15% after fluid administration, which was represented by multiple parameters as follows: the stroke volume index in 15 studies, stroke volume in 5 studies, the cardiac index in 4 studies, and the velocity–time integral in 2 studies. Eleven dynamic parameters (see Supplementary Table S2 with equations) were investigated in the 27 included studies.

The respiratory variation in aortic peak velocity (ΔVpeak) was the most common dynamic parameter examined (12/27 studies). Moreover, ΔVpeak provided a reliable diagnostic performance. All studies of ΔVpeak showed that the area under the ROC curve ranged from 0.71 to 1.00, and the cutoff value of ΔVpeak for determining fluid responsiveness ranged from 7% to 20%.

Because patients with congenital heart surgery were included in approximately half of all studies, we allocated participants to 2 new subgroups as follows: the congenital heart surgery subgroup (10–23) and the non-cardiac surgery subgroup (general surgery, neurological surgery, and general PICU patients) (24–36). In congenital heart surgery subgroup, ΔVpeak showed the best sensitivity of 100% at the cutoff value of 7% when performed by transesophageal echocardiogram (TEE) (11). The best specificity of ΔVpeak was 92% at the cutoff values 13%–14% by TEE (13, 21). Another reliable dynamic was the pulse pressure variation (PPV), with the sensitivity of 94% (at the cutoff value of 18%) and the specificity of 100% (at the cutoff value of 30%) (17). In the non-cardiac surgery subgroup, ΔVpeak performed by transthoracic echocardiogram (TTE) showed the best sensitivity of 100% (at the cutoff values 10% and 12.2%) (25, 29) with the best specificity of 100% (at the cutoff value 10%) (29). Note that plethysmographic variability index (PVI) measured by the transfectance adhesive forehead sensor exhibited the second-best sensitivity of 94.1% (at the cutoff value of 6%) (26), while stroke volume variation (SVV) provided the second-best specificity of 93.3% (at cutoff values 16.5%) (33).

The risk of bias assessment of all included studies is shown in **Table 2**. The reference standard domain was
judged to have a high risk of bias in 9 studies because the interpretation of the reference standard test was made with knowledge of index test results. The flow and timing domain were also judged to have a high risk of bias in 15 studies because all included patients were not in the final analysis (per-protocol analysis).

