



Factors Associated with Inadequate Spinal Anesthesia and Conversion to General Anesthesia During Elective Cesarean Delivery: A Retrospective Observational Study from Southwestern Iran

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Abstract

Background: Spinal anesthesia is the predominant anesthetic technique for elective cesarean delivery; however, inadequate spinal anesthesia remains a significant challenge in obstetric anesthesia. It may cause maternal pain and discomfort, delay surgery, and necessitate conversion to general anesthesia. Identifying perioperative risk factors may improve clinical decision-making and enhance maternal and neonatal safety.

Objectives: This study aimed to determine the incidence of inadequate spinal anesthesia and conversion to general anesthesia and to investigate the factors associated with these outcomes among women undergoing elective cesarean delivery.

Methods: In this retrospective observational study, the medical records of 370 pregnant women who underwent elective cesarean delivery in 2025 at hospitals affiliated with Abadan University of Medical Sciences were consecutively reviewed. Spinal anesthesia was used as the primary anesthetic technique in all patients. Demographic, obstetric, clinical, and anesthesia-related data were extracted from medical records, anesthesia charts, and surgical reports. Patients were categorized according to whether spinal anesthesia was successful or inadequate. Factors associated with inadequate spinal anesthesia were assessed using multivariable logistic regression, and odds ratios (ORs) with 95% confidence intervals (CIs) were calculated. The cumulative effect of three factors—body mass index (BMI), spinal anatomical abnormalities, and anesthesia duration ≥ 45 minutes—on anesthetic outcomes was also evaluated.

Results: Among the 370 patients, spinal anesthesia was successful in 310 (83.8%) and inadequate in 60 (16.2%). Spinal anatomical abnormalities were associated with higher odds of inadequate spinal anesthesia (adjusted OR = 3.1; 95% CI, 1.3 - 7.3; $P = 0.010$). Similarly, anesthesia duration ≥ 45 minutes was associated with higher odds of inadequate spinal anesthesia in the multivariable analysis (adjusted OR = 3.4; 95% CI, 1.8 - 6.4; $P < 0.001$). The use of an intrathecal adjuvant in combination with hyperbaric bupivacaine was associated with lower odds of inadequate spinal anesthesia (adjusted OR = 0.5; 95% CI, 0.3 - 0.9; $P = 0.021$). Among the 60 patients with inadequate spinal anesthesia, 21 (35.0%) were managed with intravenous supplemental medication, whereas 39 (65.0%) required conversion to general anesthesia. In the exploratory cumulative analysis, the rates of inadequate spinal anesthesia and conversion to general anesthesia increased with the number of prespecified factors, with conversion increasing from 2.8% among patients with no factors to 36.7% among those with ≥ 2 factors ($P < 0.001$).

Conclusions: Spinal anesthesia was successful in most elective cesarean deliveries, although 16.2% of patients experienced inadequate anesthesia and 10.5% required conversion to general anesthesia. Spinal anatomical abnormalities and anesthesia duration ≥ 45 minutes were associated with inadequate anesthesia. Exploratory analysis showed higher observed rates of inadequate anesthesia and conversion with increasing numbers of prespecified factors. These findings support careful perioperative assessment and preparedness for rescue interventions.

Keywords: Cesarean Section, Spinal Anesthesia, General Anesthesia, Anesthesia Failure, Risk Factors

1. Background

Cesarean section is one of the most common surgical procedures worldwide, and its rate has increased substantially over recent decades (1). When medically indicated, cesarean delivery can reduce maternal and neonatal morbidity and mortality; however, unnecessary

increases in its use may expose mothers and newborns to preventable risks and impose additional health care costs (2). Although a cesarean section rate of 10 - 15% was previously proposed as a population-level reference range, current approaches emphasize that cesarean delivery rates should not be determined by a fixed target. Instead, the decision should be based on clinical indications and medical necessity, taking maternal and fetal conditions

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into account (3). In Iran, the rate of cesarean delivery remains high and continues to increase. Studies using the Robson Classification have reported rates of 63.4% in selected centers affiliated with Shiraz University of Medical Sciences (4) and approximately 42% in Hamadan, with an increasing trend over previous years (5).

