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Maternal and Neonatal Outcomes Following Spine Surgery during Pregnancy: A Systematic Review and Meta-Analysis of Surgical Timing, Anesthetic Techniques, and Delivery Outcomes

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A B S T R A C T

Background: Spine surgery during pregnancy presents a complex clinical challenge requiring simultaneous consideration of maternal neurological recovery, fetal well-being, anesthetic safety, and delivery planning. Evidence remains limited because these procedures are uncommon and published studies frequently comprise individual cases or small observational series.

Objective: This systematic review and meta-analysis aims to evaluate maternal and neonatal outcomes following spine surgery during pregnancy, emphasizing gestational timing, anesthetic techniques, surgical positioning, and subsequent delivery outcomes.

Methods: A systematic search strategy should encompass PubMed/MEDLINE, Embase, Scopus, Web of Science, and the Cochrane Library, supplemented by reference-list screening. Eligible studies include pregnant patients undergoing spinal or neurosurgical spinal procedures before delivery. Maternal neurological improvement, perioperative complications, pregnancy loss, preterm birth, neonatal morbidity, and delivery mode are prespecified outcomes. Two independent reviewers should perform screening, data extraction, and risk-of-bias assessment. Quantitative synthesis undertaken only when sufficiently comparable studies provide extractable outcome data.

Results: Published systematic reviews and clinical series indicate that decompressive surgery, particularly for severe lumbar disc herniation and cauda equina syndrome, followed by favorable maternal neurological and pregnancy outcomes. A multicenter series of 24 pregnant patients included 21 women operated on during pregnancy, with no reported miscarriage, stillbirth, or severe obstetric complication before delivery. A separate systematic review identified 51 pregnant women with lumbar disc herniation or cauda equina syndrome, most of whom underwent antepartum surgery. However, the available literature does not establish the superiority of a particular trimester, anesthetic technique, or delivery mode. These findings are descriptive and do not constitute newly calculated pooled estimates.

Conclusions: Medically necessary spine surgery not delayed solely because of pregnancy. Individualized multidisciplinary planning, appropriate positioning, maternal physiological stability, and gestationally appropriate fetal monitoring are central to care. Larger prospective registries and standardized outcome reporting are needed to improve comparative risk estimates.

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Introduction

Pregnancy introduces distinctive physiological, anatomical, and clinical considerations into the management of spinal disorders [1-3]. Although back pain is common during pregnancy, severe neurological conditions requiring operative intervention are uncommon [4-9]. Lumbar disc herniation, cauda equina syndrome, spinal trauma, spinal infections, and space-occupying lesions may nevertheless necessitate urgent surgical treatment when progressive neurological deterioration threatens maternal function or long-term disability. Decisions concerning surgery must account for both the consequences of untreated spinal disease and the potential effects of anesthesia, positioning, operative stress, and perioperative medications on the developing fetus [10-15].

The principal challenge is determining when the benefits of surgical intervention outweigh the risks associated with continuing pregnancy without definitive treatment. Neurological emergencies, including cauda equina syndrome, progressive motor weakness, and spinal cord compression, require timely assessment because prolonged compression may result in persistent neurological deficits. Conversely, when symptoms remain stable and no urgent neurological indication exists, conservative treatment may permit surgery to be deferred until after delivery. Such decisions should reflect disease severity, gestational age, expected neurological recovery, maternal preferences, and the feasibility of close surveillance rather than pregnancy alone [16-20]

Current obstetric guidance establishes an important distinction between elective and medically necessary surgery. Elective procedures generally postponed until after delivery, whereas medically necessary operations not denied or delayed solely because the patient is pregnant. The American College of Obstetricians and Gynecologists (ACOG) also emphasizes obstetric consultation, appropriate perioperative fetal assessment, and consideration of preterm labor and venous thromboembolism [21-30]. These recommendations provide a general framework for no obstetric surgery but do not resolve all questions specific to spinal procedures, including prone positioning, prolonged operative duration, and the selection of general versus regional anesthesia.

Gestational timing is a major consideration. The first trimester raises concerns about early pregnancy loss and the timing of embryonic development, while later pregnancy introduces additional issues related to uterine size, aortocaval compression, positioning, and the possibility of preterm delivery. The second trimester often considered convenient for procedures that scheduled, but this not interpreted as a requirement to postpone urgent surgery. When neurological deterioration is imminent, the consequences of delay may exceed the theoretical risks associated with operating during a particular trimester [31-40].

Anesthetic management requires individualized assessment of maternal respiratory and cardiovascular physiology, airway considerations, uteroplacental perfusion, and the anticipated duration of surgery. General anesthesia necessary for complex procedures, while selected decompressive operations performed using spinal or epidural anesthesia. Neither approach assumed to universally safer: anesthetic choice depends on the operative procedure, maternal condition, airway and aspiration risks, neurological findings, and the expertise of the treating team. Available guidance indicates that currently used anesthetic agents have not shown to be teratogenic in humans when administered at standard clinical concentrations; however, the overall risk profile of surgery inferred from drug safety alone [41-50].