**Discussion**

In 2013, Gan et al. (1) studied static and dynamic parameters, and found that dynamic parameters were more reliable in predicting fluid responsiveness in children. Several
| Author, year | Sample size | Age | Setting/population | Fluid type/ volume (ml/kg) | Fluid responder | Parameters/measurement tools | Cutoff value (%) | Sensitivity (%) | Specificity (%) | AUROC curve | Measurement of fluid responsiveness |
|--------------|-------------|-----|--------------------|---------------------------|----------------|-----------------------------|-----------------|---------------|---------------|-------------|-----------------------------------|
| Choi et al., 2010 | 21 Mean: 30 months | Cardiac surgery (after VSD repair) | 10 ml/kg 6% HES | 11/21 (52%) | ΔVpeak (aortic) TTE | 20 | 91 | 90 | 0.830 | ΔSV ≥ 15%, TTE |
| Renner et al., 2011 | 27 Mean: 17 months | Congenital heart disease (before surgery of single/ biventricular repair) | 10 ml/kg 6% HES | 13/27 (48%) | ΔVpeak (aortic) TEE ΔVTI (aortic) TEE | 7 | 100 | 84 | 0.920 | ΔSVI ≥ 15%, TEE |
| Renner et al., 2012 | 26 Mean: 4-48 months | Cardiac surgery (before VSD/ASD repair) | 10 ml/kg 6% HES | 15/26 (58%) | PPV PRAM | 16 | 61 | 96 | 0.790 | ΔSVI ≥ 15%, TEE |
| Lee et al., 2014 | 26 Mean: 28 months | Cardiac surgery (after VSD repair) | 10 ml/kg 6% HES | 13/26 (50%) | SVV NICOM® | 10 | 77 | 85 | 0.888 | ΔSVI ≥ 15%, TEE |
| Saxena et al., 2015 | 100 Mean: 30 months | Cardiac surgery (n = 90) Others (n = 10) | 10 ml/kg isotonic crystalloid | 64/142 (45%) | SPV PRAM | NR | NR | NR | 0.590 | ΔSVI ≥ 15%, TPUD |
| Lee et al., 2015 | 29 Mean: 1-36 months | Cardiac surgery (after ASD/VS/TOF/AVSD repair) | 10 ml/kg 6% HES | 13/29 (45%) | SVV NICOM® | NR | NR | NR | 0.510 | ΔSVI > 15%, TEE |
| Han et al., 2017 | 46 Mean: 1.05 years | Cardiac surgery (after VSD repair) | 20 ml/kg 5% albumin or FFP | 27/38 (71%) | PPV PRAM | 17.4 | 89 | 91 | 0.890 | ΔCI ≥ 15%, PRAM |
| Han et al., 2017 | 46 Mean: 1.15 years | Cardiac surgery (after TOF repair) | 20 ml/kg 5% albumin or FFP | 26/36 (72%) | PPV PRAM | 13.4 | 81 | 80 | 0.790 | ΔCI ≥ 15%, PRAM |
| Favia et al., 2017 | 16 Mean: 2.6 years | Cardiac surgery (after CHD repair of biventricular physiology) | 10 ml/kg isotonic crystalloid or blood component | 7/16 (44%) | PPV PRAM | 30 | 67 | 100 | 0.760 | ΔCI ≥ 10%, TEE |
| Lee et al., 2017 | 30 Mean: 19 months | Cardiac surgery (after VSD/ASD repair) | 10 ml/kg 6% HES | 17/30 (57%) | Calibrated abdominal compression of 30 mmHg for 15 s PRAM for ΔDBP | 5 | 82.4 | 69.3 | 0.778 | ΔSVI > 15%, TEE |
| Han et al., 2017 | 46 Mean: 3.3 years | Cardiac surgery (VSD repair) Median sternotomy group | 16 ml/kg 5% albumin or blood components | 12/26 (46%) | PPV PRAM | 12 | 58.8 | 84.6 | 0.785 | ΔCI ≥ 15%, PRAM |
| Cheng et al., 2018 | 60 Mean: 10.9 months | Cardiac surgery (after VSD/ASD/PDA repair) | 10 ml/kg 6% HES | 32/60 (53%) | SVV USCOM® | 17 | 84.4 | 60.7 | 0.776 | ΔSVI ≥ 15%, USCOM® |