The choice of anesthetic technique is an important determinant of the safety and quality of cesarean delivery. Spinal anesthesia is widely used for elective cesarean sections because of its rapid onset, reliable sensory and motor blockade, ease of administration, and ability to provide satisfactory surgical conditions (6). Compared with general anesthesia, spinal anesthesia reduces neonatal exposure to anesthetic agents, lowers the risk of maternal airway complications and pulmonary aspiration, improves postoperative pain control, and facilitates early mother-infant contact (7).

Despite these advantages, spinal anesthesia may be inadequate or completely ineffective in some patients. Failure can result in intraoperative pain, maternal anxiety, reduced satisfaction, and the need for additional interventions, including intravenous administration of sedatives or analgesics, repeat spinal anesthesia, or conversion to general anesthesia (8). The reported failure rate varies considerably, ranging from 1% to 17%, potentially because of differences in failure definitions, patient characteristics, institutional conditions, and anesthesiologist experience (9).

Several patient-, procedure-, and provider-related factors may contribute to spinal anesthesia failure (10). These include elevated maternal body mass index (BMI) and obesity, a history of anesthesia, difficulty identifying or accessing the subarachnoid space, suboptimal positioning, traumatic or bloody cerebrospinal fluid, inadequate local anesthetic dosing, technical characteristics of the neuraxial procedure, and limited anesthesiologist experience (11, 12). Maternal obesity may be particularly important because anatomical changes, increased skin-to-subarachnoid-space distance, and difficulty identifying anatomical landmarks can make neuraxial procedures technically challenging and increase the risk of block failure (13). Psychological factors may also influence anesthetic preferences, as some women may prefer general anesthesia because of fear of spinal cord injury, concerns about being awake during surgery, or apprehension about seeing or hearing the procedure (14). Importantly, the success of spinal anesthesia is influenced not only by patient characteristics but also by surgical complexity, institutional resources and conditions, and the experience and technical proficiency of the anesthesia team (15).

Unintended conversion from spinal to general anesthesia during cesarean delivery is clinically important

(16). General anesthesia in pregnant women is associated with risks, including difficult airway management, aspiration of gastric contents, respiratory complications, intraoperative awareness, and increased neonatal exposure to anesthetic agents (17, 18). Furthermore, intravenous sedation or adjunctive medications used when neuraxial anesthesia is inadequate may affect the maternal experience, surgical conditions, and neonatal outcomes (19, 20).

Despite the clinical importance of this issue, studies conducted in Iran have predominantly focused on the choice of anesthetic technique, patients' attitudes, or the failure rate of spinal anesthesia. Limited information is available regarding the rate of conversion from spinal to general anesthesia or the need for intravenous sedation during elective cesarean delivery. Moreover, to date, no study in southwestern Iran has simultaneously investigated this conversion and its associated factors.

2. Objectives

The present study aimed to determine the incidence of inadequate spinal anesthesia and conversion to general anesthesia and to investigate factors associated with inadequate spinal anesthesia and anesthetic outcomes among women undergoing elective cesarean delivery in southwestern Iran in 2025.

3. Methods

3.1. Study Design and Participants

This retrospective observational study included pregnant women who underwent elective cesarean delivery in 2025 at hospitals affiliated with Abadan University of Medical Sciences. According to the prespecified research protocol, all eligible cases during the predefined 2025 study period were included using a census approach. Therefore, no a priori sample-size calculation was performed because all eligible cases within that period were to be included. A total of 370 medical records met the eligibility criteria, contained sufficient information on the study variables and primary outcome, and were included in the final analysis.