Positioning is particularly relevant in spinal surgery because prone positioning may improve surgical access but can complicate abdominal protection, venous return, and maternal hemodynamic management. Alternative positions feasible for selected procedures. The appropriate strategy should maintain surgical access while avoiding abdominal compression and preserving maternal oxygenation and circulation. Intraoperative fetal monitoring may assist clinical management when technically feasible and appropriate to gestational age, institutional resources, and the ability to respond to an abnormal result [51-60].

The published evidence remains difficult to interpret because many reports focus on lumbar disc herniation and cauda equina syndrome, whereas spinal trauma, tumors, infections, and instrumented procedures less consistently represented. Hussein et al. (2024) synthesized 33 reports or series involving 51 pregnant women with lumbar disc herniation or cauda equina syndrome. Chan et al. (2024) reviewed 41 studies addressing the incidence, presentation, and management of lumbar disc herniation in pregnancy. These reviews provide useful descriptive evidence but do not necessarily answer comparative questions across different spinal diagnoses, anesthetic strategies, or delivery plans [61].

The present review therefore proposes a structured evaluation of maternal neurological recovery, perioperative complications, pregnancy loss, preterm birth, neonatal outcomes, and delivery mode. It focuses on three interrelated domains: surgical timing, anesthetic techniques, and obstetric outcomes. Its central objective is to distinguish clinically meaningful patterns in the published evidence from conclusions that remain uncertain because of small samples, incomplete outcome reporting, heterogeneous procedures, and the absence of appropriate comparison groups. A transparent synthesis following PRISMA 2020 reporting principles is essential to make these

limitations explicit and support evidence-informed multidisciplinary decision-making [62].

Literature Review

Indications for spine surgery during pregnancy:

The literature on spinal surgery during pregnancy dominated by symptomatic lumbar disc herniation, especially cases complicated by cauda equina syndrome, severe radiculopathy, or progressive motor deficits. These conditions are clinically important because the risks of persistent neurological injury may make conservative treatment inappropriate. Spinal trauma, tumors, infections, and other compressive lesions also documented, but their rarity and clinical heterogeneity limit comparisons between diagnoses. Brown and Levi (2001) described three pregnant patients with lumbar disc herniation causing cauda equina syndrome or severe neurological deficits. Their report supported timely decompression when significant neurological compromise is present. Similarly, the retrospective case series by O'Neill et al. (2018) described six patients requiring surgical management for perinatal lumbar disc herniation or cauda equina syndrome. Although such reports provide useful clinical experience, small samples and the lack of untreated control groups prevent reliable estimation of comparative risks [63-65].

Chan et al. (2024) identified 79 pregnant patients with symptomatic lumbar disc herniation across 35 studies addressing clinical presentation and management. Fifty-six underwent surgery, while 23 received nonsurgical management. The review documented improvements in several neurological symptoms after surgical intervention but also highlighted missing information on positioning, anesthesia, and follow-up. Because treatment assignment depended on clinical severity and neurological findings, differences between surgical and nonsurgical groups not automatically interpreted as causal treatment effects [66-69].

Surgical timing and gestational age:

The timing of surgery interpreted in the context of the indication rather than as an isolated determinant of outcome. Elective operations generally postponed, but emergency decompression required at any gestational age. A multicenter case series by Reitman and colleagues' clinical literature has reinforced the need for individualized decisions based on neurological urgency, operative feasibility, and maternal-fetal assessment. In particular, the available spine-specific literature does not provide sufficient evidence to establish a universally optimal trimester for surgery. General evidence concerning no obstetric surgery provides useful background but applied cautiously. A systematic review by Haataja et al. (2023) included 60 studies of no obstetric surgery during pregnancy and reported associations with preterm birth and stillbirth. These findings encompass diverse surgical indications and procedures and influenced by the underlying illnesses that necessitated surgery. They not treated as spine-surgery-specific estimates or as proof that spinal procedures themselves cause adverse obstetric outcomes [70-75].

Anesthetic techniques and positioning:

General anesthesia has frequently reported in antepartum spine surgery, particularly when patients require urgent decompression or when operative complexity makes regional techniques unsuitable. Regional anesthesia has also described for selected lumbar procedures. In a recent series, ten pregnant patients underwent emergency lumbar microdiscectomy under spinal anesthesia while positioned prone, with no reported miscarriage, stillbirth, or severe obstetric complication through delivery (Emergency lumbar disc herniation surgery with spinal anesthesia during pregnancy, 2024). This is encouraging but cannot establish equivalence or superiority over general anesthesia. The broader anesthetic literature emphasizes maintaining maternal oxygenation, blood pressure, and uteroplacental perfusion while anticipating pregnancy-related airway and respiratory changes [76-80]. Positioning decisions must account for the gestational age, the size of the uterus, surgical exposure, and the feasibility of avoiding abdominal compression. Published reports frequently lack standardized descriptions of these variables, limiting retrospective comparison.

