ORIGINAL RESEARCH ORİJİNAL ARAŞTIRMA

DOI: 10.5336/anesthe.2025-110982

Traditional Versus Pulse Pressure Variation Based Approach to Intraoperative Fluid Management in Major Surgery: A Prospective Observational Study

Majör Cerrahilerde İntraoperatif Geleneksel Sıvı Yönetimi ile Nabız Basınç Değişimine Dayalı Sıvı Yönetiminin Karşılaştırılması: Prospektif Gözlemsel Bir Çalışma

Koray TAN[a], Canan YILMAZ[a], Ayşe Neslihan BALKAYA[a], Filiz ATA[a], Aycan KURTARANGİL DOĞAN[a], Derya KARASU[a], Murat ERSAL[a], Mehmet GAMLI[a], Tuğba ONUR[a]

[a]University of Health Sciences Bursa Yüksek İhtisas Training and Research Hospital, Department of Anesthesiology and Reanimation, Bursa, Türkiye

This study was presented as an oral presentation at the 3rd International Anesthesia and Reanimation Symposium, December 1-2, 2023, Bursa, Türkiye.

ABSTRACT Objective: We hypothesize that pulse pressure variation (PPV)-guided goal-directed fluid management reduces intraoperative hypotension, vasopressor requirements, and improves postoperative recovery in major surgery compared to traditional fluid therapy. Primary outcome: Intraoperative hypotension/vasopressor needs. Secondary outcomes: Post-anesthesia care unit (PACU)/hospital stays, postoperative complications. **Material and Methods:** In this single-centre prospective observational study, 75 patients (ASA I-III) aged 18-65 years were allocated to Group P (PPV) and Group T (Traditional). Inferior vena cava collapsibility index (IVCCI) was measured preoperatively and postoperatively. In Group P, when PPV was >12%, 250 ml/10 min of fluid was given until it reached ≤12%. If PPV was still ≤12% and hypotension was present, a vasopressor agent was given. Demographic data, oxygen saturation, heart rate, blood pressure, pH, lactate level, urine output, blood loss, fluid administration, and inotropic use were recorded intraoperatively. Postoperative urine output, complications, and the length of PACU/hospital stays were recorded. **Results:** There were no significant differences between the groups in demographic data, incidence of intraoperative hypotension, and requirement of vasopressor agent (p>0.05). Preoperative and postoperative IVCCI values differed significantly between groups (p=0.016 and p=0.006, respectively). Total volume of fluid intraoperatively was 1425±926.50 ml in Group P and 3260±917.02 ml in Group T (p<0.001). Postoperative pneumonia occurred significantly less frequently in Group P (3.3%) compared to Group T (13.3%) (p<0.001). The length of PACU/hospital stays was shorter in Group P (p=0.003, p=0.038, respectively). **Conclusion:** Goal-directed fluid management based on PPV reduced intraoperative fluid volume, postoperative pneumonia, and the length of PACU/hospital stays compared to traditional management in major surgery.

Keywords: Goal-directed therapy; inferior vena cava; ultrasonography; pulse pressure; general anesthesia

ÖZET Amaç: Nabız basınç değişimi (PPV) rehberliğinde hedefe yönelik sıvı yönetiminin, major cerrahilerde geleneksel sıvı tedavisine kıyasla intraoperatif hipotansiyon ve vazopressör gereksinimini azalttığı ve postoperatif iyileşmeyi arttırdığı hipotezini öne sürüyoruz. Birincil sonuç: intraoperatif hipotansiyon/vazopresör gereksinimi. İkincil sonuçlar: anestezi sonrası bakım ünitesinde (PACU)/hastanede kalış süresi, postoperatif komplikasyonlar. **Gereç ve Yöntemler:** Bu tek merkezli prospektif gözlemsel çalışmada, 18-65 yaş arası 75 hasta (ASA I-III) Grup P (PPV) ve Grup T (Geleneksel) olarak ayrıldı. İnferior vena kava kollapsibilite indeksi (IVCCI) preoperatif ve postoperatif olarak ölçüldü. Grup P'de PPV >%12 olduğunda, ≤%12'ye ulaşana kadar 250 ml/10 dk sıvı verildi. Hala PPV ≤%12 ise ve hipotansiyon mevcutsa vazopressör ajan uygulandı. Demografik veriler, parsiyel oksijen satürasyonu, kalp hızı, kan basıncı, pH, laktat düzeyi, idrar çıkışı, kan kaybı, sıvı miktarı ve inotropik kullanımı intraoperatif olarak kaydedildi. Postoperatif idrar çıkışı, komplikasyonlar ve PACU/hastanede kalış süresi kaydedildi. **Bulgular:** Gruplar arasında demografik veriler, intraoperatif hipotansiyon insidansı ve vazopressör ajan gereksinimi açısından anlamlı fark yoktu (p>0.05). Preoperatif ve postoperatif IVCCI değerlerine bakıldığında gruplar arasında anlamlı farklılık mevcuttu (sırasıyla p=0.016 ve p=0.006). İntraoperatif toplam sıvı hacmi Grup P'de 1425 ± 926.50 ml iken Grup T'de 3260 ± 917.02 ml idi (p<0.001). Postoperatif pnömoni, Grup P'de (%3,3) Grup T'ye (%13,3) kıyasla anlamlı derecede daha az görüldü (p<0,001). PACU/hastanede kalış süreleri Grup P'de daha kısaydı (sırasıyla p=0.003, p=0.038). **Sonuç:** Majör cerrahilerde PPV'ye dayalı hedefe yönelik sıvı yönetimi intraoperatif sıvı hacmini, postoperatif pnömoniyi ve PACU/hastane kalış sürelerini geleneksel sıvı yönetimine kıyasla azalttı.