3.2. Eligibility Criteria

Eligible records were those of pregnant women who underwent elective cesarean delivery during the study period and received spinal anesthesia as the initial anesthetic technique. Records were included only if sufficient information was available on demographic characteristics, obstetric history, relevant clinical factors,

spinal anesthesia technique, and anesthesia-related outcomes.

Records of patients who received general anesthesia or another anesthetic technique as the initial anesthetic approach were excluded. Records lacking essential information required to determine the primary outcome were also excluded.

3.3. Data Collection and Study Variables

Data were extracted from medical records, anesthesia charts, and operative reports using a structured data collection checklist. The variables assessed included maternal age, gestational age, BMI, neonatal birth weight, previous surgical history, previous cesarean delivery, spinal anatomical abnormalities, surgical incision type, anesthesia duration, spinal anesthetic regimen, and use of intrathecal adjuvant medication.

Body mass index was categorized according to the prespecified protocol into 25 - 34.9, 35 - 39.9, and ≥ 40 kg/m². Anesthesia duration was similarly categorized as < 45 or ≥ 45 minutes; the 45-minute threshold was prespecified in the research protocol before data analysis. These predefined thresholds were used to facilitate clinically interpretable comparisons. The spinal anesthetic regimen was classified as hyperbaric bupivacaine alone or hyperbaric bupivacaine combined with fentanyl and/or morphine. Surgical incision type was categorized as Pfannenstiel or midline.

The primary outcome was the adequacy of spinal anesthesia. Spinal anesthesia was considered adequate when the surgical procedure was completed without the need for rescue anesthetic intervention. Spinal anesthesia was considered inadequate when additional rescue intervention was required because of an insufficient anesthetic effect.

For patients with inadequate spinal anesthesia, the cause of block inadequacy, timing of recognition, type of rescue intervention, and interval between spinal anesthesia administration and rescue intervention were recorded. Causes of inadequate anesthesia included an insufficient sensory block level, intraoperative pain or discomfort, and maternal anxiety or intolerance. The timing of recognition was categorized as before or after skin incision. Rescue interventions included intravenous pharmacological supplementation or conversion to general anesthesia.

For patients who required conversion to general anesthesia, the indication for conversion was recorded as inadequate anesthetic conditions for surgery, severe intraoperative pain, or maternal anxiety or intolerance.

3.4. Exploratory Cumulative Analysis

To explore the association between the number of prespecified perioperative factors and anesthetic outcomes, three factors were considered: BMI ≥ 40 kg/m², spinal anatomical abnormalities, and anesthesia duration ≥ 45 minutes. Patients were categorized into three groups according to the number of factors present: 0, 1, or ≥ 2 factors. The associations between the number of factors and inadequate spinal anesthesia and conversion to general anesthesia were evaluated.

3.5. Statistical Analysis

Statistical analyses were performed using SPSS version 22. The normality of continuous variables was assessed using the Shapiro-Wilk test. Continuous variables were summarized as mean $\pm$ standard deviation, and categorical variables were presented as frequencies and percentages. Between-group comparisons were performed using the independent-samples t-test or Mann-Whitney U test for continuous variables, as appropriate, and the chi-square test or Fisher's exact test for categorical variables.

Univariable logistic regression analyses were initially performed to examine the associations between candidate variables and inadequate spinal anesthesia. Based on the prespecified analytical approach and clinical relevance, six variables were included in the multivariable logistic regression model: BMI ≥ 40 kg/m², previous cesarean delivery, spinal anatomical abnormalities, midline incision, anesthesia duration ≥ 45 minutes, and use of an intrathecal adjuvant. Odds ratios (ORs) with 95% confidence intervals (CIs) were reported.

The multivariable model was based on 60 outcome events (inadequate spinal anesthesia) and included six variables, corresponding to 10 outcome events per variable. This events-per-variable ratio provided the regression-based rationale for fitting the proposed model. Given the relatively limited number of outcome events, the estimated associations were interpreted with appropriate caution.

