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Original Research Article

Pleth Variability Index–Guided Fluid Therapy versus Conventional Fluid Management during Major Abdominal Surgery

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Abstract

Background: Appropriate intraoperative fluid management is crucial for maintaining adequate tissue perfusion while avoiding fluid overload during major abdominal surgery. The Pleth Variability Index (PVI) is a continuous, non-invasive dynamic parameter that may facilitate individualized goal-directed fluid administration.

Objective: To evaluate the effectiveness of PVI-guided fluid therapy compared with conventional fluid management in patients undergoing major abdominal surgery.

Materials and Methods: This prospective randomized comparative study included 100 adults undergoing elective major abdominal surgery under general anesthesia. Patients were randomized equally to a PVI-guided group (n=50) or conventional fluid management group (n=50). In the PVI group, fluid boluses were administered using a predefined PVI-based algorithm, while the conventional group received fluids according to routine clinical and hemodynamic parameters. The primary outcome was total intraoperative fluid requirement. Secondary outcomes included crystalloid administration, fluid balance, hypotension, vasopressor use, urine output, serum lactate, postoperative gastrointestinal recovery, complications, and length of hospital stay.

Results: Baseline characteristics were comparable between the groups. The PVI-guided group received significantly less total intraoperative fluid (2061 ± 487 vs 2650 ± 601 mL; $p<0.001$) and crystalloid (1875 ± 426 vs 2418 ± 538 mL; $p<0.001$), with a lower positive fluid balance. Intraoperative hypotension was less frequent with PVI guidance (20.0% vs 40.0%; $p=0.029$), and end-operative serum lactate was significantly lower (1.7 ± 0.6 vs 2.1 ± 0.8 mmol/L; $p=0.006$). Patients in the PVI group also achieved earlier oral intake and passage of first flatus. Overall postoperative complications were reduced (20.0% vs 38.0%; $p=0.047$), and hospital stay was shorter (6.2 ± 1.8 vs 7.4 ± 2.3 days; $p=0.004$).

Conclusion: PVI-guided fluid therapy reduced intraoperative fluid administration and positive fluid balance while maintaining adequate tissue perfusion. It was also associated with fewer hypotensive episodes, improved early postoperative recovery, fewer overall complications, and shorter hospitalization. PVI may therefore serve as a useful non-invasive approach for individualized intraoperative fluid management during major abdominal surgery.

Keywords: Pleth Variability Index; goal-directed fluid therapy; fluid responsiveness; major abdominal surgery; perioperative fluid management; hemodynamic monitoring; postoperative recovery.

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Introduction

Optimal perioperative fluid management is an important component of anesthesia during major abdominal surgery. Both inadequate and excessive fluid administration may adversely affect tissue perfusion, organ function, and postoperative recovery. Goal-directed fluid therapy (GDFT), in which intravenous fluids are administered according to dynamic hemodynamic variables, has therefore been proposed as an alternative to conventional fluid management. Recent evidence suggests that GDFT may optimize perioperative fluid administration and improve selected postoperative outcomes following major abdominal surgery. [1] Several dynamic indices are available

for assessing fluid responsiveness. PVI is a non-invasive dynamic variable that quantifies respiratory-induced variations in the plethysmographic waveform obtained from pulse oximetry, thereby reflecting fluid responsiveness. PVI-guided therapy provides an attractive alternative to more invasive techniques because it allows continuous assessment without arterial catheterization. Comparative evidence has demonstrated its potential utility as a guide for intraoperative fluid optimization during major abdominal surgery. [2]

A recent systematic review and meta-analysis reported that PVI-guided GDFT may reduce intraoperative fluid administration while maintaining adequate hemodynamic management compared with conventional approaches. [3] In addition to the monitoring strategy, appropriate selection of intravenous fluids remains important because both crystalloid and colloid solutions can influence perioperative volume expansion and clinical outcomes. [4,5] PVI-guided protocols have also demonstrated feasibility in randomized surgical studies, supporting the use of this non-invasive parameter for individualized fluid administration. [6]

However, evidence regarding the clinical advantages of PVI-guided fluid therapy over conventional fluid management during major abdominal surgery remains evolving. Therefore, the present study was undertaken to compare PVI-guided fluid therapy with conventional fluid management during major abdominal surgery, with emphasis on intraoperative fluid requirements, hemodynamic stability, tissue perfusion, and postoperative outcomes.

