ORIGINAL CLINICAL RESEARCH REPORT

CME

The Incidence and Predictors of Failed Spinal Anesthesia After Intrathecal Injection of Local Anesthetic for Cesarean Delivery: A Single-Center, 9-Year Retrospective Review

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BACKGROUND: The incidence of failed spinal anesthesia varies widely in the obstetric literature. Although many risk factors have been suggested, their relative predictive value is unknown. The primary objective of this retrospective cohort study was to determine the incidence of failed spinal anesthesia for cesarean deliveries at a tertiary care obstetric hospital, and its secondary objectives were to identify predictors of failed spinal anesthesia in the obstetrics population and quantify their relative importance in a predictive model for failure.

METHODS: With local institutional ethics committee approval, a retrospective review of our hospital database identified the incidence of failed spinal anesthesia for 5361 cesarean deliveries between 2010 and 2019. We performed a multivariable analysis to assess the association of predictors with failure and a dominance analysis to assess the importance of each predictor.

RESULTS: The incidence of failed spinal anesthesia requiring an alternative anesthetic was 2.1%, with conversion to general anesthesia occurring in 0.7% of surgeries. Supplemental analgesia or sedation was provided to an additional 2.0% of women. The most important predictors of a failed spinal anesthetic were previous cesarean delivery (odds ratio [OR], 11.33; 95% confidence interval [CI], 7.09–18.20; $P < .001$), concomitant tubal ligation (OR, 8.23; 95% CI, 3.12–19.20; $P < .001$), lower body mass index (BMI) ($kg \cdot m^{-2}$, OR, 0.94; 95% CI, 0.90–0.98; $P = .005$), and longer surgery duration (minutes, OR, 1.02; 95% CI, 1.01–1.03; $P = .006$). Previous cesarean delivery was the most significant risk factor, contributing to 9.6% of the total 17% variance predicted by all predictors examined.

CONCLUSIONS: Spinal anesthesia failed to provide a pain-free surgery in 4.1% of our cesarean deliveries. Previous cesarean delivery was the most important predictor of spinal failure. Other important predictors included tubal ligation, lower BMI, and longer surgery duration. (Anesth Analg 2024;138:430–7)

KEY POINTS

- **Question:** What is the incidence of failed spinal anesthesia for cesarean deliveries at a tertiary care obstetric hospital, and what are the most important predictors for failure?
- **Findings:** Spinal anesthesia failed to provide a pain-free surgery in 4.1% of our cesarean deliveries, and the most important predictors were previous cesarean delivery, tubal ligation, lower body mass index (BMI), and longer surgery duration.
- **Meaning:** Inadequate spinal anesthesia for cesarean delivery is not uncommon, with a history of previous cesarean delivery as its most significant predictor.

GLOSSARY

ASA = American Society of Anesthesiologists; **BMI** = body mass index; **CSE** = combined spinal-epidural; **GA** = general anesthesia; **IQR** = interquartile range; **IV** = intravenous; **IWK** = Izaak Walton Killiam; **RCoA** = The Royal College of Anaesthetists; **STROBE** = Strengthening the Reporting of Observational Studies in Epidemiology

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General anesthesia (GA) is associated with an increased risk of death, fetal depression, and uterine atony compared to neuraxial anesthesia for cesarean deliveries.[1,2] Successful neuraxial anesthesia for cesarean delivery has, therefore, become a marker for high-quality care. However, pain during cesarean delivery can cause significant suffering and trauma and is a leading cause of litigation in obstetric anesthesia.[3] The Royal College of Anaesthetists (RCoA) in the United Kingdom has published audit standards recommending that failure of regional anesthesia requiring conversion to GA should occur in under 1% of category 4 cesarean deliveries (ie, elective), under 5% of category 2–3 cesarean deliveries (ie, urgent without immediate threat of life of woman or fetus), and under 15% of category 1 cesarean deliveries (ie, emergent with an immediate threat of life of woman or fetus).[4]