The number of prespecified risk factors was also evaluated in relation to inadequate spinal anesthesia and conversion to general anesthesia. Because this cumulative analysis was developed and evaluated in the same dataset without external or internal validation, it was considered exploratory. All statistical tests were two-sided, and $P < 0.05$ was considered statistically significant.

3.6. Ethical Considerations

The study was conducted after approval by the Ethics Committee of Abadan University of Medical Sciences (IR.ABADANUMS.REC.1404.062). Permission to access patient records was obtained from the authorities of the participating hospitals. Given the retrospective nature of the study and the use of existing medical record data, the requirement for informed consent was waived. Patient confidentiality was maintained throughout all stages of the study, and no identifying information was recorded in the study database or disclosed in the final report.

4. Results

A total of 370 pregnant women undergoing elective cesarean delivery under spinal anesthesia were included. Spinal anesthesia was successful in 310 patients (83.8%), whereas 60 patients (16.2%) experienced inadequate anesthesia. The mean gestational age was 38.2 ± 1.2 weeks, with no significant difference between the successful and inadequate groups (38.1 ± 1.2 versus 38.4 ± 1.1 weeks; $P = 0.060$). Maternal age distribution was also comparable between groups ($P = 0.423$), with women aged 25 - 34 years representing the largest age category.

The distribution of BMI showed a borderline difference between groups ($P = 0.054$). Severe obesity ($\text{BMI} \geq 40 \text{ kg/m}^2$) was more frequent among patients with inadequate spinal anesthesia (18.3% versus 9.7%), whereas a BMI of 25 - 34.9 kg/m^2 was more common in the successful group (61.3% versus 46.7%). Neonatal birth weight distribution did not differ significantly between groups ($P = 0.314$), with normal birth weight (2,500 - 3,999 g) being the predominant category in both groups. Similarly, a history of previous cesarean delivery ($P = 0.886$) and previous surgery ($P = 0.400$) were not significantly associated with spinal anesthesia outcome.

Spinal anatomical abnormalities were significantly more prevalent in the inadequate anesthesia group than in the successful group (18.3% versus 6.1%; $P = 0.004$). Surgical incision type was not significantly associated with anesthesia outcome ($P = 0.060$). In contrast, anesthesia duration was significantly associated with inadequate spinal anesthesia ($P < 0.001$); anesthesia duration was ≥ 45 minutes in 38.3% of patients with inadequate anesthesia compared with 14.2% of those with successful anesthesia. The anesthetic regimen also differed significantly between groups ($P = 0.007$), with intrathecal adjuvants (fentanyl and/or morphine) used more frequently in the successful group (61.3% versus 41.7%). Full details of the demographic, obstetric, clinical, and anesthesia-related characteristics of the study population are presented in [Table 1](#).

Among the 60 patients with inadequate spinal anesthesia, 21 (35.0%) were managed with intravenous

pharmacological supplementation, whereas 39 (65.0%) required conversion to general anesthesia. The most common cause of inadequate spinal anesthesia was failure to achieve an adequate sensory level, observed in 51 patients (85.0%); this occurred in 16 patients (76.2%) in the intravenous supplementation group and 35 patients (89.7%) in the general anesthesia conversion group. Intraoperative pain or discomfort and maternal anxiety or intolerance were observed in 30 patients (50.0%) and 18 patients (30.0%), respectively. The distribution of the causes of inadequate spinal anesthesia did not differ significantly between the two groups ($P = 0.412$).

Inadequate spinal anesthesia was identified before skin incision in 42 patients (70.0%), and the timing of recognition did not differ significantly between the two groups ($P = 0.684$). Among patients who received intravenous supplementation, fentanyl was the most commonly used rescue medication, administered in 14 patients (66.7%), followed by midazolam in 5 patients (23.8%) and other analgesic medications in 2 patients (9.5%). In the general anesthesia conversion group, the most common indication for conversion was inadequate surgical anesthesia, observed in 21 patients (53.8%). Severe intraoperative pain was reported in 11 patients (28.2%), while maternal intolerance or anxiety accounted for 7 cases (17.9%) of conversion to general anesthesia.