(continued)
| Author, year | Sample size | Age | Setting / population | Fluid type / volume (ml / kg) | Fluid responder | Parameters / measurement tools | Cutoff value (%) | Sensitivity (%) | Specificity (%) | AUROC curve | Measurement of fluid responsiveness |
|-------------|-------------|-----|----------------------|-----------------------------|----------------|-------------------------------|----------------|----------------|----------------|-------------|----------------------------------|
| Kim et al., 2019 | 30 | 1–12 months | Cardiac surgery (after VSD/ASD repair) | 10 ml/kg isotonic crystalloid | 17/30 (57%) | ΔVpeak (carotid) Doppler US | 7.8 | 94 | 69 | 0.830 | ΔSVI > 15%, TEE |
| Park et al., 2019 | 38 | 1–6 months | Cardiac surgery (after VSD/ASD repair) and neurosurgery | 10 ml/kg 6% HES | 20/38 (53%) | ΔPOP at 0.9–1.2 N contraction force Pulse oximetry | 15 | NR | NR | 0.815 | ΔSVI > 15%, TEE/TTE |
| Song et al., 2020 | 64 | 3–8 years | Cardiac surgery (after the Fontan operation with fenestration) | 10 ml/kg 5% albumin | 30/64 (47%) | SVV PRAM | 16 | 50 | 91.7 | 0.740 | ΔCI ≥ 15%, PRAM |
| Julien et al., 2013 | 54 | Median: 48 months | General surgery | 10 ml/kg isotonic crystalloid | 45/97 (46%) | PVI Pulse oximeter | 13 | 80 | 80 | 0.850 | ΔSVI > 15%, CardioQ® |
| Achar et al., 2016 | 42 | 12–168 months | General elective surgery (preoperative) | 10 ml/kg balanced salt solution | 24/42 (57%) | ΔVpeak (aortic) TTE IVC-DI US | 12.2 | 100 | 94.4 | 0.975 | ΔSVI > 15%, TTE |
| Kim et al., 2020 | 30 | 10–72 months | General procedure (under general anesthesia) | 10 ml/kg isotonic crystalloid | 17/30 (57%) | PVI Transflectance adhesive forehead sensor | 6 | 94.1 | 61.5 | 0.800 | ΔSVI > 15%, TTE |
| Chen et al., 2020 | 27 | 8 months to 13 years | Liver cirrhosis (during liver transplantation) | 10 ml/kg isotonic crystalloid | 15/61 (25%) | PPV PRAM | 13 | 46.7 | 80.4 | 0.670 | ΔSVI ≥ 15%, TPUD |
| Zorio et al., 2020 | 55 | 6–148 months | General elective Surgery | 12 ml/kg isotonic crystalloid / balanced salt solution | 43/55 (78%) | Mini-fluid bolus (3 ml/kg in 2 min) TTE for ΔVTI | 8 | 53 | 77 | 0.770 | ΔVTI ≥ 10%, TTE |
| Pereira de Souza Neto et al., 2011 | 19 | 55–71 months | Neurological surgery (cerebrovascular disease and posterior fossa tumor) | 20 ml/kg isotonic crystalloid | 10/19 (53%) | ΔVpeak (aortic) TTE | 10 | 100 | 100 | 1.000 | ΔVTI ≥ 15%, TTE |
| | 11 | 72–143 months | Neurological surgery (posterior fossa tumor) | 20 ml/kg isotonic crystalloid | 7/11 (64%) | ΔVpeak (aortic) TTE | 10 | 100 | 100 | 1.000 | ΔVTI ≥ 10%, TTE |

(continued)
| Author, year | Sample size | Age | Setting/population | Fluid type/ volume (ml/kg) | Fluid responder | Parameters/ measurement tools | Cutoff value (%) | Sensitivity (%) | Specificity (%) | AUROC | Measurement of fluid responsiveness |
|-------------|-------------|-----|--------------------|----------------------------|----------------|-------------------------------|----------------|----------------|----------------|-------|---------------------------------|
| Byon et al., 2013 (30) | 33          | 6-108 months | Neurological surgery (during surgery) | 10 ml/kg 6% HES or Voluven | 15/33 (45%) | PVI Pulse oximeter ΔPeak (aortic) TTE | 11              | 73             | 87             | 0.767 | ΔSVI ≥ 10%, TTE |
| Vergnaud et al., 2015 (31) | 30          | 4-139 months | Neurological surgery (after craniosynostosis repair) | 20 ml/kg Artificial colloid | 15/30 (50%) | PPV NICOM SVV NICOM⁺ | 8               | 69             | 78             | 0.770 | ΔSV ≥ 15%, TTE |
| Morparia et al., 2018 (32) | 21          | 28 months to 17 years | Elective neurological Surgery | 10 ml/kg isotonic crystalloid | 13/22 (59%) | ΔVpeak (aortic) TTE | 12.3            | 77             | 89             | 0.902 | ΔSV > 15%, TTE |
| McLean et al., 2014 (33) | 13          | 2-168 months | General PICU | 10 ml/kg isotonic crystalloid | 11/26 (42%) | SVV USCOM⁺ | 16.5            | 54.5           | 93.3           | 0.797 | ΔSVI ≥ 10%, USCOM⁺ |
| Weber et al., 2015 (34) | 31          | Median: 36 months | General PICU | 10 ml/kg isotonic crystalloid | 15/31 (48%) | SVV PRAM (LiDCOrapid) IVC-DI US | NR             | NR             | NR             | 0.513 | ΔSVI ≥ 10%, TTE |
| Chaiyaphruk et al., 2018 (35) | 13          | 3 months to 15 years | General PICU | 5-10 ml/kg isotonic crystalloid | 6/13 (46%) | PLR 45° for 2 min USCOM⁺ for ΔCI | 8               | 60             | 83.3           | NR | ΔCl ≥ 10%, USCOM⁺ |
| Sun et al., 2020 (36) | 30          | 1 month to 18 years | Leukemia with neutropenia and septic shock | 20 ml/kg isotonic crystalloid | 16/30 (53%) | ΔPeak (aortic) TTE ΔVTI (aortic) TTE | 12.4            | 62             | 64             | 0.710 | ΔSV ≥ 15%, TTE |

