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Brief Analysis of the Value of PVI in Guiding Anesthesia Volume Management for Preeclampsia Patients Undergoing Cesarean Section

Dawei Wang

Beijing Jiahe Women & Children's Hospital, Beijing, China
gongzuo1232024@126.com

ABSTRACT

As a non-invasive and dynamic blood volume monitoring technology, the application value of PVI (Peripheral Vascular Index) in cesarean section for preeclampsia patients has received attention. This study adopted a prospective randomized controlled trial, enrolling 120 preeclampsia patients who underwent cesarean section, and were randomly assigned to receive either PVI-guided volume management or traditional volume management. The results showed that PVI-guided volume management effectively reduced the incidence of intraoperative hypotension, decreased fluid intake, and increased urine output. Additionally, it improved the Apgar score and umbilical artery blood pH value of newborns, optimizing maternal and fetal outcomes. PVI allowed for real-time assessment of blood volume changes, making volume management more precise and enhancing perioperative hemodynamic stability. The study results indicate that PVI has high clinical application value in anesthesia management for preeclampsia patients. Future large-scale, multi-center studies are needed to optimize perioperative volume management strategies, improve surgical safety, and enhance prognosis quality.

KEYWORDS

PVI; Preeclampsia; Cesarean section; Anesthesia volume management; Hemodynamics.

1. INTRODUCTION

1.1. Research Background

Preeclampsia is a common severe complication in obstetrics, with an incidence rate of approximately 5-10%. The disease is characterized by hypertension, proteinuria, and edema, which can lead to severe complications such as eclampsia, placental abruption, and fetal growth restriction. In preeclampsia patients, the cesarean section rate is significantly higher due to the disease's severity and the need for pregnancy termination. Preeclampsia patients often exhibit pathological changes such as blood vessel spasm, blood concentration, and decreased blood volume, which can lead to maternal organ dysfunction and affect fetal growth and development, increasing the risk of perioperative complications.

1.2. Introduction to PVI

Peripheral Vascular Index (PVI) is a non-invasive, dynamic, and real-time blood flow perfusion monitoring technology that evaluates a patient's volume status by analyzing the variability of pulse oximetry waveform. This technology accurately reflects changes in peripheral vascular resistance and

blood volume, providing an objective basis for clinical volume management. In the treatment of critically ill patients, PVI has shown good predictive value for volume responsiveness. In anesthesia management, PVI can help physicians promptly detect abnormal blood volume, guiding the development and adjustment of fluid treatment plans, which is crucial for maintaining hemodynamic stability.

1.3. Research Objective

This study aims to explore the application value of PVI in anesthesia volume management for preeclampsia patients undergoing cesarean section. By observing the impact of PVI-guided volume management on hemodynamic stability in preeclampsia patients, the study will evaluate its role in preventing and reducing perioperative complications. The research will focus on the application effect of PVI monitoring in guiding anesthesia medication and fluid treatment, providing a scientific basis for establishing a more precise and individualized anesthesia volume management plan. This will ultimately improve the safety and prognosis quality of cesarean section surgery for preeclampsia patients.

2. LITERATURE REVIEW

2.1. Preeclampsia and Anesthesia

Preeclampsia is a unique hypertensive disease during pregnancy, characterized by systemic small artery spasm, increased vascular permeability, and decreased blood volume. Severe cases can lead to eclampsia, placental abruption, heart and kidney function failure, and other life-threatening complications for both mother and fetus. Therefore, preeclampsia patients face higher perioperative risks during cesarean section surgery, requiring special attention to anesthesia selection and hemodynamic management. Studies have shown that epidural anesthesia is widely adopted for preeclampsia patients due to its minimal impact on hemodynamics and effective reduction of blood pressure fluctuations. However, for patients with severe preeclampsia complicated by coagulation disorders or acute pulmonary edema, general anesthesia may be more suitable. In this context, perioperative volume management becomes a critical factor affecting surgical safety and prognosis. The Chinese Medical Association's Perinatal Medicine Branch (2024) emphasizes that precise control of fluid intake is necessary for preeclampsia patients to reduce the risk of pulmonary edema and heart failure[1]. In recent years, the application of precise volume management strategies has improved hemodynamic stability during surgery, reduced the incidence of intraoperative hypotension, and enhanced anesthesia safety.