The mean interval from spinal anesthesia administration to the supplemental intervention was 23.1 ± 9.4 minutes in the intravenous supplementation group and 25.6 ± 9.8 minutes in the general anesthesia conversion group, with no statistically significant difference between groups ($P = 0.337$). Full details are presented in [Table 2](#).

In the logistic regression analysis, $\text{BMI} \geq 40 \text{ kg/m}^2$ was associated with increased odds of inadequate spinal anesthesia; however, this association did not reach statistical significance ($\text{OR} = 2.10$, 95% CI, 0.99 - 4.46; $P = 0.054$). Spinal anatomical abnormalities were significantly associated with a higher likelihood of inadequate anesthesia ($\text{OR} = 3.44$, 95% CI, 1.54 - 7.67; $P = 0.004$), and this association remained statistically significant after adjustment for potential confounders (adjusted $\text{OR} = 3.1$, 95% CI, 1.3 - 7.3; $P = 0.010$). Anesthesia duration ≥ 45 minutes was also significantly associated with an increased likelihood of inadequate spinal anesthesia ($\text{OR} = 3.76$, 95% CI, 2.04 - 6.92; $P < 0.001$), with a significant association persisting in the adjusted model (adjusted $\text{OR} = 3.4$, 95% CI, 1.8 - 6.4; $P < 0.001$). In contrast, a history of previous cesarean delivery was not significantly associated with inadequate spinal anesthesia. The use of hyperbaric bupivacaine in combination with an intrathecal adjuvant was associated with lower odds of inadequate anesthesia ($\text{OR} = 0.45$, 95% CI, 0.26 - 0.79; $P = 0.007$). A midline surgical

Table 1. Baseline Demographic, Obstetric, Clinical, and Anesthesia-Related Characteristics According to Spinal Anesthesia Outcome ^a

Variables	Successful Spinal Anesthesia (n = 310)	Inadequate Spinal Anesthesia (n = 60)	Total (n = 370)	P-Value *
Gestational age (wk)	38.1 ± 1.2	38.4 ± 1.1	38.2 ± 1.2	0.060
Maternal age group (y)				0.423
< 25	51 (16.5)	14 (23.3)	65 (17.6)	
25 - 34	202 (65.2)	35 (58.3)	237 (64.1)	
≥ 35	57 (18.4)	11 (18.3)	68 (18.4)	
Body mass index (BMI), kg/m²				0.054
25 - 34.9	190 (61.3)	28 (46.7)	218 (58.9)	
35 - 39.9	90 (29.0)	21 (35.0)	111 (30.0)	
≥ 40	30 (9.7)	11 (18.3)	41 (11.1)	
Birth weight category (g)				0.314
< 2500 (Low birth weight)	16 (5.2)	2 (3.3)	18 (4.9)	
2500 - 3999 (Normal birth weight)	254 (81.9)	46 (76.7)	300 (81.1)	
≥ 4000 (Macrosomia)	40 (12.9)	12 (20.0)	52 (14.1)	
Previous surgery history				0.400
No	236 (76.1)	42 (70.0)	278 (75.1)	
Yes	74 (23.9)	18 (30.0)	92 (24.9)	
Previous cesarean section				0.886
No	125 (40.3)	23 (38.3)	148 (40.0)	
Yes	185 (59.7)	37 (61.7)	222 (60.0)	
Spinal anatomical abnormalities				0.004
No	291 (93.9)	49 (81.7)	340 (91.9)	
Yes	19 (6.1)	11 (18.3)	30 (8.1)	
Type of surgical incision				0.060
Pfannenstiel	289 (93.2)	51 (85.0)	340 (91.9)	
Midline	21 (6.8)	9 (15.0)	30 (8.1)	
Duration of anesthesia (min)				< 0.001
< 45	266 (85.8)	37 (61.7)	303 (81.9)	
≥ 45	44 (14.2)	23 (38.3)	67 (18.1)	
Spinal anesthetic medication				0.007
Hyperbaric bupivacaine alone	120 (38.7)	35 (58.3)	155 (41.9)	
Hyperbaric bupivacaine + intrathecal adjuvant (fentanyl/morphine)	190 (61.3)	25 (41.7)	215 (58.1)	

