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ORIGINAL ARTICLE / ÖZGÜN MAKALE

Effects of intraoperative fluid management on hemodynamics and tissue oxygenation according to the Pleth Variability Index in thoracic surgery

Toraks cerrahisinde Pleth Değişkenlik İndeksine göre ameliyat sırası sıvı yönetiminin hemodinami ve doku oksijenizasyonu üzerine etkileri

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ABSTRACT

Background: The aim of this study was to compare the total fluid volume performed by noninvasive Pleth Variability Index in thoracic surgery patients in comparison to conventional fluid management.

Methods: In this prospective randomized controlled study conducted between May 2019 and May 2020, 80 patients (68 males, 12 females; mean age: 58.5±6.7 years; range, 18 to 65 years) were divided into two groups: control (Group C) and the Pleth Variability Index (Group P). After performing routine anesthesia and Pleth Variability Index monitoring for all patients, fluids were given at a rate of 2 mL/kg/h with the standard anesthesia technique. Additional fluid supplementation was provided based on hemodynamic data in Group C. In Group P, 250 mL bolus crystalloid fluid was provided when Pleth Variability Index was >14%. Mean arterial pressure, heart rate, oxygen saturation, arterial blood gas, and blood biochemistry were recorded. Total fluid volumes and urinary output were also recorded.

Results: There was no significant difference between the groups in terms of total fluid volumes or urinary output. In the postoperative period, the oxygen saturation and mean arterial pressure of Group P were found to be higher than those of Group C. The postoperative creatinine and lactate values of Group P were lower than those of Group C.

Conclusion: Although there was no significant difference in the total fluid given to the patients, fluid management by Pleth Variability Index monitoring had a positive effect on mean arterial pressure, oxygen saturation, lactate, and creatinine levels.

Keywords: Fluid management, hemodynamics, oxygenation, Pleth Variability Index, thoracic surgery.

ÖZ

Amaç: Bu çalışmada, göğüs cerrahisi hastalarında noninvaziv Pleth Değişkenlik İndeksi ile gerçekleştirilen toplam sıvı hacmi geleneksel sıvı tedavisiyle karşılaştırıldı.

Çalışma planı: Mayıs 2019 ve Mayıs 2020 tarihleri arasında yürütülen prospektif randomize kontrollü çalışmada 80 hasta (68 erkek, 12 kadın; ort. yaş: 58.5±6.7 yıl; dağılım, 18-65 yıl) iki gruba ayrıldı: kontrol (Grup C) ve Pleth Değişkenlik İndeksi (Grup P). Tüm hastalara rutin anestezi ve Pleth Değişkenlik İndeksi monitörizasyonu yapıldıktan sonra standart anestezi tekniği ile 2 mL/kg/sa hızında sıvı verildi. Grup C'ye hemodinamik verilere göre ek sıvı takviyesi yapıldı. Grup P'ye Pleth Değişkenlik İndeksi >%14 olduğunda 250 mL bolus kristaloid sıvı verildi. Ortalama arter basıncı, kalp atım hızı, oksijen satürasyonu, arteriyel kan gazı ve kan biyokimyası kaydedildi. Toplam sıvı hacimleri ve idrar çıkışı da kaydedildi.

Bulgular: Toplam sıvı hacmi veya idrar çıkışı açısından gruplar arasında anlamlı fark yoktu. Ameliyat sonrası dönemde Grup P'nin oksijen satürasyonu ve ortalama arter basıncı değerleri Grup C'ye göre yüksek bulundu. Grup P'nin ameliyat sonrası kreatinin ve laktat değerleri Grup C'ye göre düşüktü.

Sonuç: Hastalara verilen toplam sıvı miktarında anlamlı bir farklılık olmamasına rağmen Pleth Değişkenlik İndeksi monitörizasyonu ile sıvı yönetiminin ortalama arter basıncı, oksijen satürasyonu, laktat ve kreatinin düzeyleri üzerinde olumlu etkisi olduğu görüldü.

Anahtar sözcükler: Sıvı yönetimi, hemodinami, oksijenizasyon, Pleth Variability İndex, torasik cerrahi.

