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Evaluating the Relationship between the Pleth Variability Index and Hypotension and Assessing the Fluid Response in Geriatric Hip Fracture under Spinal Anaesthesia: An Observational Study

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Abstract

Objective: We aimed to test the efficacy of the pre-operative Pleth variability index (PVI) in evaluating hypotension that developed after spinal anaesthesia in patients who were spontaneously breathing, pre-operatively hypovolemic, and were at an advanced age.

Methods: This observational study included 94 patients aged >65 years with hip fracture. Demographic data, pre-operative heart rate, non-invasive arterial pressures, PVI values, and haemogram values were continuously measured following spinal anaesthesia. The measurements with and without hypotension were distinguished and their data were compared.

Results: The mean age of the patients was 77.4±8.2 years. In total, 56.4% of the patients developed hypotension after spinal anaesthesia, and hypotension was higher in women ($p=0.037$). Low pre-operative diastolic arterial pressures values were associated with the development of hypotension ($p=0.037$). The relationship between PVI and post-spinal hypotension was negative but significant ($r=-0.239$; $p<0.05$). Depending on the volume loss, an increase in the PVI ($p<0.001$) and its subsequent significant decrease after treatment in patients with hypotension ($p<0.001$) was observed. The correlation between noninvasively measured haemoglobin values and the values obtained from arterial blood gas samples was significant ($p<0.001$).

Conclusion: This study showed that post-spinal hypotension may be associated with increased as well as decreased PVI values. However, these values cannot be clinically used for predicting pre-operative hypotension in hypovolemic patients.

Keywords: Advanced age, hypotension, pleth variability index, spinal anaesthesia

Introduction

The ability to predict hypotension after spinal anaesthesia, especially in elderly patients with a low cardiac reserve who cannot tolerate or are adversely affected by hypotension, will provide clinicians with a good opportunity to take preventative measures and thus reduce post-operative complications in these patients. Establishing the appropriate differential diagnosis of hypotension intraoperatively will also accurately direct the treatment approaches.

Correct fluid management of intraoperative targets is crucial in geriatric patient populations with high comorbidity. Central venous pressure (CVP), pulmonary artery occlusion pressure, and cardiac output measurement are static and invasive methods of fluid management. The current approach requires the use of dynamic and non-invasive methods (1-7). Recently, pulse oximetry plethysmographic wavelength amplitude variables have been used for indicating fluid response in the operating room and in the intensive care unit (6).

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It has been previously established that the degree of hypotension after spinal anaesthesia is affected by basal peripheral vasomotor tone, volume status, and sympathetic activity (8).

The perfusion index (PI) measured using pulse oximetry reflects the vasomotor tonus and is calculated using the ratio of pulsatile flow to non-pulsatile flow in the peripheral tissue (7). The pleth variability index (PVI) is an automatic measurement of dynamic changes in the PI, especially changes that are affected by respiration.

Numerous reports have revealed that PVI can be used as a dynamic parameter in targeted fluid therapy in patients on mechanical ventilation (1-7). Most studies have been conducted on patients undergoing mechanical ventilation, and studies conducted on spontaneously breathing patient groups provide very limited and insufficient data (9). Even though the effect of PVI in predicting hypotension following spinal anaesthesia in patients who gave birth by caesarean section has been studied in literature, neither the contradictory data on this subject nor its effectiveness in elderly patients with comorbidities have been studied, which is the source for our hypothesis (9).

This study aimed to investigate the ability of pre-operative PVI values in predicting post-operative hypotension in spontaneously breathing elderly patients with multiple comorbidities who underwent spinal anaesthesia due to hip fracture by comparing with values after spinal anaesthesia and to examine the effectiveness of intraoperative serial PVI measurements in these patient groups for evaluating the response to targeted fluid therapy.

Methods

This prospective observational study commenced after obtaining approval from Erzincan Binali Yıldırım University Clinical Trials Ethics Committee and written informed consent from patients or their relatives (20.07.2016). This study was supported by Erzincan Binali Yıldırım University Scientific Research Projects Coordination Unit (Project number: TSA-2016-402, Clinical Trials.gov ID: NCT02984956, Principal investigator: Ilke Kupeli, date of registration: 12.06.2016).