In the obstetric anesthesia literature, the incidence of a failed spinal anesthesia requiring conversion to a GA varies from 0% to 1.9%.[5–10] When the definition of failed spinal anesthesia is expanded to include the need for repeat neuraxial anesthesia or supplemental analgesia, or sedation, the incidence increases to 2.7% to 10.2%. Factors that have been associated with failure in the obstetric population include early gestational age, low birth weight neonate, nulliparity, non-Caucasian ethnicity, urgency of surgery, surgery duration over 90 minutes, postpartum sterilization, needle insertion at the L4/5 vertebral level, >1 neuraxial anesthesia attempt, provider experience, and the absence of intrathecal opioids.[5–10]

Locally, we found that the predictors for failed spinal anesthesia in our orthopedic population were younger age, lower body mass index (BMI), needle insertion at L4/5 and L5/S1, 22 g spinal needles, and hyperbaric bupivacaine.[11] Considering the pathophysiological differences between the obstetric and nonobstetric populations, these factors may differ for cesarean deliveries. Quantifying the predictive value of these multiple risk factors may help clinicians anticipate and reduce the failure of spinal anesthesia. Indeed, a recent systematic review has highlighted the need to identify risk factors to optimize the management of spinal anesthesia.[5]

Our primary objective was to determine the incidence of failed spinal anesthesia, defined as a need for repeat anesthesia (GA or neuraxial procedure) within 1 hour of injection of intrathecal medications for cesarean deliveries at a tertiary care obstetric hospital. We hypothesized a 5% failure rate, with 1% of spinal anesthetics converted to GA. Our secondary objectives were to identify predictors of failed spinal anesthesia in the obstetric population and quantify their relative importance in a predictive model for failure.

METHODS

This study was conducted at IWK Health Centre, a Canadian standalone maternity teaching hospital that provides tertiary-level obstetric care. This article adheres to the applicable Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines. The IWK health research ethics board approved the study in December 2019 and waived the need for written informed consent. We conducted a retrospective review of the electronic anesthetic records (Innovian Anesthesia, version 5.0.2.15, Drager) for all cesarean deliveries performed at the IWK between September 28, 2010, and September 30, 2019. These dates were chosen to maximize the sample size, as electronic anesthetic records were introduced to the IWK in September 2010, and the study began in September 2019. Data extraction was performed for surgery type and first anesthetic technique, both discrete variables in the records. Of the 10,033 anesthetic records for cesarean deliveries during this time, 5361 were performed under spinal anesthesia. We excluded any cesarean deliveries performed under an epidural, combined spinal-epidural (CSE), or GA as the primary planned anesthetic, cesarean deliveries involving patients who received a labor epidural or CSE, cesarean deliveries that involved a study drug, cesarean hysterectomies, and cesarean deliveries where the spinal anesthesia was planned but not completed (eg, a needle was inserted, but no cerebrospinal fluid could be aspirated).

The primary outcome of the study was the failure of spinal anesthesia after injection of local anesthetic into the intrathecal space as indicated by aspiration of cerebrospinal fluid. At our center, spinal anesthesia techniques, including positioning of the patient, needle type and size, vertebral level of insertion, and dose of intrathecal medications, are based on practitioner choice. Our typical spinal procedure involves injecting 12 mg of 0.75% hyperbaric bupivacaine, 10 to 15 µg of fentanyl, and 0.1 to 0.15 mg of preservative-free morphine through a 25 g Whitacre needle. As this was a retrospective review with limited insight into the rationale for clinical decisions, a pragmatic definition of failure was chosen. Failure of spinal anesthesia was defined as the need to provide an alternative anesthetic, such as a repeat spinal, a new epidural or CSE, or conversion to GA, within 1 hour of the initial spinal. The secondary outcome was the need to provide supplemental analgesia or sedation within 1 hour of the initial spinal. Supplemental analgesia or sedation was defined as the administration of >100 µg of intravenous (IV) fentanyl; >2 mg of IV midazolam; any amount of IV ketamine, propofol, morphine, hydromorphone, remifentanil, or sufentanil; and/or inhaled nitrous oxide. We recognize that a small amount of supplemental analgesia and/or

sedation may not indicate anesthetic failure; as such, we specified a dose requirement for fentanyl and midazolam, the most frequently used supplemental medications for cesarean deliveries at the IWK. Other anesthetic medications, for example, propofol, are less commonly used in our cesarean deliveries, and we felt their inclusion would indicate higher anesthetic requirements, so no dose threshold was used for these medications. At our center, propofol is not used as an antiemetic. We manually reviewed the anesthetic records of all spinal anesthetics identified as failures to confirm they met inclusion and exclusion criteria.