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Intravenous fluid management is highly important in thoracic surgeries in terms of mortality and morbidity, just like in all surgical interventions. While insufficient fluid administration can affect multiple systems negatively, particularly hemodynamics, excessive fluid administration can also lead to some problems in tissue and organ systems, specifically the lungs.[1]

Patients undergoing surgical procedures may be at risk of different conditions, such as hypovolemia, hypervolemia, and associated tissue perfusion disorders, in the intraoperative period. Tissue perfusion is dependent on the amount of blood flow received by the tissue. Reduced blood flow in tissues can develop as a consequence of reduced cardiac output or the vasoconstriction of blood vessels feeding the tissues. In a patient for whom dynamic measurement methods are not used, a fluid deficit may be the cause of disruptions in cardiac functions and tissue perfusion. Excessive fluid administration as a treatment option in such patients can result in hypervolemia.[2] Hypervolemia may deteriorate chronic organ disease patients' clinical conditions by rendering hypertension, ventricular hypertrophy, and other cardiovascular complications.[3] In the opposite case, failing to provide sufficient fluid to prevent hypervolemia can result in hypovolemia and low cardiac output, leading to tissue perfusion disorders. When it is severe, hypovolemia can cause shock and multiorgan failure.[4] In trauma-related emergency surgeries, as well as major surgeries involving hemodynamic instability, hypervolemia is prevalent due to the retention of excess fluid provided in the intraoperative stage. Excess postoperative hydration has been defined as an increase of greater than 10% compared to preoperative weight and is associated with increased morbidity, prolonged hospitalization in the intensive care unit, and higher postoperative mortality rates.[5]

Several static and dynamic parameters are used in the monitoring of intravascular fluid volume. Dynamic parameters provide better information about the preload of the heart. It was shown that among these parameters, the change in arterial pulse pressure affected by mechanical ventilation is one of the best tools that guide volume-based treatment.[6] Stroke volume variation (SVV) and pulse pressure variation (PPV) are monitoring parameters that are important in goal-directed fluid therapy and have been accepted for a long time.[7] Significant changes in stroke volume can be measured by SVV and PPV, but these methods require invasive arterial cannulation.[8]

Therefore, the Pleth Variability Index (PVI), which is a noninvasive, easily applicable, and easily interpretable assessment tool measured based on the pulse changes in the fingertips of patients, has started to become prevalent as a reliable fluid monitoring system for observing fluid response. It has been reported that PVI has similar value to SVV in indicating hypovolemia and fluid response.[9] It is used and acknowledged in cardiovascular surgery, abdominal surgery, orthopedic surgery, and organ transplantation.[9,10]

The aim of this study was to compare the total fluid volume performed by noninvasive PVI in thoracic surgery patients in comparison to conventional fluid management. Secondarily, their effects on hemodynamics, tissue oxygenation, and organ functions were compared.

PATIENTS AND METHODS

This prospective randomized controlled study included 80 patients (68 males, 12 females; mean age: 58.5±6.7 years; range, 18 to 65 years) who had risk scores of American Society of Anesthesiologists (ASA) I-III and were scheduled for elective thoracotomy between May 2019 and May 2020. The sample of the study excluded patients with heart failure, renal failure, peripheral vascular impairment, morbid obesity [body mass index (BMI) >35], or psychiatric disorders, those whose operative time exceeded 4 h, and those who required ≥3 units of blood transfusion. Initially, 87 patients were included in the study. While four patients were excluded from the sample as their operative times exceeded 4 h (two patients in both groups), three were excluded because they needed massive blood transfusion (two patients in Group C and one in Group P). The analyses were carried out on the data collected from 80 patients (Figure 1). Eighty sealed envelopes were prepared, and the envelopes for the excluded patients were reused.

Based on the fluid management procedures to be applied, the patients were divided into two groups, including the control group (Group C), in which a conventional fluid management regimen was applied, and the PVI group (Group P), in which a fluid management regimen based on PVI monitoring was applied. Random allocation was performed using the sealed envelope method. All patients who underwent routine preoperative examinations were administered premedication with midazolam at 0.15 mg/kg intramuscularly. For the patients who were brought to the operating room, the routine monitoring process