Anahtar Kelimeler: Hedefe yönelik tedavi; inferior vena kava; ultrasonografi; nabız basıncı; genel anestezi

TO CITE THIS ARTICLE:
Tan K, Yılmaz C, Balkaya AN, Ata F, Kurtarangil Doğan A, Karasu D, et al. Traditional versus pulse pressure variation based approach to intraoperative fluid management in major surgery: A prospective observational study. Turkiye Klinikleri J Anest Reanim. 2025;23(2):58-67.

Correspondence: Canan YILMAZ
University of Health Sciences Bursa Yüksek İhtisas Training and Research Hospital, Department of Anesthesiology and Reanimation,Bursa, Türkiye
E-mail: dr_cnnylmz@yahoo.com

Peer review under responsibility of Turkiye Klinikleri Journal of Anesthesiology Reanimation.

Received: 01 Apr 2025 ***Received in revised form:*** 11 Aug 2025 ***Accepted:*** 18 Aug 2025 ***Available online:*** 27 Aug 2025

2146-894X

Determining the intravascular volume status and the need for inotropic/vasoactive agents is crucial to achieving intraoperative hemodynamic stability during major surgeries. Preoperative fluid status, comorbidities, age, and the type of surgery should be considered when assessing intraoperative fluid requirements. Insufficient fluid management can result in complications such as lactic acidosis, acute renal failure, and multi-organ dysfunction, while excessive fluid administration may lead to pulmonary edema and heart failure.[1] Traditional fluid management methods, which base the fluid volume on factors such as body weight, fasting duration, and the magnitude of surgery, carry the risk of hypervolemia. To assess fluid deficits, clinicians commonly rely on patient history, clinical examination, laboratory tests, and static measurements, although the sensitivity and specificity of these approaches are limited.[2] Consequently, advanced monitoring techniques have been recommended for more accurate assessment of fluid deficits.[3-7]

The inferior vena cava collapsibility index (IVCCI), assessed via ultrasound, emerges as a non-invasive, rapid, and practical dynamic monitoring method for evaluating fluid deficits. A high IVCCI (>50%) indicates a low volume status, while a low IVCCI (<50%) suggests a high volume status.[8,9] Restrictive or goal-directed fluid management in major surgeries reduces rates of postoperative mortality and morbidity.[10] Goal-directed fluid therapy uses dynamic assessments, like pulse pressure variation (PPV), to optimize cardiac output. By monitoring PPV, clinicians can assess fluid responsiveness and strategically administer fluids to enhance the heart's output.[2] In intubated patients, a PPV threshold value greater than 12% indicates fluid deficit.[3,11-13] In our study, IVCCI was used only as an auxiliary parameter for validating volume status and not as the primary determinant of fluid responsiveness. Several meta-analyses have shown that PPV-based goal-directed fluid therapy significantly reduces postoperative complications, hospital stay, and improves hemodynamic stability in high-risk surgeries. Compared to traditional static parameters, PPV provides real-time dynamic monitoring, especially in mechanically ventilated patients.[14]

Our study hypothesis is that goal-directed fluid management based on PPV monitoring will be more effective in reducing the incidence of intraoperative hypotension and vasopressor requirement, and also improve postoperative recovery in major surgery. The primary objective is to compare the effects of PPV-based goal-directed fluid management with traditional fluid management on the incidence of intraoperative hypotension and the need for vasopressor agents. The secondary objective is to assess the duration of stay in the post-anesthesia care unit (PACU) and hospital, as well as postoperative adverse events.

MATERIAL AND METHODS

Our study was designed as a prospective observational clinical trial, and no randomization was performed in the selection or assignment of patients. Patients undergoing major surgeries including intracranial tumor excision, cerebral aneurysm clipping, nephrectomy, and prostatectomy were included under general anesthesia between March 5-December 31, 2021 in University of Health Sciences Bursa Yüksek İhtisas Training and Research Hospital, Department of Anesthesiology and Reanimation. Our study was conducted in accordance with the principles of the Declaration of Helsinki. Written informed consent was obtained from all individual participants included in the study. Following approval from the institutional ethics committee (Bursa Yüksek İhtisas Training and Research Hospital Clinical Research Ethics Committee; date: March 17, 2021; no: 2011-KAEK-25 2021/03-24) and the acquisition of written informed consent, a total of 75 patients (aged 18-65 years, American Society of Anesthesiology I-III) were enrolled. Exclusion criteria included lung dysfunction, mental retardation, cardiac arrhythmia, preoperative inotrope dependence, thoracotomy, right heart failure, severe aortic insufficiency, uncontrolled diabetes mellitus, American Society of Anesthesiology score ≥IV, body mass index ≥35 kg/m^2, non-cooperation, and lack of Turkish language proficiency.

Following routine monitoring in the operating room, an intravenous (IV) line (18-20 G) was placed. Premedication was administered with 0.01-0.02 mg/kg IV midazolam (Zolamid®, Defarma, Ankara, Türkiye), and intra-arterial pressure was monitored. While the patients were in the supine position, the diameter of the inferior vena cava was measured approximately 3 cm distal to its exit from the right atrium using a low-frequency (3.5-5 MHz) convex probe under ultrasound guidance (Esaote MyLab 30 Gold, Italy), and the IVCCI was recorded. In this study, an IVCCI greater than 40% was accepted as indicative of fluid responsiveness.

Anesthesia induction was performed with 2-3 mg/kg propofol (Propofol®, 2% Fresenius®, Fresenius Kabi, Bad Homburg, Germany), 1-2 µg/kg fentanyl (Talinat®, Vem, İstanbul, Türkiye), and 0.6-0.9 mg/kg rocuronium (Curon®, Mustafa Nevzat, İstanbul, Türkiye), and the patients were intubated. Anesthesia maintenance was achieved with a 50% air/O_2 mixture, sevoflurane (MAC 1), IV 0.1-0.2 mg/kg rocuronium, and 1 µg/kg fentanyl routinely.