Data of 100 orthopaedic ASA I-II patients aged ≥65 years who were hypovolemic in the pre-operative period and underwent spinal anaesthesia within a 1-year period due to hip fracture were included in the study. A total of 94 patients completed the study since six patients underwent general anaesthesia. Patients who were undergoing mechanical ventilation under general anaesthesia, had contraindications to spinal anaesthesia, cardiac arrhythmia, diabetes mellitus, hypertension, drug use affecting the cardiovascular system, neurologic disorders, low left ventricular ejection fraction (<40%), and heart valve disease were excluded. Demographic data of all patients (age, sex, comorbidities) were recorded at the beginning of the study. In the operating room, the patients' heart rate (HR), non-invasive systolic arterial pressure (SAP) and diastolic arterial pressure (DAP), and peripheral oxygen saturation (SPO_2) were measured, and non-invasive PVI measurements (Masimo Radical-7; Masimo Corp., Irvine, CA, USA) were evaluated with PVI. Non-invasive haemoglobin sensors were applied and pre-operative values were recorded. After establishing vascular access and performing radial artery catheterisation procedures, the initial haemoglobin was recorded by measuring the initial arterial blood gas, after which sedation was administered with 0.015 mg kg^{-1} of midazolam (Dormicum 5 mg/5 mL; Deva, Turkey). Patients who underwent spinal anaesthesia with a dose of 15 mg of heavy bupivacaine (without opioids) after sedation (MARCAINE Spinal Heavy 0.5%; Astra Zeneca, Turkey) were operated upon, the surgical position was noted, and the time of the first incision was recorded.

The time point at which spinal anaesthetic drug injection was stopped was determined as 0 minutes, and HR, SPO_2, and SAP-DAP were recorded at 3-minute intervals, while the PVI, non-invasive haemoglobin values, and surgery times were continuously recorded. In addition, the fluid and blood transfusions administered to the patients were recorded. The patients were divided into two groups: those whose initial SAP values fell below 20% and those whose values did not, and PVI values of both groups were recorded. A ≥20% decrease in SAP from baseline was defined as hypotension. The aetiology of patients with hypotension was examined according to the time of occurrence of hypotension. The occurrence of pre-surgical hypotension was considered as hypotension being associated with sympathetic block followed by the necessary treatment (10 mg efedrin), whereas postsurgical hypotension was considered to have occurred due to volume deficit, which was followed by the necessary treatment [fluid bolus (500 mL colloid) or blood transfusion] based on non-invasive haemoglobin values and intraoperative arterial blood gas measurements.

After the operation, the patients were transferred to the post-anaesthesia care unit and sent to their respective departments after controlling the sympathetic block level.

The primary purpose of this study was to test the usefulness of pre-operative PVI in hypotension developing after spinal anaesthesia in spontaneously breathing elderly patients with comorbid hip fracture who underwent spinal anaesthesia. Our secondary purpose was to investigate its usability in distinguishing whether hypotension developed due to sympathetic block or volume deficit according to the time of occurrence, and to determine the adequacy of PVI values in response to treatment.

Statistical analysis

Power analysis was conducted using the Free Statistics Calculators version 4.0 software based on variations with ±10.6 standard deviation from baseline PVI (10), with the sample size to be studied in case the power of the study was 90%. An α-value of 0.05 was considered significant.

The results of the categorical variables were provided as numbers and percentages and those of the continuous variables were presented as mean±standard deviation, median, and minimum-maximum values. Categorical variables were compared between the groups using the Chi-square or Fisher exact tests, and normality of distribution for continuous variables was confirmed using the Kolmogorov-Smirnov test. Depending on whether the statistical hypotheses were fulfilled, the Student's *t*-test or Mann-Whitney U test was used for comparing independent continuous variables between the two groups. The paired sample *t*-test or the Wilcoxon signed rank test was similarly used for dependent continuous variables. Pre- and post-operative measurements or percentage of differences were used while comparing dependent groups. In graphical representations, the mean values of repeated measures were shown with respect to time. The Pearson correlation coefficient was used for evaluating the correlations between the measurements. The statistical level of significance for all tests was accepted at 0.05. Statistical analysis was performed using the IBM SPSS Statistics software, version 19 (IBM Software, Armonk, New York, NY, USA).