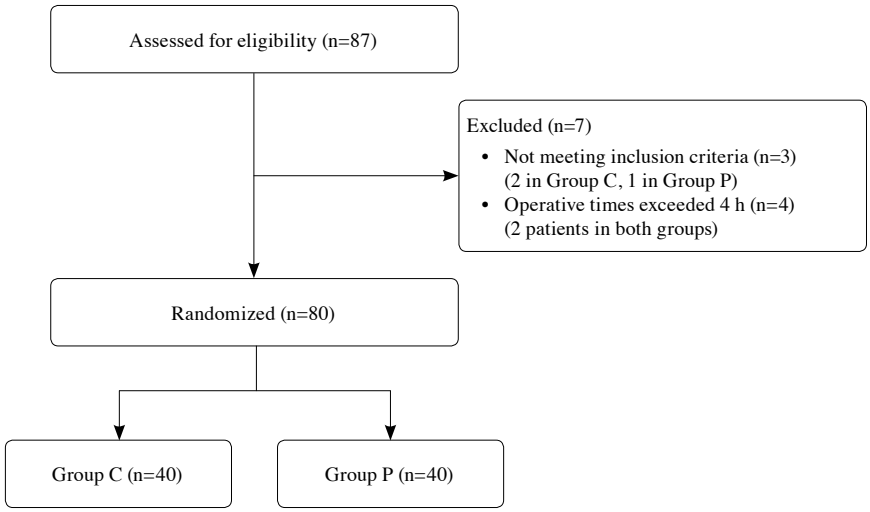

Figure 1. Patient disposition and selection of study cohort.

included an electrocardiogram, noninvasive arterial blood pressure, peripheral oxygen saturation (SpO_2) monitoring, nasopharyngeal temperature monitoring, and noninvasive PVI monitoring.

In anesthesia induction, all patients were administered intravenous 1 to 3 mg/kg of propofol, 1 to 2 µg/kg of fentanyl, and, for muscle relaxation, 0.6 mg/kg of rocuronium. Anesthesia maintenance for the patients, who were intubated and then ventilated with 8 mL/kg tidal volume, was performed by providing 50% oxygen (O_2), sevoflurane at 1-3%, and intravenous 0.15 µg/kg/h of remifentanil infusion. The patients, who were intubated using double-lumen tubes that were appropriate for their body size, were given the lateral decubitus position, and the surgery was started. The moment the patient was put into the lateral decubitus position was accepted as the starting time, and the first records in the measurements were taken at this moment. For invasive blood pressure monitoring and arterial blood gas analyses, radial artery catheterization was performed on all patients after anesthesia induction. A pulse oximeter probe was connected to the second digit of the hand of each patient (the hand without the arterial catheter), and the probe was covered so that the signals would not be affected by the ambient light. The pulse oximeter was connected to the Masimo Radical 7 monitor (Masimo SET; Masimo Corp., Irvine, CA, USA) equipped with PVI software version 7.0.3.3. The PVI values were measured and recorded after allowing the numbers on the monitor to reach constant values. After anesthesia induction in both groups, 0.9% saline fluid supplementation was started via infusion at a rate of 2 mL/kg/h. When single lung ventilation was started, tidal volume was reduced to 5 mL/kg, respiratory rate was increased, and 4 cmH_2O positive end-expiratory pressure was applied.

In Group C, additional fluids were supplied according to the conventional fluid management method using the 4-2-1 (4 mL/kg for the first 10 kg, 2 mL/kg for the second 10 kg, 1 mL/kg for the following stages) formula. The preoperative fasting duration of the patients was assumed to be approximately 8 h. The patients' fasting fluid loss volumes were calculated based on this assumption, and it was aimed to close this fluid deficit within approximately 3 h.

In Group P, the amount of fluid loss during fasting and the need for fluid supplementation were determined based on PVI values, and fluids were given as a bolus when needed. Accordingly, when PVI values over 14% persisted for 5 min, the patient was given an intravenous bolus of 250 mL 0.9% saline until PVI values decreased below 15%.

In cases of mean arterial pressure (MAP) values under 60 mmHg despite the supplementation of fluids based on the protocols determined for the two groups or when the MAP values of the patients fell more than 30% below their baseline values (5 min after midazolam), administering an intravenous bolus of 5 mg ephedrine was considered. It was planned to start intravenous dopamine infusion to reach the targeted MAP value in patients who would not respond adequately to the ephedrine bolus. The moment when the patients were given

the lateral decubitus position was accepted as the starting time, and their MAP, heart rate, SpO_2, arterial blood gas values (pH, pCO_2, pO_2, HCO_3, base excess, and SaO_2), and lactate values were recorded at the 60th min and the 120th min. All fluids and blood products given throughout the surgery, urinary output, operative time, and anesthesia time were noted. At the end of the surgery, intravenous analgesia was provided before extubating the patients, and the patients who were extubated were transferred to the intensive care unit. In the intensive care unit in the postoperative period, in the case of SpO_2 <93%, the patients were recorded and given 6 L/min O_2 using a simple facemask to achieve SpO_2 >96%. In cases of MAP values under 60 mmHg, it was planned to start dopamine infusion to reach the targeted MAP. The arterial blood gas values of all patients were measured at the first postoperative hour. Routine biochemistry values were checked 12 h after the operation. The SpO_2 values, mask oxygen requirements, and reintubation requirements of the patients were recorded throughout the postoperative 24-h period. Postoperative fluid management was carried out based on the protocol of the surgical clinic.