Anesthetic, medical, surgical, and demographic information relevant to the effectiveness of spinal anesthesia, based on known predictors and plausible associations with failed spinal anesthesia, were extracted from the Innovian database. Variables that were not collected by Innovian but were potentially important to the success of spinal anesthesia (eg, weight) were captured using data linkage with the Nova Scotia Atlee Perinatal Database, a provincial perinatal database that undergoes data quality assurance programs and validation studies.[12] Data linkage was performed using patients' hospital identification numbers and delivery dates, which were subsequently stripped from the dataset used by the investigators. The following data were extracted for each patient: age, weight, height, body mass index (BMI), American Society of Anesthesiologists (ASA) physical status, history of previous cesarean delivery, type of surgical incision, concomitant tubal ligation, surgical duration (skin incision to skin closure), gestational age, parity, neonatal birth weight, history of psychiatric illness, history of diseases associated with difficult neuraxial placement (ankylosing spondylitis, rheumatoid/psoriatic arthritis, scleroderma, scoliosis, neurofibromatosis, and Scheurmann's disease), position for the neuraxial procedure (lateral or sitting), landmark estimated vertebral level, spinal needle gauge, spinal needle type, the number of attempts documented by clinician, baricity, dose of intrathecal bupivacaine, the dose of intrathecal fentanyl, the dose of intrathecal morphine, and paraesthesia or blood during placement of the spinal. A procedure was determined to be urgent rather than elective if (1) it was described as urgent or emergent in the procedural name or diagnosis, (2) there was an "E" in the ASA physical status, indicating emergency surgery, or (3) it was performed in the evening, night, or on the weekend. The IWK Health Centre is a teaching hospital, where spinal anesthesia is provided by a small, dedicated group of obstetric anesthesia consultant medical staff or by supervised trainees (anesthesia residents or fellows). Provider experience could not be reliably extracted from the anesthesia records and, therefore, could not be analyzed.

Statistical Analysis

Univariate analyses, using binary logistic regression with the failure of spinal anesthesia (yes/no) as a binary outcome, were performed for each variable. Variables that had significant missing data were excluded from analysis, and these included the baricity of intrathecal bupivacaine and blood during placement of the spinal anesthetic.

Eleven variables were chosen to be included in the multivariable analysis: BMI, psychiatric illness, previous cesarean delivery, parity, urgent/emergent indication for surgery, type of surgical incision, tubal ligation, surgical duration, gestational age, intrathecal bupivacaine dose, and landmark estimated vertebral level. Birth weight was considered but was strongly correlated with gestational age and thus excluded from the multivariable analysis. These variables were identified in the literature as predictors of failed spinal anesthesia or were identified using clinical experience as potential risk factors for failure. Multivariable analyses used multiple binary logistic regressions with 11 predictors entered simultaneously for both primary and secondary outcomes. The effect size was calculated using odds ratios with 95% confidence intervals and McFadden's pseudo-R^2. A P value of <.05 was considered statistically significant. Data analysis was performed using SPSS 24 (IBM SPSS Statistics for Windows, Version 24.0; IBM Corp). To assess for missing data, an additional analysis of the multivariable model was performed, in which multiple imputations were used to handle the missing data and note any discrepancies with the listwise deletion conclusions in the text.

Dominance analysis using the domir package in R v4.05 software was used for determining the relative importance of the independent variables for spinal anesthesia in a predictive model.[13] In brief, this is a computationally intensive method that decomposes the pseudo-R^2 value such that the individual contribution of each predictor can be established, even in the presence of collinearity.

Post hoc power calculations are known to be misleading and logically invalid once the statistical test has been conducted, especially in studies using retrospective data where no additional data could be collected.[14] We instead reported confidence intervals that display the range of plausible effect sizes given the sample.