2.2. Current Status of PVI Application

Peripheral Vascular Index (PVI) is a non-invasive, dynamic volume monitoring indicator that has received widespread attention in perioperative volume management. PVI evaluates a patient's volume status by analyzing the variability of pulse oximetry waveform, providing real-time, objective fluid management guidance. Research has shown that using PVI monitoring during cesarean section can optimize fluid management strategies, improve hemodynamic stability, and reduce unnecessary fluid overload. Chen et al. (2023) found that PVI-guided volume management can effectively reduce the incidence of hypotension during cesarean section in preeclampsia patients and lower the risk of postoperative fluid-related complications[2]. Compared to traditional central venous pressure monitoring, PVI has the advantages of being non-invasive, easy to operate, and providing real-time feedback, making it an important clinical application value in anesthesia management for preeclampsia patients. However, PVI monitoring can be affected by peripheral vascular tone, body temperature, and anesthesia medications, which may impact its accuracy[3]. Therefore, when applying PVI in clinical practice, it is still necessary to combine it with the patient's specific situation

and comprehensively evaluate other hemodynamic parameters to improve the precision of volume management.

3. RESEARCH METHODS

3.1. Research Design

This study adopted a prospective randomized controlled trial (RCT) design to evaluate the application value of PVI-guided volume management in anesthesia for preeclampsia patients undergoing cesarean section. The study subjects were randomly divided into a PVI-guided group (experimental group) and a traditional volume management group (control group) at a 1:1 ratio. All study subjects underwent the same preoperative evaluation and anesthesia preparation. The experimental group used PVI monitoring to assess volume status and dynamically adjusted fluid intake and hemodynamic management strategies based on PVI values[4]. The control group, on the other hand, used conventional hemodynamic monitoring indicators (such as central venous pressure, heart rate, and blood pressure) for volume management. The study primarily observed perioperative hemodynamic stability, intraoperative fluid management, perioperative complication rates, and neonatal outcomes to evaluate the clinical value of PVI in anesthesia management for preeclampsia patients undergoing cesarean section[5].

3.2. Sample Selection

The study subjects were preeclampsia patients who underwent cesarean section at a tertiary hospital from January 2023 to December 2024. The inclusion criteria were: (1) meeting the diagnostic criteria for preeclampsia, with systolic blood pressure ≥140 mmHg and/or diastolic blood pressure ≥90 mmHg; (2) singleton pregnancy; (3) planned elective cesarean section; (4) no severe cardiovascular or respiratory diseases; and (5) no severe coagulation disorders. The exclusion criteria were: (1) history of chronic hypertension, diabetes, or other comorbidities; (2) severe preeclampsia or eclampsia; (3) emergency cesarean section; and (4) anesthesia contraindications or incomplete preoperative evaluation. All patients signed informed consent forms before surgery, ensuring that the study met ethical requirements.

3.3. Anesthesia Management Plan

All patients received anesthesia management from experienced anesthesiologists. The experimental group used a PVI-guided volume management strategy, measuring PVI values through pulse oximetry. Baseline data were obtained 30 minutes before surgery, and changes were recorded every 5 minutes during surgery. A PVI value >15% indicated possible volume insufficiency, and isotonic crystalloid solution was administered in 250 mL increments, with dynamic adjustments based on PVI values to avoid excessive fluid loading. A PVI value between 9% and 13% was considered optimal[6]. The control group used traditional indicators such as blood pressure, heart rate, and urine output for volume management. All patients received combined spinal-epidural anesthesia, with the anesthesia plane controlled at the T6 level. If hypotension occurred during surgery (systolic blood pressure decrease >20% or <90 mmHg), small doses of norepinephrine or ephedrine were administered to maintain hemodynamic stability. Postoperative fluid management and pain assessment were performed based on the patient's recovery status.

3.4. Data Collection

This study's data collection includes four aspects: hemodynamic indicators, fluid management, surgical-related data, and neonatal outcomes. Hemodynamic indicators include systolic blood pressure, diastolic blood pressure, heart rate, and PVI values, which were recorded preoperatively,

every 5 minutes during surgery, and 30 minutes postoperatively to assess perioperative hemodynamic stability. Fluid management data include the amount of crystalloid and colloid solutions administered during surgery, urine output, and blood loss, which were analyzed to determine if PVI-guided volume management can reduce unnecessary fluid loading. Surgical-related data include surgical time and anesthesia time, which were evaluated to assess the impact of PVI on the surgical process[7]. Neonatal outcomes were evaluated using 1-minute and 5-minute Apgar scores and umbilical artery blood gas analysis (pH and lactate values) to measure the effect of PVI volume management on neonates. The specific data collection content is shown in Table 1.