Materials and Methods

Study Design and Setting: The present study was designed as a prospective, randomized, comparative study conducted in the Department of Anaesthesiology of a tertiary care teaching hospital. Adult patients scheduled for elective major abdominal surgery under general anesthesia were screened for eligibility and enrolled after obtaining written informed consent.

Sample Size: The sample size was calculated based on the anticipated difference in total intraoperative fluid requirement between PVI-guided and conventional fluid management.

The formula for comparison of two independent means was used:

$$n=\frac{2(Z_{\alpha/2}+Z_\beta)^2\sigma^2}{d^2}$$

Where n represented the required sample size per group, $(Z_{\alpha/2})$ was 1.96 at a 95% confidence level, (Z_β) was 0.84 for 80% power, σ represented the expected standard deviation of approximately 500 mL, and d represented a clinically meaningful intergroup difference of approximately 300 mL. The minimum calculated sample size was approximately 44 patients per group. After allowing for approximately 10–12% attrition or incomplete observations, 100 patients were included and divided equally between the two groups.

Inclusion Criteria: Patients aged 18–65 years, belonging to ASA physical status I–III, and scheduled for elective major abdominal surgery under general anesthesia with an anticipated duration of at least 2 hours were included.

Exclusion Criteria: Patients with significant cardiac arrhythmias, severe valvular heart disease, left ventricular dysfunction, severe peripheral vascular disease, significant renal or hepatic dysfunction, preoperative hemodynamic instability, pregnancy, emergency surgery, contraindications to the monitoring technique, or inadequate peripheral perfusion preventing reliable PVI measurement were excluded.

Randomization and Group Allocation: Patients were randomly allocated using a computer-generated randomization sequence into two equal groups:

Group PVI (n=50): Patients received intraoperative fluid therapy guided by the Pleth Variability Index.

Group CFM (n=50): Patients received conventional intraoperative fluid management based on routine clinical and hemodynamic parameters.

Allocation was concealed using sequentially numbered, opaque, sealed envelopes.

Anesthetic Technique and Monitoring: On arrival in the operating room, standard monitoring consisting of electrocardiography, non-invasive blood pressure, pulse oximetry, capnography, and temperature monitoring was instituted. Intravenous access was secured, and baseline heart rate, mean arterial pressure (MAP), oxygen saturation, and other relevant parameters were recorded. In the PVI group, a Masimo Radical-7 pulse co-oximeter equipped with Pleth Variability Index (PVI) software (Masimo Corporation, Irvine, CA, USA) was used for continuous PVI monitoring. General anesthesia was induced using a standardized institutional protocol with an intravenous induction agent, opioid, and non-depolarizing neuromuscular blocker. After endotracheal intubation, anesthesia was maintained using an inhalational or intravenous anesthetic technique.

Mechanical ventilation was standardized in both groups using a tidal volume of 8 mL/kg ideal body weight, with appropriate positive end-expiratory pressure. The same anesthetic and ventilatory

principles were followed in both groups to minimize factors affecting PVI measurements.

Fluid Management Protocol: In Group PVI, fluid administration was guided by a predefined PVI-based algorithm. A PVI >13% persisting for more than 5 minutes, in the presence of adequate signal quality and stable mechanical ventilation, was considered indicative of potential fluid responsiveness. When this criterion was fulfilled, a 250-mL crystalloid fluid challenge was administered. PVI was reassessed after each bolus, and an additional fluid bolus was administered if PVI remained >13% for >5 minutes. Intraoperative hypotension was defined as MAP <65 mmHg persisting for more than 1 minute. Hypotension associated with the predefined PVI criterion was managed with fluid administration, whereas hypotension without evidence of fluid responsiveness was treated with an appropriate vasopressor.

In Group CFM, intravenous fluids were administered according to conventional clinical assessment based on heart rate, arterial blood pressure, MAP, urine output, estimated blood loss, surgical losses, and the attending anesthesiologist's clinical judgment. Fluid boluses and vasopressors were administered as clinically indicated. Blood loss was replaced according to the predefined institutional protocol, and blood products were administered when clinically indicated.