A single anesthesiologist meticulously recorded comprehensive intraoperative data to ensure consistency. Intraoperative heart rate, mean arterial pressure (MAP), pH, lactate, crystalloid/colloid fluids, total urine output, blood loss, erythrocyte suspension (ES), and fresh frozen plasma (FFP) requirements were recorded for all patients. If intraoperative hemoglobin <7 g/dL or hematocrit <21%, ES/FFP at a 1:1 ratio was administered. At the end of the operation, 100 mg of tramadol (Tramosel®, Haver, İstanbul, Türkiye) was administered intravenously. Patients were awakened with 2-4 mg/kg sugammadex (Bridion®, Merck Sharp Dohme, İstanbul, Türkiye). In recovery room, the diameter of the inferior vena cava and IVCCI were recorded under ultrasound guidance when the patients' Aldrete score was ≥9. The length of stay in the PACU and hospital, as well as postoperative complications, were recorded. Postoperative data was also collected by a blinded anesthesiologist to minimize bias.

This observational study categorized surgical patients into 2 groups based on intraoperative fluid administration protocols implemented by different anesthesiologists. Group P (n=30), which received goal-directed fluid management based on PPV monitoring, and Group T (n=30), which received traditional fluid management. In Group T, traditional fluid management was applied using the 4-2-1 rule, according to fasting duration and the magnitude of the surgery, with hourly fluid requirements calculated and administered throughout the operation. In Group P, PPV monitoring was performed. PPV was assessed using the standard anesthesia monitor (GE Healthcare, USA) by evaluating respiratory-induced variations in the invasive arterial pressure waveform. If the PPV was >12%, a 250 mL/10 min IV crystalloid fluid bolus was administered. This 12% cut-off was selected based on previous meta-analyses demonstrating its high sensitivity and specificity for predicting fluid responsiveness in mechanically ventilated patients. Fluid loading was continued with 250 mL/10 min IV fluids until the PPV was ≤12%. If PPV was ≤12% but intraoperative hypotension (a decrease in MAP >30% compared to baseline) was present, an inotropic agent was administered. If there was no hypotension, maintenance fluid therapy was not given.

STATISTICAL ANALYSIS

G*Power (Heinrich Heine University, Düsseldorf, Germany) analysis, using intraoperative fluid volume as the primary outcome variable, indicated a required sample size of 58 (29 per group) to detect a significant difference (effect size=0.75, standard deviation=±5, power=80%, alpha=0.05). To account for potential dropouts, we enrolled 75 participants, with 60 included in the final analysis. Data normality was assessed using the Shapiro-Wilk test. Normally distributed data were analyzed using t-tests (2 groups) or one-way analysis of variance (more than 2 groups), while non-normally distributed data were analyzed using Mann-Whitney U tests (2 groups) or Kruskal-Wallis tests (more than 2 groups). Bonferroni corrections were applied for "post hoc" multiple comparisons. Pearson's and Spearman's correlation coefficients were used to assess relationships between parametric and non-parametric variables, respectively. Categorical data were analyzed using Pearson's chi-square, Fisher's exact, or Fisher-

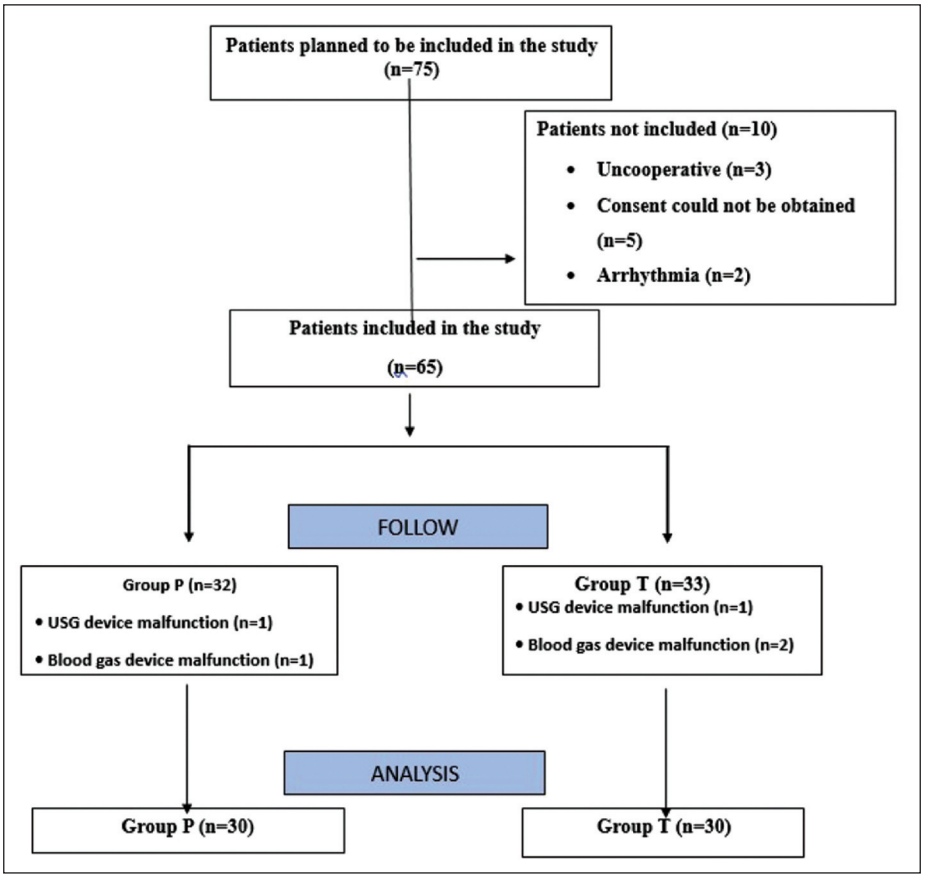

FIGURE 1: Flowchart
USG: Ultrasonography

Freeman- Halton tests. Receiver operating characteristic analysis determined threshold values, area under the curve, sensitivity, and specificity. The significance level was set at α=0.05. IBM SPSS Statistics 23.0 (IBM Corp., Armonk, NY, USA) was used for all analyses.