RESULTS

The patient characteristics are shown in Supplemental Digital Content 1, Table 1, http://links.lww.com/AA/E275. The patients' median interquartile range (IQR) age was 32 years (7). The median (IQR) weight, height, and BMI were 83 kg |(22.2), 163 cm (9), and 31.2 (4.3) $kg \cdot m^{-2}$. Of the records that noted ASA status,

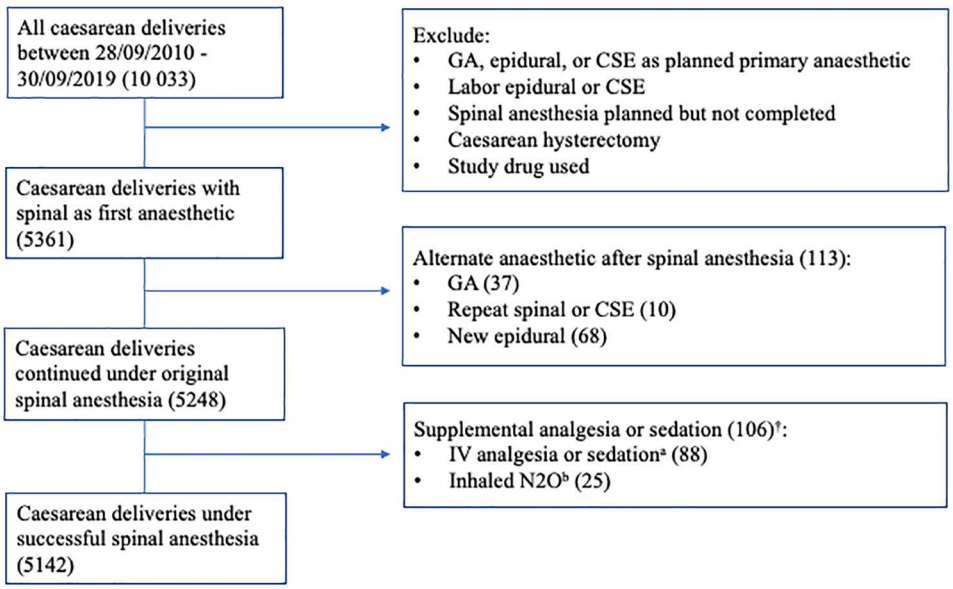
910 women were classified as ASA I, 3050 were ASA II, 66 were ASA III, and 0 were an ASA IV or higher.

Of the included 5361 cesarean deliveries under spinal anesthesia, 113 women required an alternate anesthetic within 1 hour of the spinal procedure, resulting in a spinal failure rate of 2.1% (Figure). Within this group, 37 spinal anesthetics were converted into GA (0.7%), 10 required a repeat spinal or CSE (0.2%), and 68 received a new epidural (1.3%). In 106 other cesarean deliveries, clinicians provided supplemental analgesia or sedation within 1 hour of the spinal procedure (2.0%). This group consisted of 88 patients who received IV analgesia or sedation (1.6%) and 25 patients who received inhaled nitrous oxide (0.5%). Combining these 2 groups, 219 women of 5361 (4.1%) who received spinal anesthesia for cesarean delivery required some form of alternate anesthetic, analgesic, or sedative.

The univariate analysis is summarized in Tables 1, 2. In the multivariable analysis (Table 3), the factors associated with increased odds of failed spinal anesthesia requiring an alternate anesthetic (while holding all other predictors constant) were: previous cesarean delivery, parity, earlier gestational age, lower BMI, concomitant tubal ligation, urgent or emergent compared to elective surgery, surgery duration, and L4/5 landmark vertebral level compared to higher levels. Psychiatric illness significantly increased the odds of requiring supplemental analgesia or sedation. When we used multiple imputations to assess the effect of missing data on our multivariable analysis, we found the only difference was that urgent or emergent surgery was also significantly associated with the need for supplemental analgesia or sedation (Supplemental Digital Content 1, Table 2, http://links.lww.com/AA/E275).

Correlations between predictors are summarized in Supplemental Digital Content 1, Table 3, http://links.lww.com/AA/E275. We assessed the following interaction effects based on clinical plausibility across all analyses: surgical duration and tubal ligation, surgical duration and previous cesarean delivery, surgical duration and BMI, previous cesarean delivery and parity, previous cesarean delivery and BMI, parity and tubal ligation, gestational age and urgent/emergent delivery, gestational age and incision type, BMI and incision type, and BMI and intrathecal bupivacaine dose. There were no robust interactions to report.