Statistical analysis

The sample size was determined by G*Power version 3.1.9.7 (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany). In the study conducted by Forget et al.,[9] they found the total amount of fluids in PVI and conventional method follow-ups as 2,394 (2,097-2,692) mL and 2,918 (2,478-3,358) mL, respectively (p=0.049). Since the aim of our study was to determine that there was no significant difference between the two methods in terms of the total amount of fluid, a total of 80 patients showed 95% confidence (1-α), 98% test power (1-β), and an effect size of 0.9417.

The data were analyzed blinded using IBM SPSS version 23.0 software (IBM Corp., Armonk, NY, USA). The results of the analyses were presented as mean ± standard deviation values for the quantitative data. Conformity to normal distribution was tested using the Kolmogorov-Smirnov test. The normally distributed data were compared between the two groups using independent-sample t-tests, while the nonnormally distributed data were compared using the Mann-Whitney U test. The intragroup comparisons of the data between two time points were made using paired-sample t-tests for the normally distributed data and the Wilcoxon test for the nonnormally distributed data. To compare three or more groups in the intragroup comparisons based on time, repeated-measures analysis of variance was used for the normally distributed data, whereas the Friedman test was used for the nonnormally

Table 1. Patients' general characteristics and intraoperative data

	Group C (n=40)		Group P (n=40)		
	n	Mean±SD	n	Mean±SD	*p*
Age (year)		59±12		57±14	0.183
Sex					0.080
Male	33		35		
Female	7		5		
Weight (kg)	75.50			76.03	0.112
ASA					
II	24		26		
III	11		10		
IV	5		4		
Body mass index (kg/m^2)		25±6		25±5	0.137
Operation time (min)		111±31		121±28	0.147
Anesthesia time (min)		135±33		147±33	0.127
Total fluid replacement (mL)		1327±406		1368±476	0.885
Total urine output (mL)		298±178		281±173	0.667

SD: Standard deviation; ASA: American Society of Anesthesiologists.

distributed data. The level of statistical significance was set at $p<0.05$.

RESULTS

There were no statistically significant differences between Groups C and P in terms of the demographic data of the patients, such as age, sex, weight, height, BMI, and the ASA scores or their operation types, operative times, and anesthesia times (Table 1). There was also no significant difference between the two groups in terms of their intraoperative fluid administration volumes, total urinary output, or amount of bleeding values (Table 1).

In the comparisons of hemodynamic parameters, the postoperative MAP values of Group P were significantly greater than those of Group C (78.3±9.8 and 72.3±9.8, respectively; $p<0.01$, Table 2). No significant difference was found in vasoactive drug use between groups. It was necessary to use ephedrine once in four patients in Group P and in six patients in Group C. Dopamine was not used in any patient. The postoperative SpO_2 values of Group P were also significantly higher than those of Group C (98.5±1.8 and 97.7±1.6, respectively; $p<0.01$, Table 2).

The postoperative lactate values of both groups were determined to be significantly increased in comparison to their preoperative values. In the intergroup comparisons, the postoperative lactate values in Group P were significantly lower than those in Group C (1.35±0.30 and 1.56±0.36, respectively; $p=0.023$, Table 3). Similarly, the postoperative creatinine values in Group P were significantly lower than those in Group C (0.77±0.14 and 0.84±0.28, respectively; $p=0.042$, Table 3).