RESULTS

Of the 75 patients planned for the study, 60 were included in the statistical analysis (Figure 1). Demographic analyses showed no significant differences between groups (Table 1). No statistically significant differences were observed in intraoperative heart rate, MAP, pH, or lactate levels at different time points within and between the groups (Figure 2).

TABLE 1: Demographic data

	Group P (n=30)	Group T (n=30)	p value
Female/male	15 (50.0)/15 (50.0)	17 (56.7)/13 (43.3)	0.605[c]
Age (years)	53.97±11.84	53.47±8.90	0.477[b]
BMI (kg/m^2)	24.33±2.33	24.70±2.18	0.858[a]
ASA	2 (2-3)	3 (2-3)	0.072[b]
Operation time (min)	166.90±68.10	148.36±50.30	0.236[b]
Fasting period (hours)	9.1±1.5	8.7±1.04	0.330[a]
Diabetes mellitus	6 (20)	5 (16.7)	0.739[a]
Hypertension	12 (40)	11 (36.7)	0.791[a]
Type of surgery			
Intracranial tumors	23 (76.7)	19 (63.3)	
Cerebral aneurysm	2 (6.7)	9 (30.0)	0.796[b]
Nephrectomy	3 (10)	0 (0)	
Prostatectomy	2 (6.6)	2 (6.7)	

Data are presented as mean±standard deviation, number (%), or median (minimum-maximum) as appropriate; [a]Independent samples t-test; [b]Mann-Whitney U test; [c]Pearson chi-square test; BMI: Body mass index; ASA: American Society of Anesthesiology

FIGURE 2: Changes in the intraoperative HR, MAP, pH, and lactate level
HR: Heart rate; MAP: Mean arterial pressure

TABLE 2: Perioperative fluid balance, hemodynamics, and blood loss

	Group P (n=30)	Group T (n=30)	p value
Preoperative IV crystalloid (mL)	208.33±237.47	181.67±184.99	0.811[a]
Intraoperative IV crystalloid (mL)	1,425±926.50	3,260±917.02	<0.001[a*]
Hypotension	12 (40.0)	9 (30.0)	0.588[c]
Inotropic agent requirement	3 (10)	2 (6.7)	1.000[b]
Intraoperative urine (mL)	500±290.36	716.67±472.76	0.080[a]
Intraoperative bleeding (mL)	270±162.20	296.67±151.96	0.308[a]
Preoperative hemoglobin (g/dL)	12.33±1.02	12.46±1.64	0.708[a]
Postoperative hemoglobin (g/dL)	11.47±0.83	11.40±1.25	0.800[a]

Data are presented as mean±standard deviation or number (%);
*Statistically significant (p<0.05); [a]Mann-Whitney U test; [b]Fisher's exact test;
[c]Yates-corrected chi-square test; IV: Intravenous

Intraoperative hypotension, vasopressor use, urine output, and blood loss did not differ significantly between groups. While preoperative fluid volume was similar, Group T received significantly more intraoperative fluid (3,260±917.02 mL) than Group P (1,425±926.50 mL) (p<0.001). Preoperative and postoperative hemoglobin levels were comparable across groups (Table 2). None of the patients required colloid fluids, albumin, ES, or FFP. Furthermore, 2 patients in Group P did not require any intraoperative crystalloid fluids as their intraoperative PPV values never dropped below 12%. Preoperative and postoperative IVCCI values differed significantly between groups (p=0.016 and p=0.006, respectively, Table 3).

TABLE 3: IVC diameters and IVCCI (mean±standard deviation)

		Group P (n=30)	Group T (n=30)	p value
Preoperative	IVC ins (mm)	16.01±5.78	14.91±3.10	0.373[b]
	IVC exp (mm)	22.82±6.74	19.59±3.98	0.028[b*]
	IVCCI	31.07±10.31	23.83±7.34	0.016[a*]
Postoperative	IVC ins (mm)	17.02±5.09	23.83±7.34	0.801[a]
	IVC exp (mm)	22.56±5.95	20.49±3.77	0.114[b]
	IVCCI	25.63±7.73	19.77±8.07	0.006[b*]

Values are presented as mean±standard deviation; *Statistically significant (p<0.05);
[a]Mann-Whitney U test; [b]Independent samples t-test; IVC ins: Inferior vena cava inspiratory diameter; IVC exp: Inferior vena cava expiratory diameter;
IVCCI: Inferior vena cava collapsibility index; Cut-off values: Preoperative IVCCI >34%; Postoperative IVCCI >17%