Dominance analysis determined which predictors in the multivariable model predicted the most variance for both study outcomes (Tables 4, 5). Dominance analysis standardizes effect sizes and is, therefore, more reliable than odds ratios for determining relative importance. The most important predictors for failed spinal anesthesia requiring an alternate anesthetic were previous cesarean delivery, tubal ligation, lower BMI, and longer surgery duration, which accounted for 9.6%, 1.5%, 1%, and 1% of the variance in the outcome, respectively. All the other predictors accounted for <1% of the predictive



† 8 cases involved both IV analgesia or sedation and inhaled N2O.
[a] Defined as > 100 mcg of IV fentanyl, > 2 mg of IV midazolam, or any amount of IV ketamine, IV propofol, IV morphine, IV hydromorphone, IV remifentanil, or IV sufentanil given ≤ 1 hour after spinal anesthesia
[b] Defined as ≥ 30% inhaled nitrous oxide given ≤ 1 hour after spinal anesthesia, excluding GA cases

Figure. Flow diagram. CSE indicates combined spinal-epidural; GA, general anesthesia; IV, intravenous; N_2O, nitrous oxide.

Table 1. Univariate Logistic Regression Analysis on Predictors of Failed Spinal Anesthesia Requiring an Alternate Anesthetic

Variable	Reference group	OR (95% CI, lower–upper)	*P* value
Age (y)	NA (continuous variable)	1.01 (0.98–1.05)	.482
BMI (kg·m^{-2})	NA (continuous variable)	0.95 (0.92–0.99)	.013[a]
Height (cm)	NA (continuous variable)	1.01 (0.99–1.04)	.294
ASA III	ASA I, II	3.83 (1.50–9.78)	.005[a]
Parity 1,2,3	Parity 0	1.24 (0.82–1.90)	.315
Gestational age (wk)	NA (continuous variable)	0.89 (0.84–0.94)	<.001[a]
Birth weight (unit to 100 g)	NA (continuous variable)	0.96 (0.93–0.98)	<.001[a]
Previous cesarean delivery	No previous cesarean delivery	6.67 (4.56–9.74)	<.001[a]
Number of cesarean deliveries	NA (continuous variable)	0.96 (0.75–1.24)	.750
Psychiatric illness	No psychiatric illness	1.46 (0.86–2.50)	.165
Diseases associated with difficult neuraxial placement	No diseases associated with difficult neuraxial placement	5.20 (2.19–12.33)	<.001[a]
Tubal ligation	No tubal ligation	4.63 (2.19–9.80)	<.001[a]
Classical incision	Other incision	4.54 (1.78–11.58)	.002[a]
Surgery duration (min)	NA (continuous variable)	1.01 (1.00–1.03)	.010[a]
Landmark vertebral level (L4/5)	L2/3 and L3/4	1.81 (1.06–3.10)	.031[a]
Position for neuraxial (lateral)	Sitting	2.21 (0.99–4.95)	.053
Spinal needle type (sprotte and other)	Whitacre	1.47 (0.35–6.08)	.595
Spinal needle gauge (27 g)	25 g	5.03 (1.91–13.27)	.001[a]
Number of attempts (2 or more)	1	1.30 (0.84–2.03)	.242
Paresthesia during spinal	No paresthesia	1.43 (0.34–6.04)	.624
Intrathecal bupivacaine dose (mg)	NA (continuous variable)	0.90 (0.52–1.55)	.702
Intrathecal fentanyl dose (mcg)	NA (continuous variable)	0.95 (0.90–1.00)	.070
Intrathecal morphine dose (mg)	NA (continuous variable)	0.036 (0.00–9.80)	.245

Abbreviations: BMI, body mass index; CI, confidence interval; NA, not applicable; OR, odds ratio.
[a]indicates statistical significance.