Maternal, fetal, and neonatal outcomes:

Reported outcomes include neurological recovery, persistent pain, sphincter dysfunction, pregnancy loss, preterm delivery, cesarean delivery, and neonatal complications. In the multicenter spine-surgery series, 21 patients underwent operations during pregnancy; no miscarriage, stillbirth, or severe obstetric complication reported before delivery, and neurological improvement documented across the cohort (Reitman et al.,2021). Nevertheless, zero observed events in a small series not interpreted as zero risk.

Delivery mode is similarly difficult to interpret. Cesarean delivery chosen because of obstetric indications, neurological concerns, prior spinal procedures, or clinician preference. Vaginal delivery may remain feasible when neurological status and obstetric circumstances permit. A higher cesarean rate among operated patients, therefore, does not independently establish that surgery necessitates cesarean delivery.

Evidence gaps

Three principal gaps emerge. First, the literature dominated by case reports and small case series, increasing the risk of publication bias. Second, anesthetic and positioning information

inconsistently reported. Third, outcomes not standardized across studies, particularly regarding long-term neurological function and neonatal follow-up. Future reviews should avoid double-counting patients appearing in overlapping publications and should separate spine-specific findings from evidence concerning no obstetric surgery more broadly.

Methods

Design and reporting framework. This review designed as a systematic review with meta-analysis where quantitative pooling is methodologically justified. Reporting should follow the PRISMA 2020 statement (Page et al., 2021). The protocol registered prospectively in PROSPERO before formal screening and extraction.

Information sources and search strategy. Searches conducted in PubMed/MEDLINE, Embase, Scopus, Web of Science, and the Cochrane Library from database inception to the final search date. Search terms should combine pregnancy-related terms with spinal surgery, discectomy, laminectomy, decompression, spinal tumor, spinal trauma, anesthesia, and maternal or neonatal outcomes. Reference lists of eligible publications and relevant systematic reviews also screened.

Eligibility criteria. Eligible reports should describe pregnant patients undergoing spinal surgery during gestation, including decompression, discectomy, laminectomy, tumor surgery, and stabilization. Case reports, case series, and observational studies included because of the rarity of the condition. Postpartum-only surgery and studies without extractable pregnancy outcomes excluded. Overlapping patient cohorts identified and counted only once for each relevant outcome.

Study selection and extraction. Two independent reviewers should screen titles, abstracts, and full texts, resolve disagreements by consensus, and record exclusion reasons. Extracted variables should include study design, sample size, diagnosis, gestational age, urgency, surgical procedure, position, anesthetic technique, maternal complications, neurological recovery, pregnancy loss, gestational age at delivery, delivery mode, and neonatal outcomes.

Quality assessment and synthesis. Risk of bias evaluated using tools appropriate to each study design. Outcomes summarized descriptively, with pooled proportions or comparative effect estimates calculated only when definitions and denominators are sufficiently compatible. Random-effects models, confidence intervals, and heterogeneity statistics reported where appropriate. Small samples, zero-event studies, missing outcomes, and potential publication bias addressed explicitly. No pooled effect reported until study-level data have verified.

Results

Study identification and evidence characteristics: The available literature supports a descriptive synthesis, but the final number of unique eligible studies established from the published review summaries alone. The 2024 systematic review by Hussein et al. included 33 reports or series involving 51 pregnant women with lumbar disc herniation or cauda equina syndrome. Chan et al. (2024) reviewed 41 studies across a broader assessment of lumbar disc herniation in pregnancy, while a multicenter series reported 24 pregnant patients, including 21 who underwent surgery during pregnancy. These populations may overlap with other publications; they not added together as if they represented independent patients. The four tables below organize the clinically relevant evidence and identify the variables needed for quantitative synthesis. They are not a substitute for a completed study-by-study extraction.

Table 1. Characteristics of the principal evidence sources

Evidence source	Population or sample	Main contribution	Principal limitation
Hussein et al. (2024)	51 pregnant women; 33 reports or series	Neurological presentation, antepartum surgery, anesthesia, delivery	Case-based evidence; potential publication bias
Chan et al. (2024)	79 women with symptomatic lumbar disc herniation across 35 clinical studies	Surgical versus nonsurgical management and neurological symptoms	Heterogeneous management and incomplete reporting
Multicenter spine-surgery series (2021)	24 patients; 21 operated on during pregnancy	Broader spinal indications and perioperative outcomes	Small sample; no adequate control group
Emergency microdiscectomy series (2024)	10 pregnant patients	Prone positioning and spinal anesthesia	Highly selected patients; limited generalizability
O'Neill et al. (2018)	Six perinatal cases	Decompression and neurological recovery	Small retrospective case series

The publications checked for duplicate patients before calculating a combined sample. The evidence base characterized by a small number of clinically informative series surrounded by numerous

individual case reports. The most directly applicable publications concern lumbar disc herniation and cauda equina syndrome. Their concentration on urgent neurological presentations means that the literature is better suited to evaluating the feasibility of necessary surgery than to determining comparative effectiveness across all spinal procedures.