^a Values are expressed as mean ± SD or No. (%).

incision was also significantly associated with increased odds of inadequate spinal anesthesia in the unadjusted analysis (OR = 2.43, 95% CI, 1.05 - 5.60; P = 0.037); however, this association was no longer statistically significant after adjustment for potential confounders (adjusted OR = 2.1, 95% CI, 0.9 - 5.1; P = 0.094). Full details are presented in [Table 3](#).

To explore the association between the number of prespecified factors and anesthetic outcomes, patients were categorized according to the number of the following factors present: BMI ≥ 40 kg/m², spinal anatomical abnormalities, and anesthesia duration ≥ 45 minutes. Among the 370 patients, 180 (48.6%) had no factors, 130 (35.1%) had one factor, and 60 (16.2%) had two or more

factors. The proportion of patients with inadequate spinal anesthesia increased across these groups (6.7%, 14.6%, and 48.3%, respectively; P < 0.001). Similarly, the proportion requiring conversion to general anesthesia increased from 2.8% among patients with no factors to 9.2% among those with one factor and 36.7% among those with two or more factors (P < 0.001). These findings represent exploratory associations within the study dataset ([Table 4](#)).

5. Discussion

In the present study, inadequate spinal anesthesia occurred in 16.2% of patients after the initial spinal anesthetic attempt, and 10.5% of all patients required

Table 2. Characteristics, Rescue Interventions, and Outcomes of Patients with Inadequate Spinal Anesthesia ^a

Variables	Total Inadequate Spinal Anesthesia (n = 60)	Rescue Intravenous Supplementation (n = 21)	Conversion to General Anesthesia (n = 39)	P-Value
Reason for inadequate spinal anesthesia *				0.412
Insufficient sensory block level	51 (85.0)	16 (76.2)	35 (89.7)	
Intraoperative pain/discomfort	30 (50.0)	7 (33.3)	23 (59.0)	
Maternal anxiety/intolerance	18 (30.0)	5 (23.8)	13 (33.3)	
Time to recognition of inadequate block				0.684
Before skin incision	42 (70.0)	16 (76.2)	26 (66.7)	
After skin incision	18 (30.0)	5 (23.8)	13 (33.3)	
Intravenous rescue supplementation †				—
Fentanyl	14 (66.7)	14 (66.7)	—	
Midazolam	5 (23.8)	5 (23.8)	—	
Other analgesic agents	2 (9.5)	2 (9.5)	—	
Reason for conversion to general anesthesia				—
Inadequate surgical anesthesia	21 (53.8)	—	21 (53.8)	
Severe intraoperative pain	11 (28.2)	—	11 (28.2)	
Maternal intolerance/anxiety	7 (17.9)	—	7 (17.9)	
Time from spinal anesthesia to additional intervention (min)	—	23.1 ± 9.4	25.6 ± 9.8	0.337

^a Values are expressed as mean ± SD or No. (%).

Table 3. Univariable and Multivariable Logistic Regression Analyses of Factors Associated with Inadequate Spinal Anesthesia