Abbreviations: ASD, atrial septal defect; AUROC, area under the receiver operating characteristic; AVSD, atrioventricular septal defect; CHD, congenital heart disease; CI, cardiac index; DBP, diastolic blood pressure; FFP, fresh frozen plasma; HES, hydroxyethyl starch; IVC-DI, inferior vena cava distensibility index; LiDCOrapid, a pulse contour analysis algorithm system; N, Newton; NICOM, non-invasive cardiac output monitoring; NR, not reported; PDA, patent ductus arteriosus; PICU, pediatric intensive care unit; PLR, passive leg raising test; PRAM, pressure recording analytic method; PVI, plethysmographic variability index; SV, stroke volume; SVI, stroke volume index; SVV, stroke volume variation; TEE, transesophageal echocardiogram; TOF, tetralogy of Fallot; TPUD, transpulmonary ultrasound dilution; TTE, transthoracic echocardiogram; US, ultrasound; USCOM, ultrasonic cardiac output monitoring; VSD, ventricular septal defect; ΔVpeak, respiratory variation in aortic peak velocity; VTI, velocity–time integral.
### TABLE 2 Risk of bias assessment.

| Study | Risk of bias | Applicability concern |
|-------|--------------|-----------------------|
|       | Patient selection | Index test | Reference standard | Flow and timing | Patient selection | Index test | Reference standard |
| Choi et al., 2010 (14) | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 |
| Renner et al., 2011 (15) | 😚 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 |
| Renner et al., 2012 (16) | 😊 | 😚 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 |
| Lee et al., 2014 (17) | 😊 | 😊 | 😚 | 😊 | 😊 | 😊 | 😊 | 😊 |
| Saxena et al., 2015 (18) | 😚 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 |
| Lee et al., 2015 (19) | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 |
| Han et al., 2017 (20) | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 |
| Favia et al., 2017 (21) | 😚 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 |
| Lee et al., 2017 (22) | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 |
| Han et al., 2017 (23) | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 |
| Cheng et al., 2018 (24) | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 |
| Kim et al., 2019 (25) | 😚 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 |
| Park et al., 2019 (26) | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 |
| Song et al., 2020 (27) | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 |
| Pereira de Souza Neto et al., 2011 (33) | 😚 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 |
| Byron et al., 2013 (34) | 😊 | 😚 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 |
| Vergnaud et al., 2015 (35) | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 |
| Morparia et al., 2018 (36) | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 |
| Julien et al., 2013 (28) | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 |
| Achar et al., 2016 (29) | 😚 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 |
| Kim et al., 2020 (30) | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 |
| Chen et al., 2020 (31) | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 |
| Zorio et al., 2020 (32) | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 |
| McLean et al., 2014 (37) | 😚 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 |
| Weber et al., 2015 (38) | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 |
| Chayaphruk et al., 2018 (39) | 😚 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 |
| Sun et al., 2020 (40) | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 | 😊 |

😊 low risk of bias, 😚 high risk of bias, 😉 unclear.
new dynamic parameters have since been introduced and studied in the pediatric population during the last 10 years. Therefore, we conducted this review to extend the work of Gan et al. (1) on dynamic parameters and to provide an update with newly examined parameters.

