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Adequacy of the Change in Diameter of the Inferior Vena Cava in Sonography Coupled with the Passive Leg Raise Maneuver in Estimating Intravascular Volume Prior to Performing Spinal Anesthesia

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ABSTRACT

Background: Spinal anesthesia is a commonly used technique in modern anesthetic practice and is frequently associated with hypotension, a complication that is more pronounced in patients with hypovolemia. Early identification of patients at risk for hypotension is essential in anesthetic management and may reduce anesthesia-related surgical complications. This study aimed to predict hypotensive events during surgery by evaluating the relationship between changes in the inferior vena cava (IVC) diameter following a passive leg raising (PLR) maneuver.

Methods: This observational cohort study was conducted on 100 patients undergoing surgery under spinal anesthesia. The diameter of the IVC was measured using ultrasonography before and after performing a PLR maneuver. Hemodynamic parameters, including heart rate, blood pressure, body temperature, and oxygen saturation, were recorded. In addition, the relationships between changes in IVC diameter and intraoperative fluid intake, bleeding, administration of sedative and vasopressor medications, and the occurrence of hypotension, hypertension, bradycardia, and tachycardia during the first 90 minutes of surgery were evaluated.

Results: The findings demonstrated a significant correlation between changes in the IVC diameter and systolic blood pressure, as well as with the incidence of hypotension and hypertension during surgery. The mean diameter of the IVC increased significantly following the PLR maneuver. The mean change in systolic blood pressure during surgery compared with the preoperative baseline was +14.80 mmHg. Correlation analysis revealed a significant association between changes in IVC diameter and systolic blood pressure ($p = 0.009$), as well as with the occurrence of hypotension and hypertension ($p = 0.001$ and $p = 0.004$, respectively).

Conclusion: This study provides evidence that changes in IVC diameter may serve as an indicator of alterations in systolic blood pressure and the occurrence of hypotension and hypertension during surgery under spinal anesthesia. Nevertheless, further studies are required to validate these findings and clarify their clinical implications. The results of this study suggest that assessment of IVC diameter changes may contribute to improved perioperative monitoring and patient management in procedures performed under spinal anesthesia.

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Introduction

Spinal anesthesia is a form of regional anesthesia induced by the intrathecal injection of a local anesthetic or opioid, allowing direct contact with the cerebrospinal fluid, and is commonly used for surgeries of the lower extremities and the abdomen [1-2]. It is considered an integral component of modern anesthetic practice because of its high success rate, predictable onset, increased patient satisfaction, relatively low complication rate, better pain control compared with intravenous opioids, earlier recovery of bowel function, reduced need for systemic narcotics, improved respiratory function due to better analgesia, and facilitation of participation in postoperative physical therapy [3-4].

Despite these advantages, spinal anesthesia is an invasive procedure and may be associated with a range of complications [5]. One of the most common complications is hypotension, which occurs primarily as a result of sympathetic nervous system inhibition induced by the spinal block. This inhibition leads to arterial and venous vasodilation and a relative state of hypovolemia [6]. Post-spinal anesthesia hypotension (PSAH) has been reported with an incidence ranging from 15.3% to 33% and may result in hypoperfusion of some organs and ischemic events. In addition, patient susceptibility to blood pressure reduction during surgery is influenced by preoperative intravascular volume status, which varies according to patient’s physical condition, comorbidities, preoperative medications, and the duration of preoperative fasting [7].

In critically ill patients who are at risk for organ failure, the administration of intravenous fluids may result in either benefit or harm; therefore, accurate assessment of intravascular volume status is a crucial step before any volume expansion. Excessive fluid resuscitation may contribute to endothelial injury, interstitial edema, and subsequent organ dysfunction, prolong the duration of mechanical ventilation, and increase the risk of developing intra-abdominal hypertension [8–10].

Numerous strategies have been proposed to prevent PSAH, including intravenous fluid preloading and the prophylactic use of vasopressors. Although studies have demonstrated that intravenous fluid administration can reduce the incidence of hypotension after spinal anesthesia and significantly decrease vasopressor requirements, empirical volume loading carries the risk of fluid overload, particularly in patients with underlying cardiac disease [6]. Conventional clinical parameters such as blood pressure and heart rate are commonly used to estimate intravascular volume; however, they do not provide an accurate or reliable assessment. Consequently, identifying predictors of PSAH is essential to avoid indiscriminate fluid administration and to reserve volume expansion for patients who are most likely to develop hypotension following spinal anesthesia.