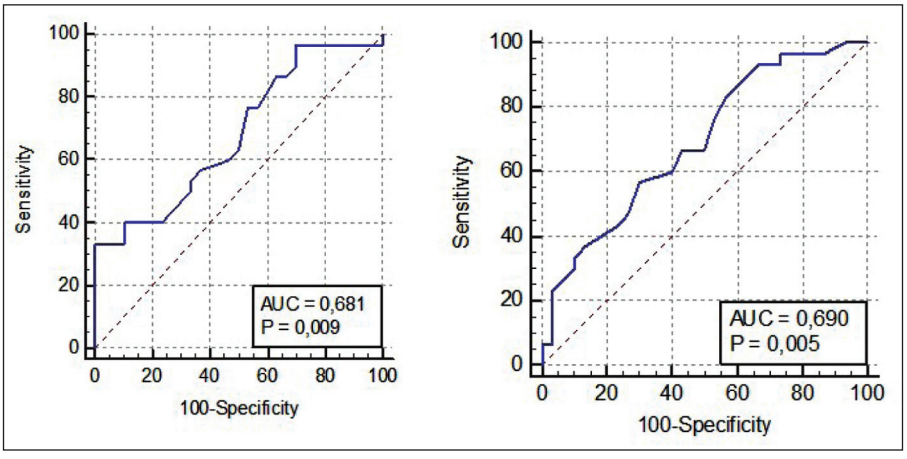

FIGURE 3: IVCCI ROC curves **A)** Preoperative IVCCI: Sensitivity 90%, Specificity 100%, **B)** Postoperative IVCCI: Sensitivity 93.33%, Specificity 90%
AUC: Area under the curve; IVCCI: Inferior vena cava collapsibility index; ROC: Receiver operating characteristic

A preoperative IVCCI cut-off value of >34% predicted fluid deficit with 90% sensitivity (73.5-97.9) and 100% specificity (88.4-100). Postoperative IVCCI, with a cut-off value of >17%, predicted fluid responsiveness with 93.33% sensitivity (77.9-99.2) and 90% specificity (73.5-97.9) (Figure 3).

PACU stay was significantly longer in Group T (39.20±3.30 hours) compared to Group P (25.80±6.39 hours, p=0.000). Similarly, hospital stay was longer in Group T (4.63±1.03 days) than in Group P (3.93±0.63 days, p=0.003). Postoperative urine output was comparable between the groups (Group P: 2,135±205.59 mL, Group T: 2,205±165.75 mL, p=0.152). The incidence of postoperative pneumonia was 3.3% in Group P and 13.3% in Group T, showing a clinically relevant reduction (p=0.038).

While Group T exhibited higher rates of hypertension (23.3% vs. 13.3%, p=0.108) and surgical infections (13.3% vs. 6.6%, p=0.197) than Group P, these differences were not statistically significant. Hypotension rates were similar between groups (5.0% in Group P and 6.6% in Group T, p=0.162). Atelectasis was observed in one patient from each group, while pulmonary edema was reported in 1 patient in Group T (Table 4).

TABLE 4: Comparison of postoperative variables between the groups [n (%), mean±standard deviation]

	Group P (n=30)	Group T (n=30)	p value
ICU stay (h)	25.80±6.39	39.20±3.30	**0.000**[*t]
Hospital stay (days)	3.93±0.63	4.63±1.03	**0.003**[*t]
Urine output (mL)	2,135±205.59	2,205±165.75	0.152[t]
Pneumonia	2 (3.3)	8 (13.3)	**0.038**[*c]
Hypertension	8 (13.3)	14 (23.3)	0.108[c]
Hypotension	3 (5)	4 (6.6)	0.162[c]
Surgical site infection	4 (6.6)	8 (13.3)	0.197[t]
Atelectasis	1 (3.33)	1 (3.33)	-
Pulmonary edema	0 (0)	1 (3.33)	-

*p<0.05; **p<0.001; [t]Student t-test, [c]Chi-square test; ICU: Intensive care unit

DISCUSSION

The careful and effective management of fluids in the period surrounding major surgical procedures is critically important. When fluid balance and administration are optimized for patients undergoing significant operations, the risk of complications following surgery is decreased. Furthermore, proper perioperative fluid management not only lowers the chance of postoperative illness and negative outcomes, but also contributes to a reduction in mortality rates among surgical patients. Ensuring intraoperative hemodynamic stability and reducing the need for inotropic and vasoactive agents through balanced fluid replacement is particularly important in the management of major surgeries. Anesthetic agents, particularly in cases of low coronary reserve

or volume deficiency, often lead to hypotension. However, excessive fluid loading to prevent or treat hypotension has been associated with increased morbidity and mortality.[14] The primary aim of fluid therapy is to ensure sufficient blood flow and cardiac output to support tissue oxygenation.[15] The traditional group received significantly more intraoperative fluid and subsequently experienced higher rates of postoperative pneumonia, extended PACU and hospital stays in our study. These results highlight the impact of the traditional approach on fluid management and adverse postoperative outcomes. This finding is not only statistically significant but also clinically significant. Shorter PACU and hospital stays translate to a reduced risk of postoperative complications, increased patient comfort, and more efficient use of healthcare resources. This is a significant advantage, particularly in terms of enhancing patient safety and reducing healthcare costs associated with major surgeries.

Today, IVCCI under ultrasound guidance is frequently used in intensive care units (ICU) to evaluate fluid deficits and fluid responsiveness.[8] In a study by Zhao and Wang evaluating 42 patients in septic shock, IVCCI had 100% sensitivity and 100% specificity with a cut-off value of 12.9% in predicting response to fluid therapy.[16] In another study involving 58 spontaneously breathing sepsis patients, IVCCI was shown to have 72.41% sensitivity and 82.76% specificity in predicting fluid responsiveness.[17] In our study, preoperative and postoperative fluid responsiveness was assessed by measuring IVCCI, with IVCCI >50% considered indicative of fluid deficit. A preoperative IVCCI cut-off value of >34% predicted fluid deficit with 90% sensitivity and 100% specificity. In both groups, preoperative IVCCI was <50%. However, significantly more intraoperative fluid was administered in the traditional fluid management group. Although significantly less fluid was administered in the goal-directed fluid management group based on PPV monitoring, there was no postoperative fluid deficit (IVCCI <50%). Postoperative IVCCI had 93% sensitivity and 90% specificity in predicting fluid responsiveness with a cut-off value of >17%. Our study demonstrated that IVCCI, which is frequently used in ICUs to evaluate fluid deficits with high sensitivity and specificity, is also an effective and easy method for use in the operating room.