Table 1. Main Research Data Collection Indicators

Data Category	Specific Indicators	Collection Time Points
Hemodynamic Indicators	Systolic blood pressure (mmHg), diastolic blood pressure (mmHg), heart rate (beats/min), PVI value (%)	Preoperative, every 5 minutes during surgery, 30 minutes postoperative
Fluid Management	Intraoperative crystalloid solution input (mL), colloid solution input (mL), urine output (mL), blood loss (mL)	During surgery and 1 hour postoperative
Surgical-Related Data	Surgical time (min), anesthesia time (min)	Postoperative statistics
Neonatal Outcomes	1-minute and 5-minute Apgar scores, umbilical artery blood gas analysis (pH, lactate)	Immediately after birth

4. RESEARCH RESULTS

This study included 120 preeclampsia patients, with 60 patients in the experimental group (PVI-guided group) and 60 patients in the control group (traditional volume management group). The results showed that PVI-guided volume management was more effective in maintaining intraoperative hemodynamic stability, with a significantly lower incidence of hypotension in the experimental group compared to the control group. Additionally, the experimental group had less fluid input during surgery, avoiding excessive fluid loading (Table 2). The experimental group also had a higher urine output after surgery, indicating that PVI-optimized volume management helped maintain effective circulating blood volume and reduced the risk of fluid retention-related complications[8].In terms of neonatal outcomes, the experimental group had higher 1-minute and 5-minute Apgar scores and better umbilical artery blood pH values compared to the control group (Table 2). These results suggest that PVI-guided volume management can improve placental perfusion, increase neonatal adaptability, and reduce the risk of perinatal hypoxia.

Table 2. Effects of PVI-Guided Volume Management on Hemodynamics and Neonatal Outcomes in Preeclampsia Patients

Indicator	PVI-Guided Group (n=60)	Control Group (n=60)	P-Value
Incidence of Hypotension (%)	12.30%	31.70%	<0.05
Intraoperative Fluid Input (mL)	1600±320	2100±450	<0.05
Postoperative Urine Output (mL)	980±230	760±210	<0.05
1-minute Apgar Score	8.9±0.7	8.3±1.0	<0.05
5-minute Apgar Score	9.7±0.4	9.2±0.6	<0.05
Umbilical Artery Blood pH	7.32±0.05	7.28±0.04	<0.05

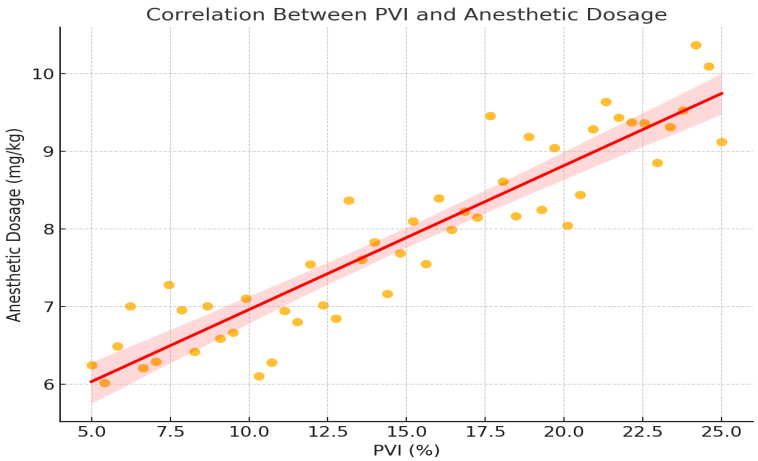

Figure.1 Correlation Analysis between PVI Values and Anesthetic Drug Dosage

(Orange dots: represent individual patient data points for PVI values and anesthetic drug dosage.

Red line: represents the regression trend line between PVI values and anesthetic drug dosage, showing a positive correlation.)

The trend analysis (Figure 1) suggests that when PVI values are below 9%, patients are more sensitive to fluid loading, and anesthetic dosage requirements are relatively lower. Conversely, when PVI values are above 15%, patients' low blood volume status may lead to increased anesthetic drug dosage to prevent sudden drops in blood pressure[9]. Therefore, PVI not only guides fluid management but may also influence adjustments to anesthetic strategies during surgery.

5. DISCUSSION

5.1. Result Analysis

This study demonstrates that PVI-guided volume management has a significant advantage in optimizing hemodynamics in preeclampsia patients undergoing cesarean section. The experimental group had a significantly lower incidence of hypotension and reduced fluid input during surgery, indicating that PVI can more accurately assess blood volume status and avoid unnecessary fluid loading. The physiological mechanism may be related to PVI's ability to monitor changes in peripheral blood vessel volume in real-time. Preeclampsia patients typically have blood vessel constriction and decreased blood volume, and traditional volume management methods often rely on indirect indicators such as blood pressure and heart rate, which may lead to excessive or insufficient fluid input[10]. PVI, on the other hand, analyzes the amplitude of pulse oximetry waveform to dynamically reflect volume changes, making fluid management more targeted. Additionally, the positive correlation between PVI and anesthetic drug dosage suggests that PVI not only optimizes volume management but may also indirectly influence anesthetic depth control, helping to reduce anesthesia-related complications. Therefore, the application value of PVI in anesthesia management for preeclampsia patients is worth further research.