Several methods have been investigated to predict PSAH, including variability of heart rate (HRV), the passive leg raising (PLR) maneuver, and the perfusion index. While some studies have reported that HRV has high sensitivity and specificity for predicting PSAH, other investigations have concluded that HRV is not a reliable predictor, as it can be influenced by multiple factors such as anxiety, ischemic heart disease, antihypertensive medications, diabetes mellitus, and spontaneous respiration [11-12].

The PLR maneuver has been shown to provide a reliable prediction of fluid responsiveness, even in patients with spontaneous breathing or cardiac arrhythmias [13]. It remains one of the most flexible and reversible techniques for assessing fluid requirements in patients admitted to the intensive care unit [14-15]. This maneuver transiently transfers approximately 200–300 mL of blood from the venous reservoir of the lower extremities to the central circulation [14]. The resulting increase in ventricular preload leads to an augmentation of stroke volume and, consequently, cardiac output, depending on the degree of preload reserve. Importantly, these hemodynamic effects are rapidly reversed once the legs are returned to the horizontal position. In a recent cohort study investigating fluid responsiveness, transthoracic Doppler echocardiography combined with the PLR maneuver was used, and the authors reported that volume expansion could be predicted by PLR-induced changes in stroke volume assessed by ultrasonography [16].

In 2019, Inna Jaremko and colleagues conducted a study involving 60 patients in which sonographic measurement of the inferior vena cava (IVC) diameter and the IVC collapsibility index (IVC-CI) were used as a non-invasive method to assess intravascular volume status. They concluded that the IVC-CI is a useful parameter for predicting severe blood pressure reduction following the induction of spinal anesthesia in spontaneously breathing patients undergoing knee arthroplasty [12]. Additionally, several studies have demonstrated that ultrasonography can be used to evaluate intravascular volume status and guide the need for fluid resuscitation [17–21].

Despite these advances, accurate assessment of intravascular volume status remains a clinical challenge. In the present study, to improve the evaluation of intravascular volume and to predict the need for fluid resuscitation, we performed a PLR maneuver combined with ultrasonographic assessment of the IVC diameter before and after the maneuver. The objective of this study was to determine whether changes in the IVC diameter measured by ultrasonography following PLR are sufficient for estimating intravascular volume status prior to the induction of spinal anesthesia.

Methods

This observational cohort study was conducted after obtaining ethical approval from the relevant institutional ethics committee (IR.MUI.REC.1402.318). The study included 100 patients, comprising 29 women and 71 men, selected from 156 patients who were assessed for eligibility (Figure 1). All participants had similar preoperative fasting (nil per os) durations and received comparable preoperative fluid therapy. On the day of surgery, baseline heart rate (HR), blood pressure (BP), body temperature (T), and oxygen saturation (SpO_2) were measured and recorded before the induction of spinal anesthesia.

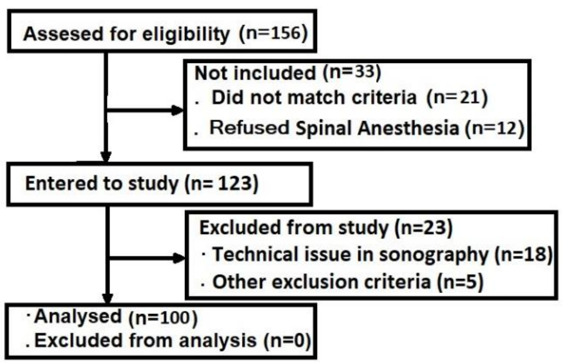

Figure 1- The flowchart of the study.

Ultrasonographic measurement of the inferior vena cava (IVC) diameter was performed using a low-frequency curvilinear probe (2–5 MHz) on a sonography device (Sonosite Edge II, Fujifilm Corporation, Bothell, Washington, USA) via a right subcostal approach [19].

The IVC was visualized in the longitudinal plane and assessed approximately 2 cm distal to the junction of the IVC and hepatic vein. Measurements of the IVC diameter were obtained from the inner wall to the inner wall.

IVC diameter measurements were first obtained with the patient in the supine position and then repeated after performing the passive leg raising (PLR) maneuver. For the PLR maneuver, both lower limbs were passively elevated to form a 30-degree angle with the trunk and maintained in this position for 30 seconds. The second IVC diameter measurement was performed at the end of the 30-second period while the legs remained elevated at a 30-degree angle relative to the body.