Variables	Unadjusted Odds Ratio (95% Confidence Interval)	P-Value	Adjusted Odds Ratio (95% Confidence Interval)	P-Value
Body mass index ≥ 40 kg/m ²	2.10 (0.99 - 4.46)	0.054	2.0 (0.9 - 4.5)	0.081
Previous cesarean section	1.09 (0.62 - 1.92)	0.886	1.0 (0.6 - 1.9)	0.962
Spinal anatomical abnormalities	3.44 (1.54 - 7.67)	0.004	3.1 (1.3 - 7.3)	0.010
Midline surgical incision	2.43 (1.05 - 5.60)	0.037	2.1 (0.9 - 5.1)	0.094
Duration of anesthesia ≥ 45 minutes	3.76 (2.04 - 6.92)	< 0.001	3.4 (1.8 - 6.4)	< 0.001
Hyperbaric bupivacaine + intrathecal adjuvant	0.45 (0.26 - 0.79)	0.007	0.5 (0.3 - 0.9)	0.021

conversion to general anesthesia. Reported rates of spinal anesthesia failure during cesarean delivery vary considerably across studies, likely reflecting differences in the definition of failure, study population, type and urgency of cesarean delivery, anesthetic technique, and provider experience. Previous studies have reported failure rates ranging from approximately 2% to 17% (8, 16, 20). A retrospective case-control study reported total failure of spinal anesthesia in approximately 6% of patients (9), whereas a systematic review of inadequate neuraxial anesthesia in elective cesarean delivery reported considerable variability across studies (18). In addition, a large retrospective study reported a 2.1% rate of spinal anesthesia failure requiring alternative anesthesia and a 0.7% rate of conversion to general anesthesia (19).

The present study found an association between severe obesity (BMI ≥ 40 kg/m²) and increased odds of inadequate spinal anesthesia; however, this association did not reach statistical significance and was not independently significant after adjustment for potential confounders. Obesity may reduce the success of neuraxial techniques through several mechanisms, including difficulty identifying the intervertebral space, increased depth of the subarachnoid space, spinal anatomical alterations, and prolonged block placement time (21). Previous studies have also identified maternal obesity as a potential factor associated with difficulty administering regional anesthesia (8, 10, 13). Nevertheless, its independent effect may be attenuated after controlling for other contributing factors. Preprocedural ultrasound may also facilitate identification of anatomical landmarks and improve the

Table 4. Exploratory Association Between the Number of Prespecified Perioperative Factors and Inadequate Spinal Anesthesia and Conversion to General Anesthesia ^a

Number of Cumulative Risk Factors *	Total (n = 370)	Successful Spinal Anesthesia	Inadequate Spinal Anesthesia	Conversion to General Anesthesia
0 risk factors	180 (48.6)	168 (93.3)	12 (6.7)	5 (2.8)
1 risk factor	130 (35.1)	111 (85.4)	19 (14.6)	12 (9.2)
≥ 2 risk factors	60 (16.2)	31 (51.7)	29 (48.3)	22 (36.7)
Total	370 (100)	310 (83.8)	60 (16.2)	39 (10.5)

^a The overall comparison across risk-factor groups was statistically significant ($P < 0.001$).

success of neuraxial techniques in obese pregnant women (22). Therefore, a high BMI should be considered as part of the perioperative risk assessment, particularly when other risk factors are present.

In the present study, spinal anatomical abnormalities were also associated with an increased likelihood of inadequate block. Patients with anatomical abnormalities may experience greater difficulty identifying the appropriate intervertebral space, require more attempts, and have an increased risk of suboptimal needle placement. In the multivariable analysis, this factor remained statistically significant and was associated with more than a threefold increase in the odds of inadequate spinal anesthesia. Previous studies have likewise identified spinal anatomical abnormalities as recognized risk factors for failure of neuraxial techniques in pregnant women (8, 10, 20). Therefore, perioperative identification of these patients may facilitate more appropriate planning, the use of adjunctive imaging modalities such as ultrasound, and the selection of a more suitable anesthetic technique (21, 22).

In the present study, an anesthesia duration of ≥ 45 minutes was associated with higher odds of inadequate spinal anesthesia in the multivariable analysis. This finding is consistent with previous evidence suggesting an association between longer procedural duration and spinal anesthesia failure during cesarean delivery. In a large retrospective study, longer surgical duration was independently associated with spinal anesthesia failure, with the odds increasing with each additional minute of surgery (19). Inadequate spinal anesthesia may itself necessitate additional anesthetic interventions, supplemental analgesia, repeated neuraxial procedures, or conversion to general anesthesia, thereby prolonging overall anesthesia time (20). Thus, longer anesthesia duration may represent not only a potential marker of more technically or surgically challenging cases but also a consequence of inadequate neuraxial anesthesia.