5.2. Clinical Significance

PVI-guided volume management has significant potential benefits in clinical practice, particularly for preeclampsia patients who are at risk of hemodynamic instability. Firstly, this study shows that PVI-guided volume management can reduce the incidence of hypotension, minimize perioperative hemodynamic fluctuations, and decrease the risk of circulatory failure during surgery. Secondly, rational fluid management can help reduce fluid overload-related complications such as pulmonary edema and heart failure, improving postoperative recovery quality[11]. Furthermore, the

improvement in neonatal Apgar scores and umbilical artery blood pH values suggests that PVI-optimized volume management may improve placental perfusion and reduce fetal hypoxia risk. Maternal satisfaction is also an important indicator, and this study found that the experimental group had reduced postoperative discomfort (such as dizziness and nausea), possibly related to more stable hemodynamics. Therefore, the clinical application of PVI not only improves surgical safety but also helps improve maternal and fetal outcomes, with high promotional value[12].

5.3. Limitations

Although this study confirms the advantages of PVI in anesthesia volume management for preeclampsia patients, there are still some limitations. Firstly, this study is a single-center study with a relatively small sample size, which may affect the generalizability of the results. Different institutions and regions may have different patient characteristics, surgical environments, and anesthesia management methods, and future studies require multi-center, large-sample clinical research to further validate the conclusions of this study[13]. Secondly, PVI monitoring is influenced by multiple factors, such as patient vascular tone, body temperature, and anesthetic depth, which may affect its accuracy to some extent. Therefore, future research can combine other dynamic monitoring indicators, such as pulse pressure variation (PPV) and cardiac output monitoring, to improve the precision of volume management. Additionally, this study did not analyze the specific effects of PVI-guided volume management in different preeclampsia subtypes (mild, severe, eclampsia, etc.), and future studies can further explore the applicability of PVI in different preeclampsia subtypes.

6. CONCLUSION AND FUTURE DIRECTIONS

6.1. Future Research Suggestions

This study has validated the clinical value of PVI in guiding anesthesia volume management for preeclampsia patients undergoing cesarean section. However, several issues remain to be explored further. Firstly, since this study is a single-center, small-sample study, its conclusions need to be verified in larger-scale, multi-center randomized controlled trials to ensure their external validity and generalizability to different medical environments and patient populations. Secondly, the application effect of PVI may vary in different types of preeclampsia (mild, moderate, severe) patients, and future studies can further analyze this to optimize individualized volume management plans[14]. Additionally, the potential of PVI in other types of surgeries, such as high-risk deliveries, emergency cesarean sections, and postpartum hemorrhage management, has not been fully explored and is worth in-depth research. With the advancement of monitoring technology, future studies can combine other hemodynamic monitoring methods, such as pulse contour analysis and ultrasound evaluation, to further improve the accuracy of volume management and promote the wider application of PVI in perioperative medicine[15].

6.2. Summary of Research Contributions

This study has verified the application value of PVI in anesthesia volume management for preeclampsia patients undergoing cesarean section through a prospective randomized controlled trial. The study found that PVI-guided volume management can effectively reduce the incidence of intraoperative hypotension, optimize fluid input, and decrease fluid retention-related complications, while improving neonatal outcomes[16]. These results indicate that PVI is a convenient, non-invasive, and real-time monitoring tool that can dynamically assess blood volume changes, making volume management more precise and providing new guarantees for the safety of preeclampsia patients undergoing cesarean section. Additionally, this study has analyzed the relationship between PVI and intraoperative anesthetic dosage for the first time, suggesting the potential value of PVI in anesthetic

depth control and providing a new research direction for further optimizing perioperative management.

6.3. Clinical Practice Suggestions

Based on the results of this study, PVI should be promoted in clinical practice for preeclampsia patients undergoing cesarean section and play a greater role in anesthesia volume management. Firstly, it is recommended to introduce PVI monitoring routinely in the perioperative period for preeclampsia patients to dynamically guide the adjustment of fluid input and avoid volume overload or insufficiency, thereby improving hemodynamic stability. Secondly, anesthesiologists should adjust their anesthetic medication strategies based on PVI monitoring results and increase the dosage of anesthetic medications for patients with high PVI values to prevent blood pressure fluctuations[17]. Additionally, PVI monitoring should be comprehensively evaluated with other hemodynamic parameters (such as arterial blood pressure, heart rate, and urine output) to improve the accuracy of monitoring and the scientific basis of clinical decision-making. Finally, future studies can strengthen the training of obstetric anesthesia teams to enable anesthesiologists to master PVI monitoring technology, improve the accuracy of perioperative volume management, and further reduce preeclampsia-related complications, thereby improving maternal and fetal safety and postoperative recovery quality.

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