Following ultrasonographic assessment, spinal anesthesia was administered with the patient in the sitting position at the L3–L4, L4–L5, or L5–S1 intervertebral space using a 23-gauge spinal needle and bupivacaine at a dose of 10 to 15 mg. During the first 90 minutes of surgery, HR, BP, T, and SpO_2 were measured and recorded at 15-minute intervals. In addition, intraoperative fluid intake, estimated blood loss, administration of sedative medications (midazolam, fentanyl, ketamine, and propofol), and vasopressor agents (ephedrine and phenylephrine) were documented. Episodes of hypotension (defined as systolic blood pressure < 90 mmHg), hypertension (systolic blood pressure > 130 mmHg), bradycardia (heart rate < 60 beats per minute), and tachycardia (heart rate > 100 beats per minute) were recorded. Ephedrine and phenylephrine were administered to treat hypotension in incremental doses of 5 mg and 20 mg, respectively.

Results

A total of 156 patients were initially assessed for eligibility to participate in the study. Of these, 26 patients did not meet the inclusion criteria, and an additional 12 patients declined to undergo surgery under spinal anesthesia. Consequently, 123 patients were enrolled in the study. During the study period, 18 patients were excluded due to technical difficulties in performing ultrasonography and the inability to obtain an acceptable sonographic view of the inferior vena cava (IVC). Furthermore, 5 patients were excluded because of intraoperative bleeding, changes in the surgical plan, or the occurrence of pain during surgery (Figure 1).

The enrolled patients underwent four different categories of surgical procedures, including orthopedic surgery, general surgery, urological surgery, and obstetrics and gynecology surgery (Figure 2).

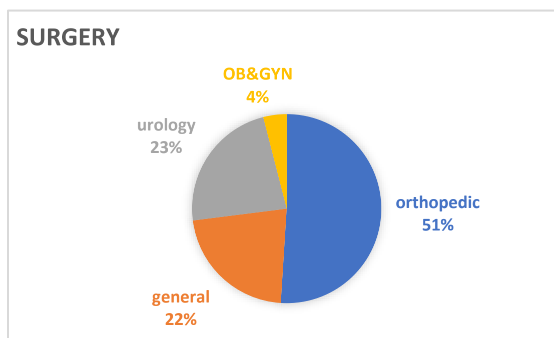

Figure 2- Distribution of surgeries among the studied patients

Statistical analyses were ultimately performed on the remaining 100 patients, of whom 29 were women and 71 were men. The mean age of the patients was 43.96 ± 16.85 years, with a minimum age of 19 years and a maximum age of 65 years.

The mean body weight was 72.46 kg, with a minimum of 48 kg and a maximum of 88 kg (Table 1). The mean diameter of the IVC before the passive leg raising (PLR) maneuver was 1.93 ± 0.29 mm, with a minimum value of 1.40 mm and a maximum value of 2.60 mm. After the PLR maneuver, the mean IVC diameter increased to

2.18 ± 0.35 mm, with a minimum of 1.3 mm and a maximum of 2.8 mm.

The intraoperative incidence of hypotension, hypertension, tachycardia, and bradycardia was 31.7%, 50%, 45.2%, and 12.5%, respectively (Table 2).

The mean systolic blood pressure (SBP) measured before the study was 132.46 ± 13.99 mmHg, whereas the mean SBP during the first 90 minutes of surgery was 117.65 ± 15.14 mmHg.

The minimum, maximum, and mean values of SBP before surgery and during the intraoperative period are presented in (Table 3). The mean change in systolic blood pressure (ΔSBP; SBP during surgery minus SBP before surgery) was +14.80 mmHg, with a minimum change of −27.5 mmHg and a maximum change of +57.25 mmHg. The mean change in IVC diameter following the PLR maneuver (ΔIVC; IVC diameter after PLR minus IVC diameter before PLR) was +0.247 ± 0.203. Correlation analysis demonstrated that the P value for the relationship between ΔIVC and mean SBP was 0.009, while the

P value for the correlation between ΔIVC and mean ΔSBP was 0.004. The P values obtained from correlation analyses evaluating the association between changes in IVC diameter and hypotension, hypertension, tachycardia, and bradycardia were 0.001, 0.004, 0.808, and 0.212, respectively. The results of correlation analysis comparing changes in IVC diameter with the volume of prescribed fluids, administered sedative medications, vasopressor use, maximum sensory block level, and intraoperative bleeding are summarized in (Table 4). The mean volume of fluids administered during the first 90 minutes of surgery was 1164.3 ± 488.8 mL. Linear regression analysis demonstrated that, for each one-unit increase in ΔIVC, the volume of fluid administered during surgery increased significantly by 519.693 mL after adjustment for potential confounding variables (Table 5).