Table 2. Univariate Logistic Regression Analysis on Predictors of Failed Spinal Anesthesia Requiring Any Type of Alternate or Supplemental Anesthesia, Analgesia, or Sedation

Variable	Reference group	OR (95% CI, lower–upper)	*P* value
Age (years)	NA (continuous variable)	1.00 (0.97–1.02)	.731
BMI (kg.m^{-2})	NA (continuous variable)	0.96 (0.93–0.99)	.003[a]
Height (cm)	NA (continuous variable)	1.01 (0.99–1.03)	.167
ASA III	ASA 1 and 2	3.53 (1.65–7.52)	.001[a]
Parity 1,2,3	Parity 0	1.11 (0.83–1.50)	.49
Gestational age (wk)	NA (continuous variable)	0.87 (0.84–0.91)	<.001[a]
Birth weight (unit to 100 g)	NA (continuous variable)	0.94 (0.93–0.96)	<.001[a]
Previous cesarean delivery	No previous cesarean delivery	3.47 (2.57–4.68)	<.001[a]
Number of cesarean deliveries	NA (continuous variable)	0.973 (0.81–1.17)	.770
Psychiatric illness	No psychiatric illness	1.78 (1.23–2.57)	.002[a]
Diseases associated with difficult neuraxial placement	No diseases	3.05 (1.37–6.79)	.006[a]
Tubal ligation	No tubal ligation	2.58 (1.28–5.20)	.008[a]
Classical incision	Other incision	5.08 (2.53–10.18)	<.001[a]
Surgery duration (min)	NA (continuous variable)	1.02 (1.01–1.03)	<.001[a]
Landmark vertebral level: L4/5	L2/3 and L3/4	1.29 (0.83–2.01)	.262
Position for neuraxial: Lateral	Sitting	2.14 (1.17–3.92)	.013[a]
Spinal needle type: Sprotte and other	Whitacre	2.37 (1.01–5.54)	.047[a]
Spinal needle gauge: 27g	25g	3.00 (1.15–7.85)	.025[a]
Number of attempts: 2 or more	1	1.25 (0.91–1.74)	.171
Paresthesia during spinal	No paresthesia	1.57 (0.55–4.46)	.401
Intrathecal bupivacaine dose (mg)	NA (continuous variable)	0.82 (0.56–1.20)	.304
Intrathecal fentanyl dose (mcg)	NA (continuous variable)	0.97 (0.93–1.01)	.123
Intrathecal morphine dose (mg)	NA (continuous variable)	0.71 (0.02–20.91)	.845

Abbreviations: BMI, body mass index; CI, confidence interval; NA, not applicable; OR, odds ratio.
[a]indicates statistical significance.

variance. When the secondary outcome of supplemental analgesia or sedation was analyzed, the most important predictors for failed spinal anesthesia were previous cesarean and surgery duration, accounting for 4.1% and 1.4% of the variance. All the other factors accounted for <1% predictive variance.

DISCUSSION

The spinal anesthesia failure rates in our study are within targets established by the RCoA and are consistent with findings from other developed countries.[6,8,10] A recent systematic review of randomized control trials assessing neuraxial anesthesia for cesarean

Table 3. Multivariable Logistic Regression on Predictors of Failed Spinal Anesthesia

	Alternate anesthetic versus no failure			Alternate anesthetic, supplemental analgesia/sedation versus no failure		
Predictors	**OR**	**CI**	***P***	**OR**	**CI**	***P***
(Intercept)	0.01	0.00–119.53	.372	2.30	0.00–1157.79	.801
Previous cesarean delivery	11.33	7.09–18.20	<.001[a]	5.03	3.50–7.18	<.001[a]
Gestational age (wk)	0.91	0.84–0.99	.028[a]	0.88	0.83–0.94	<.001[a]
Parity (para 0:0; para 1,2,3:1)	2.11	1.23–3.77	.008[a]	1.55	1.07–2.29	.024[a]
BMI ($kg \cdot m^{-2}$)	0.94	0.90–0.98	.005[a]	0.95	0.92–0.97	<.001[a]
Psychiatric illness	1.52	0.74–2.86	.223	1.74	1.08–2.70	.017[a]
Surgery duration (min)	1.02	1.01–1.03	.006[a]	1.02	1.01–1.03	<.001[a]
Tubal ligation	8.23	3.12–19.20	<.001[a]	3.71	1.55–7.85	.001[a]
Incision type (other:0; classical:1)	0.85	0.12–3.59	.843	1.19	0.39–3.22	.740
Urgent or emergent surgery	1.68	0.99–2.80	.050[a]	1.26	0.85–1.83	.240
Intrathecal bupivacaine dose (mg)	1.34	0.66–2.77	.442	1.05	0.65–1.75	.855
Landmark vertebral level (L2/3 and L3/4:0; L4/5:1)	2.12	1.08–3.87	.019[a]	1.45	0.86–2.33	.142

Abbreviations: BMI, body mass index; CI, confidence interval; OR, odds ratio.
[a]indicates statistical significance.