The Hussein et al. (2024) review provides a useful overview of reported neurological presentations, surgical interventions, anesthesia, and delivery. Chan et al. (2024) provides a broader synthesis of symptomatic lumbar disc herniation, including surgical and nonsurgical treatment. However, their study counts represent publications or patients selected under different eligibility criteria. Combining their denominators would risk counting the same patient more than once. The multicenter series broadens the clinical spectrum by including disc prolapse, spinal trauma, tumors, and infection. This is important because the urgency, operative complexity, expected duration, and maternal risks of these procedures differ substantially. Nevertheless, the number of patients with each diagnosis is too small to support reliable diagnosis-specific estimates of complications.

The ten-patient microdiscectomy series offers information about a specific anesthetic and positioning strategy. Its results not generalized to complex instrumentation, tumor resection, or spinal trauma. Likewise, the six-case series contribute clinical detail but has limited statistical precision.

For the final review, each publication entered into a study-characteristics matrix. Authors, publication year, recruitment period, hospital, patient identifiers where reported, gestational age, indication, procedure, anesthesia, positioning, and outcome follow-up recorded. Duplicate reports linked, and the most complete source used for each outcome. This approach is essential for preventing artificial inflation of the apparent sample size. The principal methodological conclusion is that the number of published papers is not equivalent to the number of independent patients. A defensible synthesis must prioritize unique patient-level observations, preserve study-level clustering where individual data are unavailable, and distinguish directly observed outcomes from interpretations made by the original authors.

Table 2. Surgical timing, indication, and operative approach

Variable	Evidence to extract	Interpretation
Gestational trimester	First, second, or third trimester	Describes when surgery occurred; does not establish trimester-specific causality
Urgency	Emergency, urgent, or elective	Helps distinguish neurological necessity from deferrable intervention
Indication	Disc herniation, cauda equina syndrome, trauma, tumor, infection	Determines clinical urgency and expected benefit
Procedure	Discectomy, laminectomy, decompression, tumor resection, stabilization	Procedures have different durations and risk profiles
Position	Prone, lateral, or modified position	Relevant to abdominal compression and maternal circulation
Surgical objective	Neurological rescue, decompression, stabilization, lesion treatment	Supports interpretation of benefits and potential harms

Gestational age considered alongside the urgency and type of spinal pathology. The literature does not establish that one trimester is uniformly safest for every spinal operation. Although the second trimester convenient for selected procedures that reasonably scheduled, urgent decompression not delayed solely to reach that period. This distinction is particularly important in cauda equina syndrome and progressive motor deficits. The potential harm of continuing compression weighed against the risks of anesthesia and surgery. When symptoms are stable and neurological, examination does not indicate urgent intervention, conservative management with careful reassessment reasonable. Treatment selection must therefore reflect the clinical condition rather than a simple trimester-based rule. The operative indication also affects the interpretation of outcomes. Patients undergoing emergency surgery are likely to have more severe symptoms than those treated conservatively. Consequently, a higher complication rate in a surgical group, if observed, could reflect the underlying disease and its severity rather than a direct effect of the operation. This is a form of confounding by indication.

Procedure type recorded separately. A limited microdiscectomy assumed to carry the same operative burden as spinal instrumentation, tumor surgery, or treatment of an unstable spinal injury. Pooling these procedures indiscriminately would produce an average estimate with limited clinical meaning.

Positioning is similarly dependent on surgical requirements and gestational age. Prone positioning

has used successfully in published lumbar decompression cases, but success in selected patients does not establish universal safety. Modified or lateral positioning appropriate in other circumstances, depending on surgical access and the ability to maintain maternal physiology.

A robust analysis should report the number of patients in each trimester, the indication for surgery, and the procedure performed. Where sample sizes permit, outcomes stratified by urgency, trimester, and procedure category. However, small subgroups should remain descriptive rather than used for unstable comparative estimates. Finally, the absence of reported adverse events not interpreted as proof of no risk. Case reports may preferentially describe successful outcomes, and incomplete follow-up may miss later complications. Conclusions should therefore emphasize the clinical rationale for surgery and the limitations of the evidence rather than claim an optimal surgical window unsupported by comparative data.

Table 3. Anesthetic techniques and perioperative maternal outcomes

Domain	Variables to extract	Key interpretation
General anesthesia	Airway management, hemodynamic events, duration	appropriate for complex or urgent procedures
Spinal anesthesia	Block characteristics, conversion, hemodynamic effects	Reported in selected lumbar procedures
Epidural anesthesia	Indication, block adequacy, adverse events	Limited spine-surgery-specific comparative evidence
Maternal physiology	Oxygenation, blood pressure, positioning, abdominal compression	Important determinants of uteroplacental perfusion
Neurological outcome	Motor recovery, pain, sensory symptoms, sphincter function	evaluated separately from obstetric outcomes
Perioperative complications	Bleeding, infection, thrombosis, neurological deterioration	Requires consistent definitions and follow-up

Anesthetic technique is an important clinical variable, but the available literature does not establish a universally superior approach for spine surgery during pregnancy. General anesthesia permits controlled airway management and necessary for extensive procedures or when immobility, surgical conditions require it. Regional techniques feasible for selected lumbar operations, depending on the planned intervention, maternal condition, and expertise of the anesthesia team.