Discussion

Spinal anesthesia is commonly associated with hypotension, and this adverse effect is exacerbated in the presence of hypovolemia [5–7]. Identifying patients who are susceptible to hypotension is a critical aspect of anesthetic practice and can contribute to the reduction of anesthesia- and surgery-related complications [9,10,22].

The present study was designed to evaluate the predictive ability of changes in the inferior vena cava (IVC) diameter following the passive leg raising (PLR) maneuver in predicting the incidence and severity of hypotension after spinal anesthesia.

Table 1- Mean, minimum, maximum, and standard deviation of age and weight within the studied patients.

	Minimum	Maximum	Mean	Std. Deviation
Age	19.00	65.00	43.9600	14.85004
Weight	48.00	88.00	72.4600	10.48753

Table 2- Frequency of incidence of hypotension, hypertension, tachycardia, and bradycardia during surgery in studied patients.

	Frequency (Percent)
Hypotension	33
Hypertension	52
Bradycardia	13
Tachycardia	47

Table 3- The minimum, maximum, and mean of SBP before and during surgery in the studied patients.

	Minimum	Maximum	Mean	Std. Deviation
Before anesthesia	95.00	160.00	132.4600	13.99814
After anesthesia	80.83	155.50	117.6535	15.14757
Delta	-27.50	57.25	14.8065	17.40119

Table 4- The results of correlation tests comparing changes in IVC diameter, prescribed fluids, sedatives, vasopressors, maximum level of sensory block, and bleeding in studied patients.

	Delta-IVC	
	Pearson Correlation (r)	P value
Fluid	0.225	0.024
Bleeding	0.074	0.467
Ephedrine	-0.079	0.436
Phenylephrine	0.108	0.284
Max. block level	-0.240	0.016

*. Correlation is significant at the 0.05 level (2-tailed). DeltaIVC = IVC diameter before maneuver - IVC diameter after maneuver.

Table 5- The results of a linear regression analysis. Each row corresponds to a different variable included in the model, showing the coefficient, the 95.0% confidence interval for the coefficient, and the associated P value.

	Coefficient	95.0% Confidence Interval		P value*
		Lower Bound	Upper Bound	
Delta IVC	519.693	19.929	1019.457	.042
Weight	-0.744	-10.103	8.615	.875
Mean of SBP	3.816	-2.216	9.847	.212
Kind of surgery	-206.237	-301.552	-110.922	.000

The findings demonstrated a significant correlation between PLR-induced changes in IVC diameter and changes in mean systolic blood pressure, as well as with the incidence of hypotension and hypertension after spinal anesthesia and the volume of fluids prescribed during surgery. According to the statistical analysis, for each one-unit increase in ΔIVC, the amount of fluid administered increased by 519.693 mL. This observation may be explained by an autotransfusion phenomenon resulting from the redistribution of venous blood from the lower extremities to the central circulation during leg elevation, which may be more pronounced in relatively hypovolemic patients.

These findings are consistent with those reported by Zhang and Critchley, who demonstrated that ultrasonographic assessment of IVC parameters can identify patients at risk of hypotension following anesthesia induction [23]. Similar observations have been reported in studies evaluating IVC diameter for assessing fluid overload and volume responsiveness in various clinical settings [18-19,21].

In the present study, no significant correlation was observed between changes in heart rate and changes in IVC diameter, suggesting that this parameter may be more useful for predicting blood pressure-related changes than heart rate alterations. Although the results support the potential utility of this non-invasive approach, further investigations are required to confirm these findings and to determine their broader clinical applicability.

Limitations

The study's limitations include its relatively small sample size and single-center design, which may restrict the generalizability of the findings. The operator-dependent nature of ultrasonographic IVC measurements may have introduced measurement variability.

Additionally, the observational study design, absence of randomization, potential uncontrolled confounding factors, and lack of long-term follow-up limit the applicability of the results and warrant further investigation in larger, multicenter studies.

Conclusion

The results of this study indicate that changes in inferior vena cava diameter following the passive leg raising maneuver are significantly associated with systolic blood pressure variations and the occurrence of hypotension after spinal anesthesia. Ultrasonographic assessment of IVC diameter, as a noninvasive method, may contribute to the estimation of intravascular volume status in patients undergoing spinal anesthesia.

These findings support the potential usefulness of this approach as an adjunct to perioperative hemodynamic assessment. Nevertheless, further studies are required to validate these observations and to clarify their applicability across different patient populations and clinical settings.

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