Other parameters among the arterial blood gas values of the patients, their status of requiring mask oxygen support after extubation, and their status of requiring reintubation after extubation did not differ significantly between the groups. It was necessary to use mask oxygen support after extubation in two patients in Group P and in four patients in Group C. One

Table 2. Hemodynamics and respiratory function and PVI values at measurement times

	Group C (n=40)	Group P (n=40)	
	Mean±SD	Mean±SD	*p*
HR (beats/min)			
t=0 (lateral decubitus)	78.5±13.7	76.1±13.5	0.434
t=1 (60 min)	77.6±15.6	77.8±13.3	0.963
t=2 (120 min)	77.5±15.5	73.6±11.8	0.341
Postoperative	78.2±13.1	73.1±13.7	0.093
MAP (mmHg)			
t=0 (lateral decubitus)	82.2±12.8	77.0±13.0	0.078
t=1 (60 min)	74.1±11.3	73.7±10.5	0.871
t=2 (120 min)	70.8±8.8	72.3±9.8	0.594
Postoperative	72.3±9.8	78.3±9.8	<0.01*
SpO_2			
t=0 (lateral decubitus)	98.3±1.3	98.8±1.7	0.29
t=1 (60 min)	96.3±3.0	95.9±3.0	0.461
t=2 (120 min)	97.2±2.6	98.1±1.9	0.240
Postoperative	97.7±1.6	98.5±1.8	<0.01*
PVI			
t=0 (lateral decubitus)	13.68±6.54	11.83±5.39	0.216
t=1 (60 min)	14.68±6.15	11.96±4.82	0.092
t=2 (120 min)	13.85±6.54	11.56±4.82	0.152

PVI: Pleth Variability Index; SD: Standard deviation; HR: Heart rate; MAP: Mean arterial pressure; SpO_2: Peripheral oxygen saturation; * $p<0.01$.

Table 3. Comparison of lactate, blood urea nitrogen, and creatinine

	Group C (n=40)	Group P (n=40)	
	Mean±SD	Mean±SD	*p*
Lactate (mmol/L)			
t=0 (lateral decubitus)	0.93±0.38	0.94±0.34	0.713
t=1 (60 min)	0.96±0.35	0.98±0.28	0.664
Postoperative	1.56±0.36	1.35±0.30	0.023*
BUN (mg/dL)			
Preoperative	15.85±3.66	16.28±4.24	0.632
Postoperative	14.73±4.06	15.03±4.47	0.754
Creatinin (mg/dL)			
Preoperative	0.86±0.23	0.85±0.16	0.671
Postoperative	0.84±0.28	0.77±0.14	0.042*

BUN: Blood urea nitrogen; SD: Standard deviation; * $p<0.05$.

patient in Group C was reintubated after extubation. Acute kidney injury (AKI), acute lung injury, or other severe organ injury was not observed in any patient included in the study.

DISCUSSION

This study showed that in comparison to the conventional fluid management method, intraoperative fluid management performed via PVI monitoring provides better SpO_2, MAP, lactate, and creatinine. We speculate that PVI could ensure the necessary fluid treatment at the right time and dosage in thoracotomy and lung resection operations.

There are no sufficient studies on the use of hemodynamic measurement methods in thoracic surgeries where single lung ventilation is applied. These surgeries have some different features in terms of ventilation management. Measurement methods used to predict fluid responsiveness may be insufficient in these surgeries where single lung ventilation is performed, and significant changes occur in respiratory and hemodynamic parameters. Dynamic measurement methods such as SVV and PPV have some disadvantages in their use in thoracic surgeries. Patients must be ventilated with sufficient tidal volume (usually above 6-8 mL/kg) to show changes in preload in SVV and PPV measurements. Therefore, the effectiveness of SVV and PPV in regulating fluid therapy may decrease in surgeries in which single lung ventilation is applied and adjustments in tidal volume and respiratory rates are required.[11] It has also been reported that changes in heart rate/respiratory rate ratio may affect the prediction of fluid responsiveness.[12] The use of PVI, which is thought to be less affected by single lung ventilation than other methods, may be considered in thoracic surgeries. However, it has the disadvantages of being affected by some conditions, such as low perfusion pressure, sympathetic tone change, arrhythmia, and spontaneous breathing. Our study may shed light on future studies using PVI in thoracic surgeries. In general practice, PVI cutoff values between 10 and 15% are usually used. In a systematic review and meta-analysis on PVI, it was stated that the threshold value was 8 to 20%.[13] It has been emphasized that PVI should be interpreted according to patient and clinical condition characteristics, taking into account potential confounding external factors, such as vasoactive drug use, hypothermia, and low cardiac output.[14] In line with this information and our previous clinical practices with PVI, we used 14% as the threshold value.