Table 4. Dominance Analysis for Predictors of Failed Spinal Anesthesia Requiring an Alternate Anesthetic

Variable	Dominance	Percent of R^2	Ranks
Previous cesarean delivery	0.096	0.564	1
Tubal ligation	0.015	0.086	2
BMI ($kg \cdot m^{-2}$)	0.010	0.061	3
Surgery duration (min)	0.010	0.057	4
Birth weight (unit to 100 g)	0.008	0.049	5
Urgent or emergent surgery	0.008	0.045	6
Parity	0.007	0.039	7
Gestational age (wk)	0.005	0.030	8
Landmark vertebral level	0.005	0.029	9
Intrathecal bupivacaine dose	0.004	0.022	10
Surgical incision	0.002	0.010	11
Psychiatric illness	0.001	0.008	12
McFadden Pseudo R^2	0.170		

McFadden Pseudo R^2 describes the fit of the model. The R^2 of our model is 0.170, meaning that the model explains 17.0% of the variance in outcome. The dominance column describes the contribution of each variable to R^2 so that all 12 values sum to the total pseudo-R^2. The percent of R^2 column expresses the dominance value as a percentage of the overall pseudo-R^2 value (eg, 0.096/0.170 = 0.564) and thus sum to 100%. The rank column sorts the predictors in order of relative importance.
Abbreviation: BMI, body mass index.

Table 5. Dominance Analysis for Predictors of Failed Spinal Anesthesia Requiring Any Type of Alternate or Supplemental Anesthesia, Analgesia, or Sedation

Variable	Dominance	Percent of R^2	Ranks
Previous cesarean delivery	0.041	0.409	1
Surgery duration (min)	0.014	0.139	2
Birth weight (unit to 100 g)	0.009	0.093	3
Gestational age (wk)	0.009	0.092	4
BMI ($kg \cdot m^{-2}$)	0.006	0.060	5
Tubal ligation	0.005	0.048	6
Urgent or emergent surgery	0.005	0.048	7
Psychiatric illness	0.004	0.039	8
Parity	0.003	0.029	9
Surgical incision	0.002	0.024	10
Intrathecal bupivacaine dose	0.001	0.011	11
Landmark vertebral level	0.001	0.010	12
McFadden Pseudo R^2	0.100		

Abbreviation: BMI, body mass index.

deliveries reported a 0% conversion to GA rate but a 10.9% overall failure rate that included alternate anesthetics and supplemental analgesia in those that received a spinal anesthetic.[5] They may have found a lower GA rate because they included only elective surgeries and had a smaller sample size (1842 patients) in the spinal group than our study. Their higher overall failure rate may be due to a broader definition of supplemental analgesia. Our rationale was to capture cases where the pain was severe and occurred early in surgery, suggesting a true failure of spinal anesthesia.

The systematic review called for further studies on predictors of inadequate neuraxial anesthesia, which we have attempted to identify in our study.[5] The multivariable results and dominance analysis demonstrate that the most important predictor of failed spinal anesthesia was a history of previous cesarean deliveries. It is plausible that scarring from previous deliveries may translate to greater surgical stimulation and the need for a denser block in subsequent surgeries. Interestingly, the number of cesarean deliveries was not significantly associated with failure in the univariate analysis so we cannot conclude that there is increased risk with an increased number of previous surgeries. Other patient predictors that contributed to variance in the dominance model were earlier gestational age and lower BMI. Adesope et al[8] also found a greater risk of failed spinal anesthesia in preterm parturients. They hypothesized that the smaller uterus size of preterm parturients resulted in less aortocaval compression and, therefore, larger epidural and subarachnoid space volumes. Using a similar rationale, lower BMI patients may have less intraabdominal pressure and larger subarachnoid space volumes, increasing the risk of failure.