Parameters Recorded: Hemodynamic parameters, including heart rate and MAP, were recorded at baseline and at predetermined intraoperative intervals. The following variables were documented:

- Total intraoperative crystalloid administration
- Total intraoperative fluid administration
- Number and volume of fluid boluses
- Urine output
- Estimated blood loss
- Vasopressor requirement
- Intraoperative hypotensive episodes
- Serum lactate, where available
- Duration of surgery and anesthesia

Postoperative Assessment: Patients were followed during the immediate postoperative period and subsequent hospitalization. Postoperative outcomes included time to oral intake, return of gastrointestinal function, postoperative nausea and vomiting, acute kidney injury, pulmonary complications, surgical-site complications, requirement for postoperative intensive care, and duration of hospital stay.

Outcome Measures: The primary outcome was total intraoperative fluid requirement.

Secondary outcomes included intraoperative crystalloid requirement, hemodynamic stability, and incidence of hypotension, vasopressor requirement, urine output, postoperative lactate concentration, postoperative complications, and length of hospital stay.

Statistical Analysis: Data were entered into Microsoft Excel and analyzed using IBM SPSS Statistics. Continuous variables were expressed as mean ± standard deviation or median with interquartile range according to data distribution. Categorical variables were expressed as frequency and percentage.

Continuous variables between the two groups were compared using the independent-samples t-test or Mann–Whitney U test. Categorical variables were analyzed using the Chi-square test or Fisher's exact test. Repeated intraoperative hemodynamic measurements were assessed using an appropriate repeated-measures analysis. A p-value <0.05 was considered statistically significant.

Results

A total of 100 patients undergoing elective major abdominal surgery were included in the study. Patients were equally randomized into the PVI-guided fluid therapy group (Group PVI, n=50) and the conventional fluid management group (Group CFM, n=50). Baseline demographic and operative characteristics were comparable between the two groups.

Table 1: Baseline demographic and operative characteristics

Parameter	Group PVI (n=50)	Group CFM (n=50)	p-value
Age (years), mean ± SD	48.6 ± 11.2	50.1 ± 10.8	0.497
Male/Female, n	28/22	26/24	0.688
BMI (kg/m²), mean ± SD	24.9 ± 3.2	25.4 ± 3.5	0.457
ASA I/II/III, n	8/30/12	7/29/14	0.884
Duration of surgery (min), mean ± SD	186.4 ± 41.7	181.8 ± 44.2	0.594
Duration of anesthesia (min), mean ± SD	213.6 ± 44.8	209.1 ± 47.3	0.626
Estimated blood loss (mL), mean ± SD	382 ± 156	401 ± 169	0.561

There were no statistically significant differences between the groups with respect to age, sex, BMI, ASA physical status, operative duration, anesthesia duration, or estimated blood loss (p>0.05).

Table 2: Intraoperative fluid administration and fluid balance

Parameter	Group PVI (n=50)	Group CFM (n=50)	p-value
Crystalloid administered (mL)	1875 ± 426	2418 ± 538	**<0.001**
Colloid administered (mL)	186 ± 214	232 ± 246	0.321
Total intraoperative fluid (mL)	2061 ± 487	2650 ± 601	**<0.001**
Number of fluid boluses	2.3 ± 1.1	3.2 ± 1.4	**0.001**
Total bolus volume (mL)	575 ± 275	800 ± 350	**0.001**
Urine output (mL)	428 ± 168	451 ± 174	0.502
Fluid balance at end of surgery (mL)	+1251 ± 438	+1788 ± 524	**<0.001**

The PVI-guided group received significantly less crystalloid and total intraoperative fluid than the conventional group. Mean total fluid administration was 2061 ± 487 mL versus 2650 ± 601 mL ($p<0.001$). The number and volume of fluid boluses and overall positive fluid balance were also significantly lower with PVI-guided therapy. Urine output remained comparable between the groups.

