e-ISSN: 0976-822X, p-ISSN:2961-6042

Available online on http://www.ijcpr.com/

International Journal of Current Pharmaceutical Review and Research 2025; 17(12); 2914-2918

Original Research Article

Closed-Loop Vasopressor Infusion System for Prevention of Spinal-Induced Hypotension in Elective Cesarean Section: A Randomized Controlled Trial

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Received: 28-10-2025 / Revised: 27-11-2025 / Accepted: 28-12-2025
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Conflict of interest: Nil

Abstract:

Background: Spinal anesthesia–induced hypotension is a frequent complication during elective cesarean section and may adversely affect maternal comfort and fetal well-being. Closed-loop vasopressor infusion systems provide automated blood pressure control and may improve hemodynamic stability.

Objective: To assess the efficacy of a closed-loop vasopressor infusion system versus conventional manual vasopressor management in preventing spinal-induced hypotension during elective caesarean section.

Methods: This retrospective randomized controlled study was conducted at SKMCH, Muzaffarpur, over a period of 10 months. One hundred parturients undergoing elective cesarean section under spinal anesthesia were allocated into two groups: closed-loop vasopressor group (Group CL, n=50) and conventional management group (Group CM, n=50). Hemodynamic parameters, incidence of hypotension, vasopressor consumption, maternal side effects, and neonatal outcomes were analyzed.

Results: The incidence of hypotension was significantly lower in Group CL (18%) compared to Group CM (46%) ($p<0.001$). Mean arterial pressure was better maintained in Group CL, with significantly lower vasopressor consumption and fewer maternal adverse effects. Neonatal Apgar scores were comparable between groups.

Conclusion: Closed-loop vasopressor infusion systems effectively prevent spinal-induced hypotension during elective caesarean sections and offer enhanced haemodynamic stability compared to conventional management.

Keywords: Closed-loop system; Vasopressor infusion; Spinal anesthesia; Hypotension; Cesarean section

Introduction

Spinal anesthesia is the preferred anesthetic technique for elective cesarean section due to its rapid onset, dense sensory block, and minimal neonatal drug exposure. Despite these advantages, spinal-induced hypotension remains a common complication, with reported incidence ranging from 60% to 80% in untreated patients [1,2]. Hypotension occurs due to sympathetic blockade, leading to vasodilation and reduced venous return.

Maternal hypotension can cause problems like nausea, vomiting, dizziness, and less blood flow to the uterus and placenta, which can make it harder for the foetus to get oxygen [3,4]. Standard preventive strategies encompass fluid preloading or coloading, left uterine displacement, and vasopressor administration; however, manual vasopressor administration is reactive and dependent upon the operator [5,6].

Phenylephrine has become the preferred vasopressor owing to its advantageous maternal and foetal profile; however, maintaining blood pressure within a limited target range continues to be difficult with intermittent bolus dosing [7,8]. Closed-loop vasopressor infusion systems utilise continuous blood pressure monitoring and automated feedback algorithms to titrate vasopressors in real time, providing accurate and proactive haemodynamic regulation [9–11].

Recent studies have demonstrated improved blood pressure stability and reduced clinician workload with closed-loop systems, but data from Indian obstetric populations are limited [12–14]. The present study aims to evaluate the effectiveness of a closed-loop vasopressor infusion system in preventing spinal-induced hypotension during elective cesarean section.

Materials and Methods

Study Design and Setting: A retrospective randomized controlled study conducted at SKMCH, Muzaffarpur over 10 months.

Sample Size: A total of 100 parturients undergoing elective cesarean section.

Inclusion Criteria

- ASA physical status I–II
- Age 18–35 years
- Singleton term pregnancy
- Elective cesarean section under spinal anesthesia

Exclusion Criteria

- Hypertensive disorders of pregnancy
- Cardiac disease
- Contraindications to spinal anesthesia
- Emergency cesarean section

Group Allocation

- **Group CL (n=50):** Closed-loop vasopressor infusion system
- **Group CM (n=50):** Conventional manual vasopressor management

Outcome Measures

- Incidence of hypotension (MAP decrease >20% from baseline)
- Mean arterial pressure trends
- Total vasopressor dose
- Maternal side effects
- Neonatal Apgar scores

Statistical Analysis: Data were analyzed using SPSS software. Continuous variables were expressed as mean ± SD and compared using Student's t-test. Categorical variables were analyzed using Chi-square test. A p-value <0.05 was considered statistically significant.