Tubal ligation is our model's second most important predictor of failure and the most important surgical risk factor. Sng et al[6] also identified postpartum

sterilization as an independent risk factor for failed spinal anesthesia. The procedure requires additional surgical manipulation and is performed later in cesarean delivery when the spinal block may be regressing. Every 1 minute of surgery duration is associated with a 1.02 increase in the odds of failure or roughly a 3.3-fold increase in odds per hour of surgery. In the dominance analysis, surgery duration accounted for 1.0% and 1.4% of the variance in primary and secondary outcomes, respectively, and it is possible that its effect size would have been larger with a less stringent time criterion. While odds ratios are difficult to compare across dichotomous (eg, tubal ligation) and continuous (eg, surgery duration and BMI) predictor variables due to differences in scaling, the dominance analysis relies on a standardized metric based on the log-likelihoods (McFaddens R^2) that allows for more direct comparisons of effect sizes by placing them on the same scaled metric. As a result, when determining the relative predictive power of variables, the R^2 values from the dominance analysis should be trusted more than the odds ratios. The time lag between spinal anesthesia and skin incision was not available to be reported but should be similar for both failed and successful groups, considering this was a single-center study. Kinsella[7] likewise found that the duration of operation beyond 90 minutes increased the risk of failure. Kinsella also found that spinal anesthetics were more likely to fail in the presence of acute fetal distress. In our cases, the odds of a spinal requiring an alternate anesthetic were 68% higher in urgent or emergent deliveries compared to elective procedures. Emergent situations make spinal procedures more difficult and limit the time available for an adequate surgical block.

The only significant anesthesia predictor was landmark-based vertebral level, with a spinal placed at the L4/5 level at increased risk of failure than one placed at L2/3 or L3/4. A lower vertebral interspace is often chosen for safety but may require a larger spinal dose to achieve adequate cephalad spread. Another possible mechanism of failure in the lower interspaces includes restriction in spread due to osteophytes, septations, or spinal deformities.[15] This finding is consistent with other studies.[9,11] However, clinical estimation of vertebral interspace can be unreliable, so caution is required when interpreting this finding.

The Association of Anaesthetists and The French Practice Bulletin Taskforce have provided recommendations on pain during cesarean delivery.[16,17] Prevention strategies include adequate dosing of intrathecal local anesthetic, intrathecal liposoluble opioid, consideration for a CSE, and appropriate sensory and motor testing. If the block is inadequate, one can wait longer for block onset or create a head-down tilt when using hyperbaric bupivacaine.[18]

This was a retrospective single-center study, which entails several limitations. Our academic hospital is staffed by a small group of obstetric anesthetists using similar practices. This may explain why there were no differences in outcomes when assessing bupivacaine, fentanyl, and morphine doses. Another limitation is that the decision to provide alternative or supplemental techniques was left to the discretion of the clinician. The level of sensory and motor blockade following spinal anesthesia was not available in the records. We, therefore, chose hard end points of conversion to GA, a repeat spinal or CSE, or a new epidural within an hour of the spinal for the primary outcome as a pragmatic definition for failure. We included supplemental analgesia and sedation as the secondary outcome to capture the rest of the cases where spinal anesthesia was inadequate. The dominance analysis found that our 11 predictors accounted for 17% of the variance in the primary outcome. Several other possible predictors had low event rates in our databases (eg, diseases associated with difficult neuraxial placement) or were otherwise unavailable (eg, provider experience) and could not be included in the analysis. Similarly, as CSEs are not commonly performed at our center for cesarean deliveries, we did not include them as predictors in our analysis due to low event rates.

In conclusion, spinal anesthesia failed to provide a pain-free surgery in 4.1% of our cesarean deliveries, with 2.1% requiring an alternate anesthetic and 0.7% requiring conversion to GA within 1 hour of spinal anesthesia. The most important predictor for a failed spinal by a large margin was a history of previous cesarean delivery, followed by tubal ligation, lower BMI, and longer surgery duration. To our knowledge, this quantification of risk factors has never been conducted. Future studies may investigate the reasons for these associations and techniques to prevent failures.

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DISCLOSURES

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