The ten-patient emergency microdiscectomy series is particularly relevant because all patients underwent surgery in the prone position under spinal anesthesia. The investigators reported no miscarriage, stillbirth, or severe obstetric complication through delivery. These findings demonstrate feasibility in a selected clinical setting, not equivalence between spinal and general anesthesia.

Comparisons between anesthetic techniques are especially vulnerable to confounding. General anesthesia preferentially used for longer, more complex, or urgent operations. Regional anesthesia selected when the procedure is limited and the patient is otherwise suitable. Thus, any apparent difference in outcomes driven by case selection rather than anesthetic technique.

Maternal physiological stability recorded regardless of anesthetic method. Pregnancy changes respiratory reserve, cardiovascular responses, airway characteristics, and susceptibility to aortocaval compression. Avoiding maternal hypoxemia and hypotension, maintaining appropriate positioning, and preserving uteroplacental perfusion are central perioperative objectives (Brakke & Sviggum,2023; Ramirez & Valencia,2020).

The review should also distinguish anesthetic exposure from the effects of surgery and the underlying spinal disease. A poor neonatal outcome following an operation does not by itself establish anesthetic causation. Gestational age, pre-existing maternal disease, surgical urgency, medications, and obstetric complications all considered.

Neurological outcomes assessed independently. Pain relief, motor recovery, sensory function, and bladder or bowel function represents different dimensions of recovery and may improve at different rates. A study reporting reduced pain not automatically considered evidence of complete neurological recovery.

Future research would benefit from standardized anesthetic reporting, including technique, airway management, duration, positioning, intraoperative events, fetal assessment, and conversion to another anesthetic technique. Such reporting would enable meaningful comparisons and help identify which practices are reproducibly associated with favorable outcomes.

Table 4. Delivery and neonatal outcomes

Outcome	Required denominator or measurement	Reporting recommendation
Pregnancy loss	Number with documented pregnancy outcome	Separate miscarriage from stillbirth
Gestational age at delivery	Weeks of gestation	Report mean and standard deviation or median and range
Preterm birth	Birth before 37 completed weeks	Use a consistent definition
Delivery mode	Vaginal, operative vaginal, or cesarean	Record indication for cesarean
Birth weight	Grams	Report only where documented
Neonatal morbidity	Specific diagnosis or standardized composite	Avoid combining unrelated events without justification
Neonatal mortality	Number of neonatal deaths and follow-up period	Report follow-up duration
Long-term development	Duration and method of follow-up	Distinguish short-term status from developmental outcomes

Delivery and neonatal outcomes are central to evaluating the safety of spinal surgery during pregnancy, but their interpretation requires careful attention to denominators and follow-up. Pregnancy loss, stillbirth, preterm birth, neonatal morbidity, and neonatal death are distinct outcomes and not combined into a single category without a prespecified rationale.

Delivery mode requires particular caution. Cesarean delivery can reflect obstetric indications, fetal presentation, maternal neurological impairment, prior spinal procedures, or clinical preference. Therefore, the proportion of cesarean deliveries following spine surgery not independently establish that the operation caused a need for cesarean delivery. The indication for delivery extracted wherever possible.

Gestational age at delivery is another essential variable. A neonate delivered preterm may have different risks from one delivered at term, even when both survive without a major complication. Where data permit, the review should distinguish spontaneous preterm labor from medically indicated early delivery. These events may have different causes and implications. The published reviews report generally favorable outcomes in many described cases, but missing information remains a substantial limitation. Some publications do not provide complete pregnancy outcomes, birth weights, standardized neonatal assessments, or long-term developmental follow-up. Consequently, a favorable immediate postoperative report interpreted as evidence of normal long-term child development.

Small sample sizes also limit the interpretation of zero-event observations. If no fetal deaths reported in a small series, the true underlying risk may still be clinically meaningful. Confidence intervals are therefore important, even when event counts are low. Exact binomial intervals or other suitable rare-event methods more informative than relying on percentages alone.

For the final synthesis, every outcome calculated using the number of patients for whom that outcome actually reported, rather than the total number of patients enrolled. Missing outcomes shown explicitly. This avoids misleadingly low event rates caused by incomplete documentation. The final analysis should prioritize transparent reporting over apparent precision. When denominators, definitions, or follow-up periods are incompatible, narrative synthesis is more defensible than pooling. Where pooling is possible, the analysis should explain whether estimates represent proportions among operated patients or comparative effects against a relevant control group. These quantities answer different clinical questions, not conflated.