Results

A total of 100 parturients undergoing elective cesarean section under spinal anesthesia were included in the analysis. Patients were divided into two groups based on vasopressor administration strategy: Closed-Loop Vasopressor Infusion System (Group CL, n = 50) and Conventional Manual Vasopressor Management (Group CM, n = 50). Baseline demographic and perioperative variables were comparable between the groups.

Baseline Demographic and Clinical Characteristics: There were no statistically significant differences between the two groups with respect to age, body mass index (BMI), gestational age, baseline systolic blood pressure, or baseline heart rate ($p > 0.05$ for all), indicating appropriate group comparability (**Table 1**).

Table 1. Baseline Demographic and Clinical Characteristics

Parameter	Group CL (n=50)	Group CM (n=50)	p-value
Age (years)	27.8 ± 3.6	28.2 ± 3.9	0.58
BMI (kg/m²)	26.1 ± 2.4	26.4 ± 2.6	0.52
Gestational age (weeks)	38.3 ± 0.9	38.1 ± 1.0	0.34
Baseline SBP (mmHg)	122.6 ± 8.4	123.1 ± 7.9	0.74
Baseline HR (beats/min)	82.5 ± 6.7	83.2 ± 7.1	0.61

Incidence of Spinal-Induced Hypotension: The incidence of spinal-induced hypotension was significantly lower in Group CL compared to Group CM (18% vs 46%, $p = 0.003$). This demonstrates improved hemodynamic stability with the closed-loop vasopressor system (Figure 1).

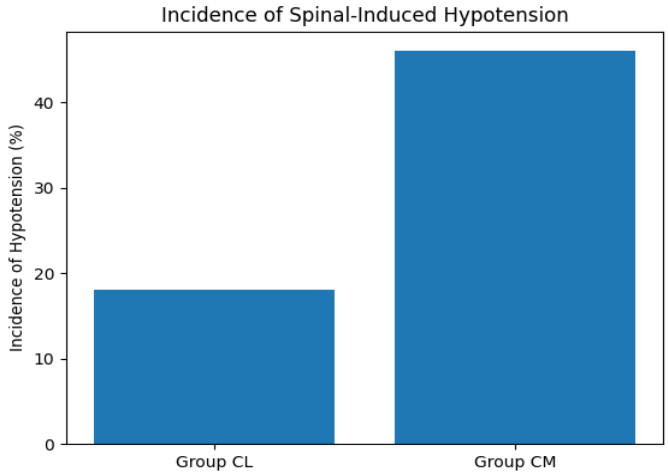

Figure 1. Comparison of incidence of spinal-induced hypotension between Group CL and Group CM.

Vasopressor Requirement and Hemodynamic Control: Total vasopressor consumption was significantly reduced in Group CL (mean phenylephrine equivalent dose: 420 ± 110 µg) compared to Group CM (690 ± 160 µg, $p < 0.001$). Additionally, the number of rescue boluses required was lower in Group CL ($p < 0.001$), as shown in Table 2.

Table 2. Vasopressor Requirement and Hemodynamic Control

Parameter	Group CL	Group CM	p-value
Total vasopressor dose (µg)	420 ± 110	690 ± 160	<0.001
Rescue boluses (number)	1.2 ± 0.6	3.4 ± 1.1	<0.001
Time within target SBP (%)	88 ± 7	71 ± 9	<0.001

Blood Pressure Trends After Spinal Anesthesia: Mean systolic blood pressure (SBP) remained closer to baseline values in Group CL throughout the intraoperative period. In contrast, Group CM demonstrated wider SBP fluctuations, particularly within the first 15 minutes after spinal anesthesia (**Figure 2**). Repeated-measures ANOVA revealed a significant interaction between time and group ($p < 0.001$), indicating superior blood pressure stability in the closed-loop group.