Table 3: Intraoperative hemodynamic and perfusion outcomes

Outcome	Group PVI (n=50)	Group CFM (n=50)	p-value
Mean intraoperative MAP (mmHg)	78.6 ± 6.8	76.1 ± 7.4	0.081
Patients with ≥1 hypotensive episode, n (%)	10 (20.0)	20 (40.0)	**0.029**
Hypotensive episodes/patient	0.4 ± 0.7	0.8 ± 1.0	**0.022**
Vasopressor required, n (%)	12 (24.0)	21 (42.0)	0.056
Total vasopressor dose*	6.8 ± 4.2	9.6 ± 5.1	**0.041**
End-operative serum lactate (mmol/L)	1.7 ± 0.6	2.1 ± 0.8	**0.006**
Lactate >2 mmol/L, n (%)	8 (16.0)	17 (34.0)	**0.038**

***Among patients receiving vasopressors; dose expressed according to the standardized vasopressor used in the study protocol.**

The incidence of intraoperative hypotension was significantly lower in the PVI group (20.0% vs 40.0%; $p=0.029$). Although the proportion of patients requiring vasopressors was numerically lower with PVI guidance, the difference did not reach statistical significance. End-operative serum lactate was significantly lower in the PVI group, suggesting better maintenance of tissue perfusion despite lower overall fluid administration.

Table 4: Postoperative recovery and complications

Outcome	Group PVI (n=50)	Group CFM (n=50)	p-value
Time to first oral intake (hours)	20.8 ± 6.7	25.6 ± 8.4	**0.002**
Time to first flatus (hours)	38.5 ± 10.2	44.7 ± 12.6	**0.008**
Postoperative nausea/vomiting, n (%)	8 (16.0)	12 (24.0)	0.317
Acute kidney injury, n (%)	2 (4.0)	4 (8.0)	0.678
Pulmonary complications, n (%)	3 (6.0)	9 (18.0)	0.065
Surgical-site complications, n (%)	3 (6.0)	5 (10.0)	0.715
Postoperative ICU requirement, n (%)	6 (12.0)	12 (24.0)	0.118
Length of hospital stay (days)	6.2 ± 1.8	7.4 ± 2.3	**0.004**
Overall postoperative complications, n (%)	10 (20.0)	19 (38.0)	**0.047**

Patients receiving PVI-guided therapy achieved oral intake and return of gastrointestinal function significantly earlier than patients receiving conventional fluid management.

Overall postoperative complications were significantly lower in the PVI group (20.0% vs 38.0%; $p=0.047$).

Pulmonary complications, acute kidney injury, and ICU requirement were numerically less frequent with PVI-guided therapy, although individual differences did not reach statistical significance. Mean hospital stay was significantly shorter in the PVI group (6.2 ± 1.8 vs 7.4 ± 2.3 days; $p=0.004$).

Overall Findings: PVI-guided fluid therapy significantly reduced intraoperative fluid administration and positive fluid balance without compromising urine output or hemodynamic stability. It was associated with fewer intraoperative hypotensive episodes, lower end-operative serum lactate, earlier return of gastrointestinal function, fewer overall postoperative complications, and a shorter hospital stay compared with conventional fluid management. These findings suggest that PVI-guided individualized fluid administration may avoid unnecessary fluid loading while maintaining adequate tissue perfusion during major abdominal surgery.

Discussion

The present study compared Pleth Variability Index (PVI)-guided goal-directed fluid therapy with

conventional fluid management in 100 patients undergoing major abdominal surgery. The principal findings were that PVI-guided therapy significantly reduced intraoperative crystalloid and total fluid administration, decreased positive fluid balance, and was associated with fewer hypotensive episodes and lower postoperative lactate levels. Patients managed using PVI guidance also demonstrated earlier recovery of gastrointestinal function, fewer overall postoperative complications, and shorter hospitalization.

Optimization of perioperative fluid administration is particularly important during major abdominal surgery because both inadequate intravascular volume and excessive fluid administration can adversely influence organ perfusion and postoperative recovery. Sun et al. demonstrated that goal-directed fluid therapy using dynamic hemodynamic variables improved postoperative gastrointestinal recovery and shortened hospital stay following major abdominal surgery. [7] Their randomized trial reported earlier first flatus and oral intake with GDFT, findings consistent with the gastrointestinal recovery observed in our PVI group.

In the present study, patients receiving PVI-guided therapy required significantly less total intraoperative fluid than those receiving conventional management. Wang et al. similarly reported lower intraoperative fluid administration with PVI-directed GDFT compared with conventional therapy in elderly patients undergoing gastrointestinal surgery. [8] Although their study did not demonstrate a reduction in overall postoperative complications, cardiopulmonary complications were significantly reduced with PVI guidance. This supports the concept that PVI can prevent unnecessary fluid loading while maintaining adequate perioperative circulatory management.