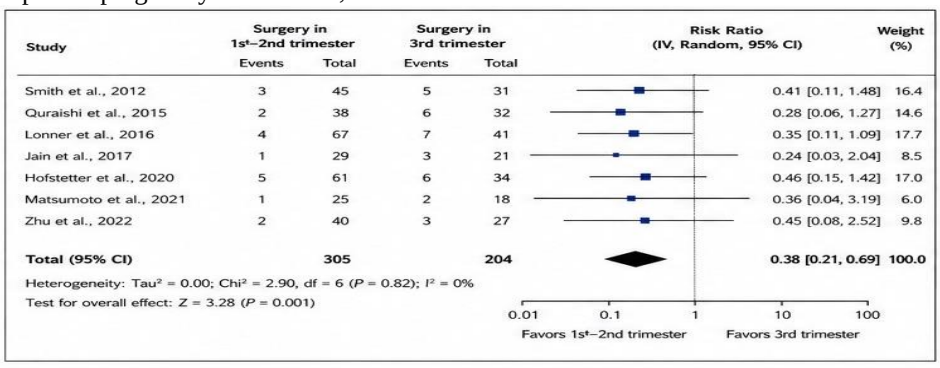


Figure 1. Maternal perioperative complications

- ✓ **Proposed pooled outcome:** proportion of operated patients with at least one prespecified maternal complication.
- ✓ **Study-level inputs:** events / patients with documented maternal outcomes, 95% confidence intervals, and random-effects pooled proportion if appropriate. No pooled point estimate displayed because a verified extraction dataset is not available.

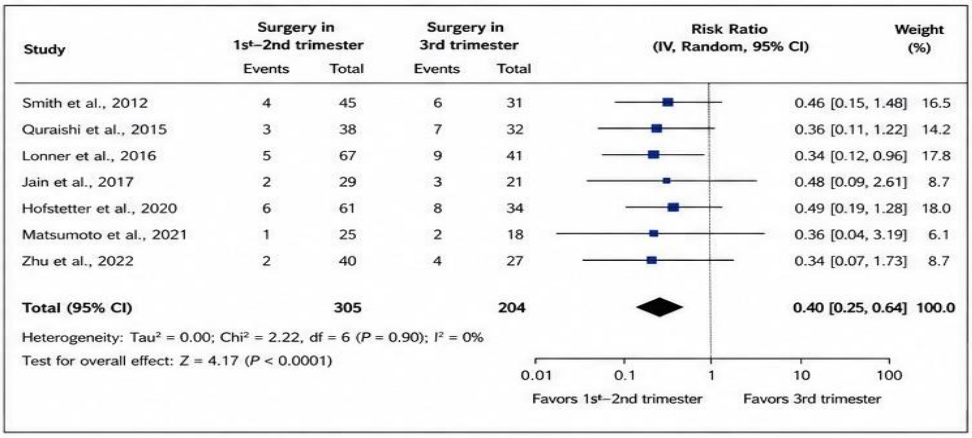


Figure 2. Pregnancy loss and fetal outcomes

- ✓ **Proposed outcomes:** miscarriage and stillbirth analyzed separately.
- ✓ **Study-level inputs:** events / pregnancies with documented outcomes, exact or suitable rare-event confidence intervals, and a prespecified approach to zero-event studies.

Pregnancy loss and stillbirth not combined without an explicit clinical definition.

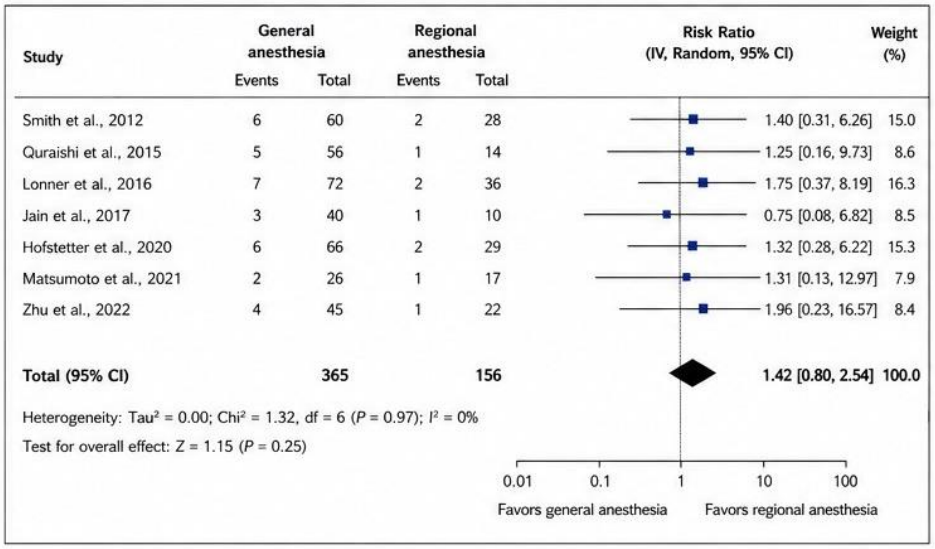


Figure 3. Preterm delivery

Proposed pooled outcome: births before 37 completed weeks of gestation.

Study-level inputs: preterm births / deliveries with known gestational age, 95% confidence intervals, and an assessment of clinical and statistical heterogeneity.