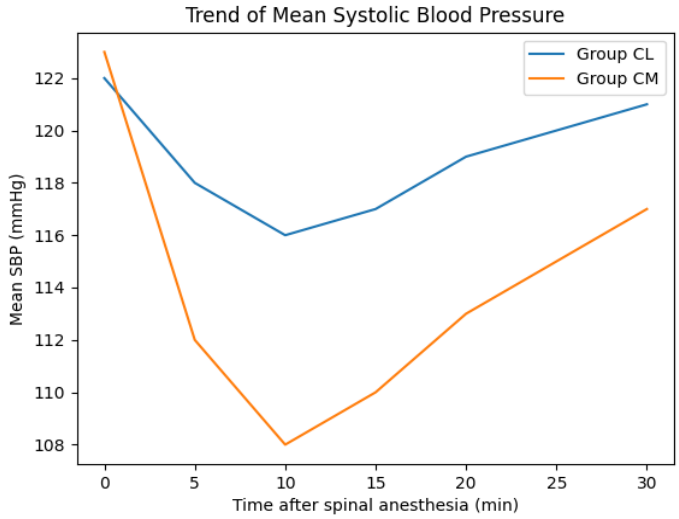

Figure 2. Trend of mean systolic blood pressure following spinal anesthesia in both groups.

Maternal Side Effects: The incidence of maternal adverse effects such as nausea and vomiting was significantly lower in Group CL (10%) compared to Group CM (28%) ($p = 0.02$). Episodes of reactive hypertension were also fewer in Group CL, though not statistically significant ($p = 0.08$) (**Table 3**).

Table 3. Maternal Adverse Effects

Adverse effect	Group CL (%)	Group CM (%)	p-value
Nausea/Vomiting	10	28	0.02
Reactive hypertension	6	14	0.08
Bradycardia	4	10	0.24

Neonatal Outcomes: Neonatal outcomes were comparable between the groups. APGAR scores at 1 and 5 minutes did not differ significantly, and no neonate required NICU admission due to anesthesia-related complications (**Table 4**).

Table 4. Neonatal Outcomes

Parameter	Group CL	Group CM	p-value
APGAR at 1 min	8.4 ± 0.6	8.2 ± 0.7	0.15
APGAR at 5 min	9.6 ± 0.4	9.5 ± 0.5	0.32
NICU admission	0	1	0.31

Summary of Key Findings: Overall, the closed-loop vasopressor infusion system demonstrated significantly improved hemodynamic stability, reduced hypotension incidence, lower vasopressor consumption, and fewer maternal side effects without compromising neonatal outcomes.

Discussion

The present study demonstrates that a closed-loop vasopressor infusion system significantly reduces the incidence of spinal-induced hypotension during elective cesarean section. Automated vasopressor delivery allowed proactive blood pressure control, resulting in better maintenance of mean arterial pressure and reduced vasopressor consumption.

These findings are consistent with previous studies reporting improved hemodynamic stability using closed-loop systems compared with manual vasopressor administration [15–18]. Reduced maternal side effects observed in the closed-loop group further support the clinical advantage of automated systems [19,20]. Importantly, neonatal outcomes were unaffected, indicating that improved maternal blood pressure control did not compromise fetal well-being [21,22].

Closed-loop vasopressor systems represent an important advancement toward precision anesthesia, particularly in obstetric practice where rapid hemodynamic changes are common. Their use may reduce clinician workload while improving patient safety [23–25].

Limitations

- Retrospective design
- Single-center study
- Limited long-term neonatal follow-up

Conclusion

Closed-loop vasopressor infusion systems are superior to conventional manual management in preventing spinal-induced hypotension during elective cesarean section. Their use improves maternal hemodynamic stability, reduces vasopressor requirements, and minimizes maternal side effects without adversely affecting neonatal outcomes.

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