Results

Demographic data

A total of 94 patients (51 females and 43 males) were included in the study. The mean age of the patients was 77.4±8.2 years. Hypotension developed after spinal anaesthesia in 56.4% (n=53) of the patients. After spinal anaesthesia, PVI decreased in 87.2% of all cases and in 84.9% of hypotension cases, and there was no significant difference noted between PVI changes in those with and without hypotension. When the demographic data affecting hypotension were examined, it was found that hypotension developed significantly in women as compared to men (p=0.037), and there was no relationship between age and hypotension (p=0.165) (Table 1).

Intraoperative data

The SAP values in all patients without separating the groups are shown in Figure 1.

When examining the pre-operative HR, SAP, DAP, and PVI values that are used to predict hypotension, we found that pre-operative HR and SAP values were statistically insignificant, but low pre-operative DAP values were associated with the development of hypotension (p=0.037). Furthermore, we observed that pre-operative PVI values were higher in the group with developed hypotension but these values were not significant (p=0.187) (Table 2).

The relationship between PVI and post-spinal anaesthesia hypotension was negative but significant (r=−0.239; p<0.05).

When data on the use of PVI in the differential diagnosis of hypotension were examined, we found that hypotension developed due to sympathetic block in 53 patients during the intraoperative period, bleeding was seen in 22 patients, and fluid loss without bleeding was seen in 13 patients. While decreased PVI values were observed in hypotensive patients

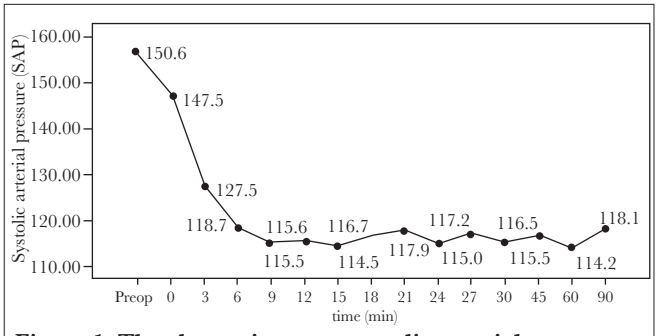

Figure 1. The change in mean systolic arterial pressure over time

Table 1. Demographic data of all patients

	Hypotension		
	Developed (n/%)	**Not developed (n/%)**	**p**
Patients (n)*	53 (56.4)	41 (43.6)	
Sex*			
Male	19 (44.2)	24 (55.8)	0.037
Female	34 (66.7)	17 (33.3)	
Age (years)*	78.4±8.5	76.0±7.8	0.165
Decline in PVI*			
Yes	45 (84.9)	37 (90.2)	
No	8 (15.1)	4 (9.8)	0.442

*Chi-Square Tests. PVI: pleth variability index

Table 2. Pre-operative hemodynamic indicators in patients with and without hypotension

		Preop HR (beats minute^{-1})		Preop SAP (mmHg)		Preop DAP (mmHg)		Preop PVI
		<70	>70	<140	>140	<90	>90	
Hypotension	Developed (%)	55.6	56.5	46.7	58.2	70.6	48.3	27.1
	Not developed (%)	44.4	43.5	53.3	41.8	29.4	51.7	24.8
p		0.958		0.571		0.037		0.187

Chi-Square Tests. Preop: pre-operative; HR: heart rate; SAP: systolic arterial pressure; DAP: diastolic arterial pressure; PVI: pleth variability index

Table 3. The change in PVI values with respect to the aetiology of hypotension and the response of PVI to the treatment using fluid/blood products

		Hypotension induced by sympathetic block	Hypotension induced by bleeding	Hypotension induced by fluid loss
PVI values±SD	Previous value	27.1±8.6	18.9±4.1	15.8±7.4
	Value at the moment of hypotension	23.7±8.9	23.5±3.7	20.1±6.1
p		0.813	<0.001	<0.001
	Value after the intervention		18.3±3.5	18.7±6.5
	p*		<0.001	<0.001

One-Sample Statistics p*: the difference between the value at the moment of hypotension and the value after the intervention. PVI: pleth variability index

Table 4. Predictors of PVI values

	F	Df	β	t	R^2
PVI-sympathetic**	17.9	93	-0.40	−4.24	0.16
PVI-fluid loss**	215.1	75	0.86	14.66	0.74
PVI-blood loss**	13.5	21	0.16	3.68	0.40
PVI-the amount of fluid replacement**	311.4	75	-0.89	−17.64	0.80
PVI-blood transfusion**	31.2	21	-0.78	−5.587	0.609