New dynamic parameters from non-invasive ultrasonic cardiac output monitoring, electrical cardiometry, and ultrasound are easily accessible and widely used in the PICU. These new parameters are reliable and can be measured by non-experienced physicians in a few minutes (40, 41). Therefore, they could be useful tools for clinicians to determine whether patients should undergo a fluid challenge.

This systematic review showed that ΔVpeak had a promising diagnostic performance across all populations. The ΔVpeak was studied as a single parameter or together with other dynamic parameters. The cutoff values for predicting fluid responsiveness ranged from 7% to 20%, while the average values ranged from 12% to 14%. In group of congenital heart surgery, the echocardiogram performed by transesophageal technique but in other groups, mostly performed by transthoracic technique. A major disadvantage of ΔVpeak is that this parameter requires an experienced operator of echocardiography.

The highest sensitivity of ΔVpeak in patients who had congenital heart surgery is advantage because fluid overload can increase the risk of acute kidney injury and poor postoperative outcomes in patients with congenital heart disease (42, 43). Therefore, a parameter with high specificity, such as ΔVpeak, could reduce such adverse events and complications by decreasing an unnecessary fluid challenge in this patient subgroup. When ΔVpeak is not accessible, new dynamic parameters from non-invasive methods such as ultrasonic cardiac output monitoring, electrical cardiometry, and arterial line variable parameters should be considered, because of easy accessibility and mostly non-operator dependent methods. Pulse pressure variation could be used as alternative because it also had a high specificity. Patients in the non-cardiac subgroup are most likely to benefit from early fluid resuscitation. The ΔVpeak and PVI should be considered in this context because they have a high sensitivity.

Each study with patients in the congenital heart surgery group reported inotropic and vasopressor administration in various forms, including the percentage of inotrope use in the population and the Vasoactive Inotropic Score, and some studies did not report inotropic or vasopressor data. Therefore, we did not perform analysis for specific dynamic parameters based on inotropic status.

There are some limitations to our study. First, our search strategy was limited to the last 10 years. The reason for his limitation was to focus on new dynamic parameters that appeared after the systematic review in 2013 by Gan et al. (1) Second, there was heterogeneity of the study design, including multiple participant groups in different clinical settings, different fluid types, varying amounts of volume (5–20 ml/kg), and the definition of fluid responsiveness using different parameters across the studies.

The findings from this systematic review suggest some future research opportunities. The ΔVpeak, which is the most reliable parameter for predicting fluid responsiveness in mechanically ventilated children, has not been investigated in children with spontaneous breathing. Preload challenge maneuvers (e.g., calibrated abdominal compression, mini-fluid bolus, the passive leg raising test, and the end-expiratory occlusion test) have been extensively studied in the adult population for predicting fluid responsiveness (44). However, these maneuvers have not been well investigated in pediatric population.

Conclusions

The ΔVpeak exhibited a promising diagnostic performance in predicting fluid responsiveness in mechanically ventilated children. The sensitivity of ΔVpeak is advantageous in non-cardiac surgical patients and the PICU setting because early fluid resuscitation improves survival in these patients. Furthermore, the specificity of ΔVpeak is beneficial in congenital heart surgery because fluid overload is particularly detrimental in this group of patients.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

Conceptualization: RL; methodology: PY, WK, SC, RL, and PU; investigation: PY and WK; data curation: PY and WK; validation: SC, RL, and PU; writing—original draft preparation: PY; writing—review and editing: WK, SC, RL, and PU; visualization: PY; supervision: SC, RL, and PU. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fped.2022.1010600/full#supplementary-material

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