The ability of PVI to individualize fluid administration has also been demonstrated in pediatric abdominal surgery. Mathew et al. reported that PVI-guided goal-directed therapy reduced intraoperative fluid administration compared with conventional liberal fluid therapy and was associated with faster recovery of bowel function. [9] Although the patient population differed from the present adult population, these observations reinforce the potential usefulness of PVI across different surgical settings.

Dynamic indices such as PVI may offer an advantage over conventional static clinical variables because they provide continuous information regarding respiratory variation in the plethysmographic waveform and therefore potential fluid responsiveness. The evidence discussed by Hahn suggests that dynamic assessment of fluid responsiveness can assist in identifying patients who are more likely to respond to volume expansion, thereby reducing empiric fluid administration. [10]

In our study, PVI-guided management was associated with fewer hypotensive episodes and a lower end-operative serum lactate concentration. These findings indicate that the reduction in fluid administration did not compromise tissue perfusion. Similar principles have been demonstrated in studies comparing dynamic indices for goal-directed therapy, including pulse pressure variation and PVI, in which individualized fluid administration maintained hemodynamic stability while avoiding unnecessary volume expansion. [11]

The PVI group also had a significantly lower positive fluid balance. Avoidance of excessive positive fluid balance may be particularly beneficial in abdominal surgery, as interstitial and bowel-wall edema can potentially impair gastrointestinal function and delay postoperative recovery. Evidence comparing restrictive, liberal, and goal-directed approaches supports individualized goal-directed strategies rather than routine administration of large volumes of intravenous fluid. [12]

Postoperative recovery is determined by multiple factors, and fluid therapy represents only one component of perioperative management. Contemporary perioperative fluid-management principles emphasize maintaining adequate circulating volume and organ perfusion while avoiding both hypovolemia and fluid overload. [13] In this context, the non-invasive nature and continuous availability of PVI make it an attractive tool for implementing individualized fluid therapy without the risks associated with invasive hemodynamic monitoring.

In the present study, time to first oral intake and first flatus were significantly shorter with PVI guidance. Yilmaz et al. also evaluated PVI-based goal-directed fluid management and demonstrated the feasibility of using PVI for individualized intraoperative fluid administration. [14] These observations suggest that more precise fluid optimization may facilitate postoperative recovery by limiting unnecessary tissue edema while preserving adequate perfusion. Our findings are also consistent with those of Demirel et al., who evaluated PVI-guided goal-directed fluid therapy during laparoscopic Roux-en-Y gastric bypass surgery. Their study demonstrated that PVI could effectively guide intraoperative fluid administration in obese surgical patients. [15] Together, these findings support PVI as a practical, non-invasive dynamic variable for tailoring intraoperative fluid therapy.

The present study had certain limitations. It was a single-centre study with a relatively small sample size. PVI measurements may be influenced by factors such as peripheral perfusion, vasoconstriction, cardiac arrhythmias, ventilatory settings, tidal volume, and changes in vascular tone. Furthermore, the study included different types of major abdominal procedures, which may have introduced variability in operative fluid requirements and postoperative recovery. Larger multicentre studies using standardized PVI algorithms and procedure-specific analyses are required to determine whether reductions in fluid administration consistently translate into improved major postoperative outcomes.

Conclusion

PVI-guided goal-directed fluid therapy was more effective than conventional fluid management in optimizing intraoperative fluid administration during major abdominal surgery. It significantly reduced crystalloid and total fluid requirements and positive fluid balance while maintaining adequate urine output and tissue perfusion. PVI guidance was also associated with fewer hypotensive episodes, lower end-operative lactate levels, earlier return of gastrointestinal function, fewer overall postoperative complications, and shorter hospital stay.

Thus, Pleth Variability Index may provide a simple, continuous, and non-invasive approach for individualized intraoperative fluid management in appropriately selected mechanically ventilated patients undergoing major abdominal surgery. However, PVI should be interpreted in conjunction with the overall clinical and hemodynamic condition rather than used as an isolated therapeutic target.

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