Multivariate and regression analysis. Dependent variable: PVI. **p<0.001. PVI: pleth variability index

Table 5. The relationship between arterial blood gas haemoglobin values and non-invasive haemoglobin values

	Pre-operative	During fluid loss	During blood loss
Haemoglobin	11.0±1.0	10.3±0.8	8.8±0.5
Arterial blood gas	12.2±1.1	11.3±0.7	10.1±0.5
R*	0.884**	0.928**	0.700**
p	<0.001	<0.001	<0.001

*R: Pearson Correlation **Correlation is significant at the level of 0.01 (2-tailed)

based on both sympathetic block and pre-operative hypovolemia, a significant increase was seen in PVI values in cases of hypotension induced by volume loss (p=0.001) (Table 3).

When examining the patients intraoperatively, PVI values in the group with hypotension induced by volume loss were observed to increase as compared to the previous measurements, whereas PVI values did not change or decrease according to fluid treatment in the group that did not develop hypotension. This change in mean PVI value was noted to be statistically significant (p=0.024).

Another objective of the present study was to assess the response of PVI values to fluid treatment and determine the adequacy of these values on fluid regulation therapy in these patient groups. Patients with hypotension induced by blood loss were treated with blood products and those with hypotension due to volume loss were treated with a crystalloid + colloid combination. A significant decrease in PVI values was obtained following the interventions (p=0.001) (Table 3).

Regarding the conditions affecting PVI without separating groups, it was found that blood pressure and PVI were inversely proportional in all patients. A total of 76 patients who had fluid loss but were not defined as hypotensive were found to

have a significantly increased PVI as their fluid loss increased. In these patients, the PVI decreased as the amount of fluid replacement increased. PVI changes were significant in patients with blood loss and transfusion (p=0.001) (Table 4).

A significant correlation was noted when comparing non-invasive haemoglobin and arterial blood gas haemoglobin in the pre-operative period and comparing the fluid and blood loss as well (p=0.001) (Table 5).

ROC analyses of PVI were used to evaluate its predictive ability for hypotension, and the results showed that the PVI had no predictive value in diagnosing hypotension. The area under the curve was 0.574 and p=0.221 for PVI>22 (sensitivity 66% and specificity 46.3%) pre-operatively.

Discussion

Development of hypotension after spinal anaesthesia can cause severe patient morbidity and mortality (11). Predicting hypotension prior to spinal anaesthesia is crucial to protect patients from associated adverse effects. Findings of the present study revealed that occurrence of hypotension was higher in patient groups with higher pre-operative PVI values, but this was not statistically significant. Sun and Huang (9) also reported that PVI values did not predict hypotension after spinal anaesthesia in patients who gave birth by caesarean section. In the study of Kuwata et al. (12), PVI after spinal anaesthesia was a good predictor of the effectiveness of the anaesthesia-induced hypotension in patients undergoing caesarean deliveries. Regardless of the pre-operative PVI values, it is good clinical practice to identify the correct blood volume level prior to spinal anaesthesia.

Age, HR, and SAP values were not noted to be effective in predicting hypotension. Furthermore, we found that the development of hypotension after spinal anaesthesia was more common in patients with low DAP. A study has shown that a decrease in DAP and an increase in pulse pressure are associated with low cardiac reserve (13). In this study, the tendency toward post-spinal hypotension due to the decrease in DAP was also attributed to this cardiac failure. Moreover, we determined that post-spinal hypotension was more common in females, which was associated with reaching higher sensorial levels at equivalent doses in women as compared to men. Therefore, we believe that lower doses should be used in female patients.

Pleth variability index is an automatic measurement of the dynamic change in PI that occurs during a complete respiratory cycle. PVI calculation measures changes in PI over a time interval that is sufficient to include ≥1 complete respiratory cycles and this was continuously displayed during the surgery in our study. An alteration in the local blood circulation under general anaesthesia alters the PVI (7, 10). In our study, we found that PVI decreased in 87.2% of all cases and in 84.9% of hypotension cases after spinal anaesthesia, and that there was no significant difference between PVI changes in those with and without hypotension. This occurred due to an increase in regional blood flow from the peripheral vasodilatation resulting from the sympathetic block in the lower part of the body after spinal anaesthesia.