In lung resections during thoracic surgeries, a restrictive fluid regimen is frequently preferred to prevent the pathological effects of excess fluid on the lungs. Møller et al.[15] examined the risk factors of postoperative complications in 107 patients who underwent elective pneumonectomy operations, and they observed severe arrhythmia, pulmonary complications, and cardiovascular complications in 31 patients. As one of the risk factors of postoperative complications, the authors stated intraoperative fluid administration volumes greater than 4,000 mL, and they reported that excess fluid load was the most significant factor in morbidity and mortality rates following pneumonectomy. Suehiro et al.[16]

investigated the causes of postoperative right heart failure in 65 patients who underwent pneumonectomy operations due to pulmonary malignancies and found that postoperative acute right heart failure developed in 51% of 33 patients whose intraoperative fluid balance exceeded 2,000 mL. The researchers concluded that a restrictive fluid management regimen could be an effective method of preventing postpneumonectomy pulmonary edema. In our study, the total volume of fluid given to each patient did not exceed 2,000 mL in both groups. However, arterial oxygen saturation, which is an indicator of tissue oxygenation, was higher in Group P in comparison to Group C. The higher level of oxygenation in the PVI group in the postoperative period may be a consequence of providing the appropriate volume of fluid to the patients at the appropriate time thanks to PVI monitoring and the prevention of potential lung injury that could develop as a result of excess fluid load.

One of the indicators of improved tissue oxygenation, along with fluid treatment performed at the right time and within optimal limits, is serum lactate. In the presence of hypoperfusion and insufficient tissue oxygenation, an increase occurs in serum lactate levels. In their randomized controlled study, Forget et al[9] divided 82 patients who underwent major abdominal surgeries into two groups based on MAP and central venous pressure values in different fluid management regimens: the control and PVI groups. While there was no significant difference in hemodynamic parameters, they found that more fluid was given to the patients in the control group, and these patients showed higher lactate levels. In our study, we assumed that as a result of the fluid treatment provided with the right timing in the postoperative period, higher MAP values were obtained in the PVI group. Sufficient blood pressure led to better perfusion in the tissues and facilitated a better metabolic status. As a consequence of better oxygenation and better tissue perfusion, the lactate levels in the PVI group were found to be lower.

The implementation of a restrictive fluid management regimen to prevent the potentially harmful effects of excess fluid on the lungs in thoracic surgeries substantially increases the risk of postoperative AKI. Acute kidney injury is one of the most feared complications in the usage of restrictive fluid management regimens for the fluid administration of patients undergoing critical surgeries.[17] Previous studies have also argued that synthetic colloids increase the risk of postoperative renal injury even further. In cases undergoing lung resections between 2006 and 2010, Ishikawa et al.[18] reported the prevalence of AKI development within the first 72 h in the postoperative period as 5.9% and concluded that using synthetic colloids increased this risk. Schmid et al.[19] found the incidence of AKI following major abdominal surgery to be 13.4% and determined that long-term and nonrenal complications also increased in patients who developed AKI. In a meta-analysis covering 28 studies, Egal et al.[20] determined that renal dysfunction was less prevalent in patients who were monitored by goal-directed therapy without regard to oliguria compared to those who were monitored by a conventional fluid management regimen focused on oliguria. In our study, fluid administration was performed using crystalloid fluids to lower the risk of renal failure, and colloid fluids were not used for fluid administration. In both groups, no patients showed signs of oliguria or AKI. Nevertheless, in the PVI group, postoperative creatinine values showed a significant decrease in comparison to the control group. We believe that the reason for the better renal function outcomes in the PVI group may be the higher values of blood pressure, which are independent predictors of AKI development, in the group and better renal perfusion due to these values. While the volumes of fluid provided to the patients in the two groups were similar, according to the protocol described in the methodology section of this study, the calculated loss in fluids through fasting was replaced continuously in a period extending to 3 h in the control group, and fluids were provided constantly at baseline rates. In the PVI group, on the other hand, since fluids were provided in bolus form to meet the fluid needs of the patient when their PVI values increased based on their hemodynamic status in addition to the main fluid regimen, the hemodynamic imbalance that was noticed was corrected right away, and better renal perfusion was provided. The effects of this close monitoring process and hemodynamic observations were positively reflected in renal parameters.