Dynamic parameters based on cardiopulmonary interactions during mechanical ventilation have recently become useful and frequently used methods for evaluating fluid deficits.[3] PPV, a dynamic parameter, is a valuable and highly accurate method for predicting fluid deficit.[2] However, its utility is limited in certain clinical scenarios, including irregular cardiac rhythms (e.g., atrial fibrillation or frequent ectopy), where beat-to-beat variability confounds interpretation; low tidal volume ventilation (<8 mL/kg) or spontaneous breathing, which fail to generate sufficient intrathoracic pressure changes; open-chest conditions such as cardiac surgery; right ventricular dysfunction or elevated intra-abdominal pressure; and pediatric or obese populations where anatomical variations may reduce reliability, particularly in sepsis or acute respiratory distress syndrome settings.[18,19] These limitations underscore the need for complementary assessments, such as IVCCI, to ensure accurate prediction of fluid deficits. A meta-analysis evaluating the effectiveness of PPV in predicting fluid deficit, which included 22 scientific studies, showed that PPV is highly objective and useful in predicting fluid deficit and assessing fluid responsiveness in mechanically ventilated patients with tidal volumes exceeding 8 mL/kg [receiver operating characteristic area under the curve 0.94, 95% confidence interval (CI): 0.91-0.95], with an average cut-off value of 12% (10-13%), yielding 88% (CI: 0.81-0.92) sensitivity and 89% (CI: 0.84-0.92) specificity.[18] In our PPV-based goal-directed fluid management adopted this 12% PPV cut-off based on this meta-analysis's robust findings.

Intraoperative hemodynamic monitoring and adjusting fluid therapy based on close monitoring of a patient's fluid losses are recommended in major surgeries.[20] Proper fluid management is critical in major surgeries because both inadequate and excessive fluid administration can have serious consequences. Insufficient fluid administration can cause lactic acidosis, acute renal failure, and multiorgan dysfunction. Conversely, excessive fluid administration can lead to pulmonary edema and

exacerbate or precipitate heart failure.[1,5] Excessive IV fluid loading can result in life-threatening complications, such as pulmonary edema and heart failure.[1] Maintaining intravascular volume and achieving hemodynamic stability during surgery are critical to reducing postoperative morbidity and mortality. de Aguilar-Nascimento et al. compared postoperative outcomes in 61 patients undergoing abdominal surgery who received restrictive versus traditional fluid therapy. The average fluid volumes of 2,100 mL and 3,575 mL were given to restrictive and traditional groups, respectively.[21] Another study emphasized that dilutional anemia could be a significant cause of shock at the cellular level. It was noted that each additional 500 mL of fluid replacement reduced hemoglobin levels by approximately 1.1 g/dL and increased the need for postoperative blood transfusion.[22] In the literature, it has been reported that less crystalloid fluid is administered with PPV-based fluid management compared to the standard method.[22-25] In an other study, although more fluid was administered intraoperatively in the PPV-based goal-directed fluid management group, postoperative serum lactate levels were lower, and peripheral organ perfusion was beter.[26] In our study, 1,425 mL of fluid was administered in the PPV-based goal-directed fluid management group, while 3,260 mL was administered in the traditional fluid management group. Hypotension was observed in 40% of Group P and 30% of Group T. Inotropic agent use was required in 10% of Group P and 6.7% of Group T. Despite less fluid administration in Group P, hypotension and inotropic agents use remained similar across groups. In Group P, 2 (6.7%) patients did not receive any fluid during the surgery because their PPV values remained below 12% throughout the procedure. These 2 patients remained hemodynamically stable, with no need for inotropic agents or any postoperative complications.

Traditional fluid management, which is based on the physician's clinical experience, can lead to complications associated with unnecessary volume overload. One study observed increased hospital stay, postoperative weight gain, and complications related to increased fluid load in patients undergoing traditional fluid management for intra-abdominal surgery.[27] In another study comparing PPV-based and standard fluid management in high-risk surgeries, the PPV group had shorter hospital stays and fewer complications.[23] A study in abdominal surgeries showed that the restrictive group (with an average of 2,100 mL) had reduced postoperative morbidity and shorter hospital stays compared to the traditional group (with an average of 3,575 mL).[21] In a study involving 450 patients, it was found that patients managed with goal-directed fluid therapy had lower rates of postoperative complications, such as pneumonia, superficial wound infection, acute kidney injury, and pulmonary edema, as well as shorter ICU stays compared to patients managed with standard fluid therapy. However, 180-day mortality did not differ significantly between groups.[28] A meta-analysis comparing goal-directed fluid therapy and traditional methods in gastrointestinal surgeries found that goal-directed fluid therapy reduced morbidity and ICU/hospital stay durations, but mortality rates remained similar.[29] PPV-based goal-directed fluid management reduced hospital and ICU stays and pneumonia incidence in proportion to traditional fluid management in our study, consistent with prior studies. The average ICU stay in Group P was approximately 25.8 hours, while in Group T, it was approximately 39.2 hours. The average hospital stay was approximately 3.93 days in Group P and 4.63 days in Group T. Pneumonia developed in 3.3% of patients in Group P versus 13.3% in Group T. The liberal, "traditional" fluid strategy used in Group T was associated with significantly more postoperative complications than the PPV-based, goal-directed protocol applied in Group P. Excessive intra-operative crystalloids create subclinical interstitial lung edema that compromises surfactant, mucociliary clearance, and alveolar immune function, leading to micro-atelectasis, bacterial colonization, and ultimately a higher pneumonia rate, even when overt pulmonary edema is uncommon. By preventing unnecessary fluid loading, PPV-based goal-directed fluid management reduces pulmonary complications, shortens ICU and hospital stays, enhances patient safety and comfort, and lowers overall healthcare costs after major surgery.