Intraoperative hypotension is not only associated with sympathetic block after spinal anaesthesia but can also be caused by factors such as volume deficit and blood loss. Establishing a differential diagnosis of this condition will also guide treatment. In our study, a significant increase in PVI values was observed in hypotension patients due to volume deficit and blood loss. While a larger sample size is required to make this claim, we think that PVI can be used effectively for detecting volume deficit or blood loss quickly and for guiding treatment.

Targeted fluid therapy is crucial for reducing mortality and morbidity in elderly patients. In 2008, a study by Cannesson et al. (7) revealed that PVI was more effective than pulmonary capillary wedge pressure (PCWP) and CVP in assessing the fluid response in patients who were undergoing cardiac bypass. In a meta-analysis investigating six studies, the PVI values were 84% sensitive and 81% specific in evaluating the fluid response in patients on mechanical ventilation (14). However, these studies have always been conducted on hospitalised patients on mechanical ventilation, whether in the operating room or in the intensive care unit. Conversely, data on spontaneously breathing patients who underwent spinal anaesthesia are inadequate (15-18). In this study, PVI values responded significantly to fluid management in spontaneously breathing patients undergoing spinal anaesthesia. We believe that normal PVI values can be achieved by treatment with fluid or blood products in high PVI values and by a fluid restriction at low values. Thus, intraoperative targeted fluid therapy may be planned, specifically for patients with non-invasive data.

Hip fracture surgeries have the potential for severe bleeding and require serial haemogram follow-ups. Both invasive and non-invasive methods of arterial blood gas application are needed. In the present study, non-invasive haemogram values and arterial blood gas parameters were compared, and the results were found to be correlated. However, this correlation was observed to develop more slowly in non-invasive measurements in case of acute blood loss. Nevertheless, the PVI device can be seen as an important non-invasive tool for monitoring surgical blood loss.

The present study had several limitations. First, when the cut-off value of PVI was accepted as 14.8%, with 87.5% sensitivity and 84.8% specificity (19), we could see that our patients

were pre-operatively hypovolemic (pre-operative PVI=25.9). Due to this, the responses to the epidural and spinal anaesthesia may have been more exaggerated in hypovolemic patients than in normovolemic patients. Further studies are required for evaluating the effect of spinal anaesthesia in patients with and without hypovolaemia (inclusion criteria: normovolemia; exclusion criteria: hypovolemia). The second limitation is that the volume status of the patients was not compared with the CVP and PCWP values in the present study. Even though PVI values were shown to be used in fluid management in spontaneously breathing patients undergoing spinal anaesthesia, comparative studies with invasive static values such as CVP and PCWP are required.

Conclusion

This study shows that post-spinal hypotension may be associated with high or low PVI values, but these values cannot be clinically used for predicting hypotension in hypovolemic patients pre-operatively. However, we determined that PVI is safe and effective in predicting the occurrence of hypotension and evaluating both the intraoperative volume condition and the fluid response of the blood volume status. We showed that measurements maybe conducted with an accuracy similar to that of arterial blood gas measurements in an intraoperative haemogram follow-up and non-invasive surgical blood loss monitoring may be applicable in the future.

Ethics Committee Approval: Ethics committee approval was received for this study from the ethics committee of Erzincan Binali Yıldırım University Clinical Trials Ethics Committee (20.07.2016-5/08).

Informed Consent: Written informed consent was obtained from patients or their relatives who participated in this study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – İ.K., F.S., N.E.; Design – İ.K., F.S., N.E.; Supervision – İ.K., Y.K.A.; Resources – İ.K., F.S., N.E.; Materials – İ.K., F.S., N.E.; Data Collection and/or Processing – İ.K., F.S., N.E.; Analysis and/or Interpretation – İ.K., F.S., N.E., Y.K.A.; Literature Search – İ.K., F.S.; Writing Manuscript – İ.K., F.S.; Critical Review – İ.K., F.S., N.E., Y.K.A.