Serum lactate levels are one of the most sensitive methods that show organ and tissue perfusion. With this method, tissue perfusion can be assessed indirectly but sensitively. Lactate levels are correlated with intravascular volume sufficiency and tissue hypoxia. Lactate levels can be improved by optimizing fluid status and cardiac preload.[21] Therefore, these levels can be used as target values to evaluate the sufficiency and effectiveness of resuscitation. This is why lactate levels were also studied in our study. Bakker et al.[22] reported that perioperative blood lactate levels directly affected postoperative

complications and hospitalization times. Forget et al.[9] measured lactate levels to evaluate tissue perfusion in patients who underwent abdominal surgeries and determined significantly lower intraoperative and postoperative plasma lactate levels in the group in which goal-directed therapy was implemented by PVI monitoring. In their study conducted with patients who underwent high-risk surgeries, Lopes et al.[23] revealed significantly lower postoperative lactate levels in the group in which goal-directed therapy was provided. In our study, the serum lactate levels of both groups increased significantly from the preoperative to the postoperative measurements, but the postoperative lactate levels in the PVI group were lower than those in the control group. The increased lactate levels observed in both groups were an expected result associated with the surgical stress response of thoracotomy, which is a major surgery, and the effects of the administration of fluids that were provided. In the PVI group, we speculated that as a result of better MAP values, which were reflected in oxygen saturation values, lactate levels were found to be lower.

Patients who are scheduled for intermediate- and high-risk surgical procedures have a high risk of morbidity and mortality. Intraoperative fluid losses lead to an insufficient intravascular volume in these patients, and this situation causes inadequate tissue and organ perfusion associated with reduced stroke volume and cardiac output. If the appropriate interventions are not made, this situation can result in severe complications, prolonged hospital stays, and increased mortality rates. In their study where 2,250 patients were examined in terms of their postoperative complications, hospitalization durations, and costs, Boltz et al.[24] showed that at least one complication developed in 457 patients. They stated that increased complication rates significantly raised hospitalization times and patient costs. As observed in our study, although the total volumes of fluids given intraoperatively to the two groups were similar, better MAP, SpO_2, lactate, and creatinine levels were achieved in the PVI group. We attributed these results to the insufficiency of the volumes of fluids given to the control group within the first hour and the achievement of better tissue perfusion in the PVI group by providing bolus fluid administration at PVI values over 14%. As mentioned in the methodology section of our study, PVI monitoring was performed in both groups, but fluid administration was provided based on the measured PVI values only in the PVI group. The observation of intraoperative increases in PVI values in the control group may be accepted as an indicator of the importance of this method in terms of the real-time detection of intravascular volume administration needs of the patient and the implementation of the necessary interventions without delay.

There are some limitations to this study. Patients who underwent pneumonectomy are more sensitive in terms of fluid management. The study would have had more valuable results if it had been conducted only on patients who underwent pneumonectomy. The threshold value for PVI-based goal-directed therapy was taken as 14%; however, no assessment of sensitivity or specificity was made. In this study, there was no parameter or state variable that could determine the cutoff value. Although it was observed that better laboratory values were obtained by PVI monitoring, the effects of these values on clinical outcomes were not investigated. This is not definitive to conclude that PVI monitoring improves patients' morbidity and mortality, but it may be a good argument to plan a larger trial powered to detect clinical outcomes. Although SpO_2 is a measure of arterial oxygen saturation, it does not reflect actual tissue oxygenation measurements. Moreover, the fact that the statistical difference observed in SpO_2 values between the groups is not apparent in PaO_2 (arterial partial pressure of oxygen) values is another limitation of the study. Using methods such as rSO_2 (regional oxygen saturation) could have provided more accurate information in evaluating actual tissue oxygenation in this study. Therefore, it is a necessity to study the 30-day postoperative complications of patients, their durations of hospitalization, and mortality rates and obtain long-term results. These issues can be considered the aspects of our study that could be improved in future studies.

In conclusion, while the total volumes of fluids provided to the thoracic surgery patients in the two groups were similar, the fluid management regimen that was implemented based on noninvasive Pleth Variability Index monitoring provided better mean arterial pressure, oxygen saturation, lactate, and creatinine levels in the postoperative period. There is a need for studies on fluid management based on Pleth Variability Index monitoring in surgeries where intraoperative fluid balance is important, such as pneumonectomy.

Ethics Committee Approval: The study protocol was approved by the Karadeniz Technical University Scientific Research Ethics Committee (date: 20.05.2019, no: 2019/144). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: A written informed consent was obtained from each patient.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

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