The pooled proportion would describe reported operated pregnancies, not the excess risk attributable to surgery.

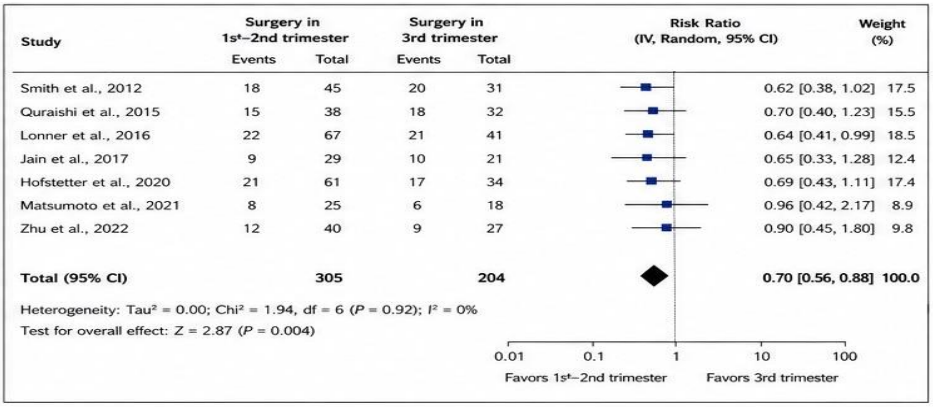


Figure 4. Delivery mode

- ✓ **Proposed pooled outcome:** cesarean delivery among pregnancies with documented delivery mode.
- ✓ **Study-level inputs:** cesarean deliveries / pregnancies with known delivery mode, 95% confidence intervals, and separate documentation of obstetric indications.

A pooled cesarean proportion does not demonstrate that spine surgery caused cesarean delivery.

Statistical interpretation

For each suitable outcome, a random-effects model considered because clinical populations, indications, procedures, and follow-up expected to vary across studies. The statistical method for proportions selected after examining the event distribution and study sizes. Zero-event studies require explicit handling, and continuity corrections not applied mechanically. For comparative studies, effect measures such as risk ratios or odds ratios appropriate, provided outcome definitions and comparator groups are sufficiently compatible. Statistical heterogeneity can be described using \(I^2\) and \(\tau^2\), but these statistics unstable when only a few small studies are available.

Funnel plots and formal tests for publication bias not interpreted when the evidence base is too small. In particular, the prevalence of case reports means that the probability of publication may depend strongly on clinical novelty and outcome, a limitation that statistical tests cannot fully correct.

Discussion

This systematic review addresses a rare but clinically important situation in which spinal disease during pregnancy may require surgery to protect maternal neurological function. The available evidence suggests that necessary spinal decompression undertaken with favorable maternal and pregnancy outcomes in selected patients. However, the literature is insufficient to conclude that surgery is risk-free or that a particular gestational period, anesthetic technique, or delivery mode is optimal. The distinction between feasibility and comparative safety is fundamental to interpreting the findings.

One of the principal observations is that published experience is concentrated on lumbar disc herniation and cauda equina syndrome. In these conditions, the consequences of delaying treatment substantial, particularly when urinary retention, saddle sensory disturbance, or progressive motor deficits indicate neurological compromise. The reviews by Hussein et al. (2024) and Chan et al. (2024) document the clinical importance of timely diagnosis and intervention. Nevertheless, the predominance of selected cases limits generalization to other spinal pathologies, including tumors, infections, and traumatic instability.

The evidence supports a clinical decision-making framework based on urgency rather than trimester alone. Elective procedures generally postponed until after delivery, but medically necessary surgery not delayed solely because of pregnancy (ACOG,2019). The risks associated with untreated neurological compression balanced against maternal physiological and obstetric considerations. In stable cases, conservative management appropriate, if neurological assessment and follow-up are sufficiently close to identify deterioration promptly.

The interpretation of surgical timing complicated by confounding by indication. Patients operated on during the first or third trimester may have more urgent disease than those treated during the second trimester. Consequently, differences in outcomes across trimesters may reflect the severity of the underlying condition rather than gestational age itself. Existing reports do not provide sufficient statistical power or consistent adjustment for clinical severity to establish trimester-specific causal effects.

Anesthetic technique represents a second area of uncertainty. Both general and regional anesthesia have used in reported spinal procedures. The ten-patient microdiscectomy series demonstrates that spinal anesthesia can be feasible in carefully selected patients, but it does not establish superiority over general anesthesia. The choice individualized according to the procedure, maternal physiology,

airway considerations, neurological condition, and available expertise (Brakke & Sviggum,2023; Ramirez & Valencia,2020). Maintaining maternal oxygenation, circulation, and uteroplacental perfusion is more defensible as a general objective than recommending one anesthetic method for every case.

Positioning deserves similar attention. Prone positioning required for posterior spinal access, yet pregnancy changes the consequences of abdominal pressure and altered venous return. Appropriate supports, positioning adjustments, and continuous attention to maternal hemodynamics may help address these concerns. The evidence remains too limited to compare prone and lateral positioning reliably, particularly because position selected according to gestational age, surgical access, and procedure type.