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References

1. Michard F, Teboul JL. Predicting fluid responsiveness in ICU patients: a critical analysis of the evidence. Chest 2002; 121: 2000-8. [CrossRef]
2. Marik PE, Baram M, Vahid B. Does central venous pressure predict fluid responsiveness? A systematic review of the literature and the tale of seven mares. Chest 2008; 134: 172-8. [CrossRef]
3. 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: 2642-7. [CrossRef]
4. Hofer CK, Muller SM, Furrer L, Klaghofer R, Genoni M, Zollinger A. Stroke volume and pulse pressure variation for prediction of fluid responsiveness in patients undergoing off-pump coronary artery bypass grafting. Chest 2005; 128: 848-54. [CrossRef]
5. Le Manach Y, Hofer CK, Lehot JJ, Vallet B, Goarin JP, Tavernier B, et al. Can changes in arterial pressure be used to detect changes in cardiac output during volume expansion in the perioperative period? Anesthesiology 2012; 117: 1165-74. [CrossRef]
6. Cannesson M, Attof Y, Rosamel P, Desebbe O, Joseph P, Metton O, et al. Respiratory variations in pulse oximetry plethysmographic waveform amplitude to predict fluid responsiveness in the operating room. Anesthesiology 2007; 106: 1105-11. [CrossRef]
7. Cannesson M, Desebbe O, Rosamel P, Delannoy B, Robin J, Bastien O, et al. Pleth variability index to monitor the respiratory variations in the pulse oximeter plethysmographic waveform amplitude and predict fluid responsiveness in the operating theatre. Br J Anaesth 2008; 101: 200-6. [CrossRef]
8. Toyama S, Kakumoto M, Morioka M, Matsuoka K, Omatsu H, Tagaito Y, et al. Perfusion index derived from a pulse oximeter can predict the incidence of hypotension during spinal anaesthesia for Caesarean delivery. Br J Anaesth 2013; 111: 235-41. [CrossRef]
9. Sun S, Huang SQ. Role of pleth variability index for predicting hypotension after spinal anesthesia for cesarean section. Int J Obstet Anesth 2014; 23: 324-9. [CrossRef]
10. Keller G, Cassar E, Desebbe O, Lehot JJ, Cannesson M. Ability of pleth variability index to detect hemodynamic changes induced by passive leg raising in spontaneously breathing volunteers. Crit Care 2008; 12: R37. [CrossRef]
11. Lee JE, George RB, Habib AS. Spinal-induced hypotension: Incidence, mechanisms, prophylaxis, and management: Summarizing 20 years of research. Best Pract Res Clin Anaesthesiol 2017; 31: 57-68. [CrossRef]
12. Kuwata S, Suehiro K, Juri T, Tsujimoto S, Mukai A, Tanaka K, et al. Pleth variability index can predict spinal anaesthesia-induced hypotension in patients undergoing caesarean delivery. Acta Anaesthesiologica Scandinavica 2018; 62: 75-84. [CrossRef]
13. Guichard JL, Desai RV, Ahmed MI, Mujib M, Fonarow GC, Feller MA, et al. Isolated diastolic hypotension and incident heart failure in older adults. Hypertension 2011; 58: 895-901. [CrossRef]
14. Yin JY, Ho KM. Use of plethysmographic variability index derived from the Massimo((R)) pulse oximeter to predict fluid or preload responsiveness: a systematic review and meta-analysis. Anaesthesia 2012; 67: 777-83. [CrossRef]
15. Haas S, Trepte C, Hinteregger M, Fahje R, Sill B, Herich L, et al. Prediction of volume responsiveness using pleth

variability index in patients undergoing cardiac surgery after cardiopulmonary bypass. J Anesth 2012; 26: 696-701. **[CrossRef]**

16. Hood JA, Wilson RJ. Pleth variability index to predict fluid responsiveness in colorectal surgery. Anesth Analg 2011; 113: 1058-63. **[CrossRef]**
17. Zimmermann M, Feibicke T, Keyl C, Prasser C, Moritz S, Graf BM, et al. Accuracy of stroke volume variation compared with pleth variability index to predict fluid responsiveness in mechanically ventilated patients undergoing major surgery. Eur J Anaesthesiol 2010; 27: 555-61. **[CrossRef]**
18. Forget P, Lois F, de Kock M. Goal-directed fluid management based on the pulse oximeter-derived pleth variability index reduces lactate levels and improves fluid management. Anesth Analg 2010; 111: 910-4. **[CrossRef]**
19. Lu N, Zheng R, Lin H, Yu J, Shao J, Wu X, et al. A prospective clinical study of pleth variability index in prediction of volume responsiveness in patients with septic shock. Zhonghua Wei Zhong Bing Ji Jiu Yi Xue 2015; 27: 17-21.