In conclusion, our findings demonstrate the superiority of PPV-based goal-directed fluid management in reducing intraoperative fluid volumes, postoperative complications (e.g., pneumonia), and lengths of stay compared to traditional methods, while maintaining hemodynamic stability. Future studies should prioritize multicenter randomized controlled trials to validate PPV's efficacy in diverse cohorts, including PPV-limiting scenarios like low tidal volume ventilation or arrhythmias, through integrations with IVCCI or other dynamic parameters. Furthermore, studies examining long-term outcomes (e.g., 1-year mortality, quality of life) and the application of artificial intelligence for real-time fluid responsiveness prediction are warranted.

LIMITATIONS

One of the limitations of our study is the small sample size. Since we were unable to measure cardiac output during the preoperative and postoperative periods, we relied on IVCCI measurements to assess the patients' fluid status. Although preoperative fasting durations could not be standardized, baseline intravascular volume status was objectively assessed using IVCCI, and the preoperative IV fluid volume was similar in both groups. Due to the inability to apply goal-directed fluid management based on PPV monitoring in surgeries involving thoracotomy, patients with spontaneous breathing, tidal volume <8 mL/kg, right heart failure, or arrhythmias, our study was conducted in selected major surgeries. The need for arterial cannulation, an invasive procedure, for PPV monitoring in every patient limits the applicability of this method. Due to the limited sample size, we were not able to evaluate long-term outcomes such as mortality or ICU readmissions, which have been addressed in larger randomized controlled trials.

CONCLUSION

IVCCI is valuable for assessing fluid status and responsiveness, especially in operating rooms for patients with unknown cardiac output, beyond its common use in ICUs. Goal-directed fluid management using PPV in major surgery patients reduced intraoperative fluid needs, ICU and hospital stays, and pneumonia rates compared to traditional fluid management. PPV-guided fluid therapy stabilizes hemodynamics in major surgery more safely and effectively than traditional methods, minimizing the risk of overhydration. We recommend PPV monitoring for balanced fluid replacement in the anesthesia management of major surgeries. More advanced prospective, randomized controlled studies with greater sample sizes are required to compare different monitoring methods for intraoperative fluid management.

Source of Finance

During this study, no financial or spiritual support was received neither from any pharmaceutical company that has a direct connection with the research subject, nor from a company that provides or produces medical instruments and materials which may negatively affect the evaluation process of this study.

Conflict of Interest

No conflicts of interest between the authors and / or family members of the scientific and medical committee members or members of the potential conflicts of interest, counseling, expertise, working conditions, share holding and similar situations in any firm.

Authorship Contributions

Idea/Concept: *Koray Tan, Canan Yılmaz, Ayşe Neslihan Balkaya, Aycan Kurtarangil Doğan;* ***Design:*** *Koray Tan, Canan Yılmaz, Ayşe Neslihan Balkaya;* ***Control/Supervision:*** *Canan Yılmaz, Tuğba Onur;* ***Data Collection and/or Processing:*** *Koray Tan, Canan Yılmaz, Derya Karasu, Murat Ersal;* ***Analysis and/or Interpretation:*** *Ayşe Neslihan Balkaya, Filiz Ata, Mehmet Gamlı;* ***Literature Review:*** *Koray Tan, Tuğba Onur;* ***Writing the Article:*** *Koray Tan, Canan Yılmaz, Filiz Ata, Aycan Kurtarangil Doğan, Mehmet Gamlı, Tuğba Onur;* ***Critical Review:*** *Filiz Ata, Mehmet Gamlı, Tuğba Onur* ***References and Fundings:*** *Koray Tan, Canan Yılmaz, Mehmet Gamlı;* ***Materials:*** *Koray Tan, Canan Yılmaz, Derya Karasu, Murat Ersal.*