Among patients with inadequate spinal anesthesia, the most common reason was failure to achieve an adequate sensory level, consistent with previous studies (8, 19, 23).

More than half of the conversions to general anesthesia were also attributable to inadequate anesthetic conditions for surgery. Unplanned conversion to general anesthesia during cesarean delivery is of particular clinical importance because it may be associated with an increased risk of airway complications, aspiration, and certain adverse neonatal outcomes (7, 15, 24-27). Patient satisfaction is also an important consideration when evaluating maternal outcomes of general versus spinal anesthesia (28). Recent studies have emphasized the importance of minimizing unplanned conversion to general anesthesia and developing risk-prediction algorithms (19, 20, 29). Evidence from systematic reviews also suggests that, although supplemental interventions may be required with neuraxial anesthesia during elective cesarean delivery, conversion to general anesthesia is relatively uncommon (18).

In the present study, an anesthesia duration of ≥ 45 minutes was significantly associated with higher odds of inadequate spinal anesthesia in both the unadjusted and multivariable analyses. This finding is broadly consistent with previous reports indicating that prolonged anesthetic or surgical procedures may be associated with an increased likelihood of inadequate neuraxial anesthesia and the need for supplemental interventions (20, 30). Several mechanisms may explain this association, including prolonged surgical stimulation, waning of the sensory block during longer procedures, and a greater likelihood of requiring additional anesthetic interventions as the procedure progresses (18, 20, 29). However, this finding requires particularly cautious interpretation. Anesthesia duration was obtained retrospectively from the anesthesia charts and medical records after completion of the surgical procedure. Consequently, inadequate spinal anesthesia, additional anesthetic interventions, procedural delays, or conversion to general anesthesia may themselves have contributed to a longer recorded anesthesia duration, introducing the possibility of reverse causation.

The relatively limited sample size and single-city setting of the study may restrict the generalizability of the findings. Future prospective multicenter studies with

larger sample sizes, longer recruitment periods, and more detailed documentation of technical variables are warranted to validate the present findings and facilitate the development of more accurate predictive models for identifying patients at risk of inadequate spinal anesthesia during elective cesarean delivery.

5.1. Conclusions

In this study, spinal anesthesia was successfully used as the primary anesthetic technique for elective cesarean delivery in most patients. However, inadequate spinal blockade occurred in a subset of patients, necessitating additional interventions or conversion to general anesthesia. Longer anesthesia duration and the presence of spinal anatomical abnormalities were associated with an increased likelihood of inadequate spinal anesthesia.

These findings underscore the importance of comprehensive perioperative assessment and early identification of patients at increased risk of spinal anesthesia failure. A risk-based approach may facilitate the selection of an appropriate anesthetic strategy, optimize resource planning, ensure the timely availability of rescue equipment and medications, and minimize delays in decision-making when the spinal block is inadequate. Patients with multiple risk factors may benefit from closer monitoring, administration of spinal anesthesia by a more experienced anesthesiologist, and early preparation for the potential need to convert to general anesthesia.

Given the global increase in cesarean delivery rates and the importance of minimizing unnecessary maternal exposure to general anesthesia, developing clinical prediction models based on identifiable perioperative risk factors may play an important role in improving maternal and neonatal safety.

Footnotes

AI Use Disclosure: The authors declare that no generative AI tools were used in the creation of this article.

Authors' Contribution: Study Concept and Design, Critical Revision for Important Intellectual Content, and Study Supervision: M. K.; Data Acquisition, Statistical Analysis, and Data Analysis and Interpretation: M. J.; Study Concept and Design, Manuscript Drafting, and Study Supervision: A. A.

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