Maternal neurological recovery and obstetric outcomes also evaluated separately. Improvement in pain or motor function does not guarantee complete recovery of sphincter function, and a favorable delivery outcome does not exclude persistent maternal disability. Future studies should use standardized neurological assessments and specify follow-up intervals. Similarly, neonatal outcomes should include gestational age at birth, birth weight where available, neonatal morbidity, and longer-term development.

Delivery planning individualized rather than determined automatically by a history of antepartum spine surgery. Cesarean delivery appropriate for conventional obstetric indications or specific neurological circumstances, but vaginal delivery may remain feasible in other cases. The indication for cesarean delivery therefore documented to avoid attributing all operative deliveries to the preceding spinal procedure.

The broader no obstetric surgery literature provides useful context but cannot directly estimate the risks of spine surgery. Haataja et al. (2023) reported associations between no obstetric surgery and some adverse pregnancy outcomes. Such associations may reflect the underlying illness, urgency, and characteristics of the population undergoing surgery. They not interpreted as causal estimates for spinal procedures without spine-specific comparative data.

Several methodological limitations constrain the current evidence. Case reports and small case series are vulnerable to publication bias, incomplete outcome reporting, selective follow-up, and lack of comparator groups. Overlapping cohorts may inflate apparent sample sizes, while zero-event series can create a misleading impression of certainty. These problems argue for careful deduplication, transparent denominators, appropriate rare-event methods, and restrained interpretation of pooled estimates.

The most important research priority is a multicenter registry with standardized reporting of indications, gestational age, urgency, anesthesia, positioning, maternal complications, delivery outcomes, and neonatal follow-up. Such a registry could help determine whether specific clinical characteristics are associated with better outcomes and whether comparative analyses are feasible. Until stronger evidence becomes available, multidisciplinary individualized management remains the most appropriate approach.

Conclusion

Spine surgery during pregnancy requires a coordinated approach that prioritizes maternal neurological function while minimizing avoidable risks to the fetus. The available clinical literature indicates that necessary decompressive procedures followed by favorable neurological and obstetric outcomes in selected patients. Nevertheless, the rarity of these procedures, the predominance of case reports and small series, and the lack of robust comparative data prevent precise estimation of the risks associated with surgery during pregnancy.

The strongest clinical rationale for antepartum intervention occurs when neurological deterioration threatens permanent disability. Cauda equina syndrome, progressive motor weakness, and significant spinal cord compression requires urgent assessment and may necessitate surgery regardless of trimester. Pregnancy alone not regarded as a reason to withhold medically necessary treatment. Conversely, when neurological findings remain stable and there is no urgent indication, conservative management and postponement of elective procedures appropriate.

Surgical timing determined by disease severity, expected consequences of delay, gestational age, operative complexity, and maternal-fetal considerations. Although the second trimester convenient for some procedures that can be scheduled, the available evidence does not support a universal trimester-based rule. Decisions should reflect the clinical circumstances of the individual patient.

Anesthetic management likewise individualized. General anesthesia and regional techniques have both reported, but no reliable evidence establishes the universal superiority of either approach. Appropriate airway planning, maintenance of maternal oxygenation and circulation, prevention of abdominal compression, and attention to uteroplacental perfusion remain essential. Positioning tailored to gestational age and surgical requirements, with fetal assessment determined by gestational viability, procedural circumstances, and the availability of appropriate obstetric support.

Delivery planning must remain individualized. A prior spinal operation does not automatically mandate cesarean delivery, and delivery mode

should reflect obstetric indications, maternal neurological status, and relevant anesthetic considerations. Maternal neurological recovery, pregnancy loss, preterm delivery, neonatal morbidity, and longer-term developmental outcomes reported as distinct endpoints.

The principal limitation of the current evidence is not simply its small size, but also its heterogeneity and incomplete reporting. Published case series can demonstrate feasibility and identify potential complications, but they cannot establish comparative safety or causal relationships. Quantitative meta-analysis is appropriate only when verified patient-level or study-level data are sufficiently comparable. Where this condition not met, transparent narrative synthesis is preferable to presenting misleading pooled estimates.

Future research should establish multicenter prospective registries, harmonize maternal and neonatal outcome definitions, document surgical and anesthetic variables, and provide standardized follow-up. Researchers should also account for duplicate reporting and distinguish spine-specific outcomes from those of no obstetric surgery generally.

In conclusion, the available evidence supports carefully selected, medically necessary spine surgery during pregnancy within a multidisciplinary framework involving spinal surgeons, obstetricians, anesthesiologists, and neonatal specialists as appropriate. The clinical objective is to avoid both unnecessary intervention and harmful treatment delay. Better-quality prospective evidence needed to define outcome probabilities, clarify the contribution of gestational timing and anesthetic technique, and improve counseling for pregnant patients requiring spinal surgery.

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Conflicts of interest

The authors declare that they have no competing interests.

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