REFERENCES

1. Holte K, Kehlet H. Compensatory fluid administration for preoperative dehydration—does it improve outcome? Acta Anaesthesiol Scand. 2002;46(9):1089-93. [Crossref] [PubMed]
2. Cannesson M, Le Manach Y, Hofer CK, Goarin JP, Lehot JJ, Vallet B, et al. Assessing the diagnostic accuracy of pulse pressure variations for the prediction of fluid responsiveness: a "gray zone" approach. Anesthesiology. 2011;115(2):231-41. [PubMed]
3. Yang X, Du B. Does pulse pressure variation predict fluid responsiveness in critically ill patients? A systematic review and meta-analysis. Crit Care. 2014;18(6):650. [Crossref] [PubMed] [PMC]
4. Temel H, Karslı B. Sıvı tedavisinde güncel uygulamalar: dün ve bugün [Current applications in fluid therapy: yesterday and today]. Akd Med J. 2020;6(3):334-40. [Link]
5. Yeager MP, Spence BC. Perioperative fluid management: current consensus and controversies. Semin Dial. 2006;19(6):472-9. [PubMed]
6. Lassen K. Intravenous fluid therapy. Br J Surg. 2009;96(2):123-4. [Crossref] [PubMed]
7. Lobo DN. Fluid overload and surgical outcome: another piece in the jigsaw. Ann Surg. 2009;249(2):186-8. [PubMed]
8. Vincent JL, Weil MH. Fluid challenge revisited. Crit Care Med. 2006;34(5):1333-7. [PubMed]
9. Dipti A, Soucy Z, Surana A, Chandra S. Role of inferior vena cava diameter in assessment of volume status: a meta-analysis. Am J Emerg Med. 2012;30(8):1414-9.e1. [PubMed]
10. Navarro LH, Bloomstone JA, Auler JO Jr, Cannesson M, Rocca GD, Gan TJ, et al. Perioperative fluid therapy: a statement from the international Fluid Optimization Group. Perioper Med (Lond). 2015;4:3. [PubMed] [PMC]
11. Pinsky MR. Functional haemodynamic monitoring. Curr Opin Crit Care. 2014;20(3):288-93. [Crossref] [PubMed] [PMC]
12. Biais M, Nouette-Gaulain K, Roullet S, Quinart A, Revel P, Sztark F. A comparison of stroke volume variation measured by Vigileo/FloTrac system and aortic Doppler echocardiography. Anesth Analg. 2009;109(2):466-9. [PubMed]
13. Jacques D, Bendjelid K, Duperret S, Colling J, Piriou V, Viale JP. Pulse pressure variation and stroke volume variation during increased intra-abdominal pressure: an experimental study. Crit Care. 2011;15(1):R33. [Crossref] [PubMed] [PMC]
14. Marik PE, Cavallazzi R, Vasu T, Hirani A. Dynamic changes in arterial waveform derived variables and fluid responsiveness in mechanically ventilated patients: a systematic review of the literature. Crit Care Med. 2009;37(9):2642-7. [PubMed]
15. Giglio M, Dalfino L, Puntillo F, Rubino G, Marucci M, Brienza N. Haemodynamic goal-directed therapy in cardiac and vascular surgery. A systematic review and meta-analysis. Interact Cardiovasc Thorac Surg. 2012;15(5):878-87. [Crossref] [PubMed] [PMC]
16. Zhao J, Wang G. Inferior vena cava collapsibility index is a valuable and noninvasive index for elevated general heart end-diastolic volume index estimation in septic shock patients. Med Sci Monit. 2016;22:3843-8. [PubMed] [PMC]
17. Nagi AI, Shafik AM, Fatah AMA, Selima WZ, Hefny AF. Inferior vena cava collapsibility index as a predictor of fluid responsiveness in sepsis-related acute circulatory failure. Ain-Shams J Anesthesiol. 2021;13:75. [Crossref]
18. Oh AR, Lee JH. Predictors of fluid responsiveness in the operating room: a narrative review. Anesth Pain Med (Seoul). 2023;18(3):233-43. [Crossref] [PubMed] [PMC]
19. Kan CFK, Skaggs JD. Current commonly used dynamic parameters and monitoring systems for perioperative goal-directed fluid therapy: a review. Yale J Biol Med. 2023;96(1):107-23. [PubMed] [PMC]
20. Ishihara H, Hashiba E, Okawa H, Saito J, Kasai T, Tsubo T. Neither dynamic, static, nor volumetric variables can accurately predict fluid responsiveness early after abdominothoracic esophagectomy. Perioper Med (Lond). 2013;2(1):3. [Crossref] [PubMed] [PMC]
21. de Aguilar-Nascimento JE, Diniz BN, do Carmo AV, Silveira EA, Silva RM. Clinical benefits after the implementation of a protocol of restricted perioperative intravenous crystalloid fluids in major abdominal operations. World J Surg. 2009;33(5):925-30. [PubMed]
22. Perel A. Iatrogenic hemodilution: a possible cause for avoidable blood transfusions? Crit Care. 2017;21(1):291. [PubMed] [PMC]
23. Lopes MR, Oliveira MA, Pereira VO, Lemos IP, Auler JO Jr, Michard F. Goal-directed fluid management based on pulse pressure variation monitoring during high-risk surgery: a pilot randomized controlled trial. Crit Care. 2007;11(5):R100. [PubMed] [PMC]
24. Kannan G, Loganathan S, Kajal K, Hazarika A, Sethi S, Sen IM, et al. The effect of pulse pressure variation compared with central venous pressure on intraoperative fluid management during kidney transplant surgery: a randomized controlled trial. Can J Anaesth. 2022;69(1):62-71. English. [PubMed]
25. De Cassai A, Bond O, Marini S, Panciera G, Furian L, Neri F, et al. Reposição de volume orientada pela variação da pressão de pulso durante transplante renal: estudo randomizado controlado [Pulse pressure variation guided fluid therapy during kidney transplantation: a randomized controlled trial]. Braz J Anesthesiol. 2020;70(3):194-201. [PubMed] [PMC]
26. Hasanin A, Zanata T, Osman S, Abdelwahab Y, Samer R, Mahmoud M, et al. Pulse pressure variation-guided fluid therapy during supratentorial brain tumour excision: a randomized controlled trial. Open Access Maced J Med Sci. 2019;7(15):2474-9. [Crossref] [PubMed] [PMC]
27. Nisanevich V, Felsenstein I, Almogy G, Weissman C, Einav S, Matot I. Effect of intraoperative fluid management on outcome after intraabdominal surgery. Anesthesiology. 2005;103(1):25-32. [PubMed]
28. Calvo-Vecino JM, Ripollés-Melchor J, Mythen MG, Casans-Francés R, Balik A, Artacho JP, et al; FEDORA Trial Investigators Group. Effect of goal-directed haemodynamic therapy on postoperative complications in low-moderate risk surgical patients: a multicentre randomised controlled trial (FEDORA trial). Br J Anaesth. 2018;120(4):734-44. [Crossref] [PubMed]
29. Rollins KE, Lobo DN. Intraoperative goal-directed fluid therapy in elective major abdominal surgery: a meta-analysis of randomized controlled trials. Ann Surg. 2016;263(3):465-76. [Crossref] [PubMed] [PMC]