

Review article

Hemodynamic adaptation after spinal anesthesia in cesarean section

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Abstract

Neuraxial anesthesia is the preferred technique for cesarean section (CS), as recommended by the National Institute for Health and Care Excellence. Among these, spinal anesthesia (SA) is preferred over general anesthesia for its rapid onset, reliable blockade, and improved maternal safety. In addition, it minimizes airway-related complications such as failed intubation and aspiration while allowing maternal consciousness and early maternal–neonatal bonding. CS involves the surgical delivery of the fetus, placenta, and amniotic fluid through abdominal and uterine incisions and is typically indicated in maternal or fetal compromise. Despite its advantages, SA is commonly associated with considerable hemodynamic changes, particularly post-spinal hypotension, which is a major concern in obstetric anesthesia, and a potential health risk. Previous studies have primarily focused on hypotension management using vasopressors or fluid therapy, often in isolation. As a result, a comprehensive understanding of the overall hemodynamic adaptation following SA remains limited. The incidence of hypotension varies widely (29.0%–80.0%), thus reflecting the complexity of maternal cardiovascular responses. Moreover, dynamic parameters such as cardiac output, systemic vascular resistance, and maternal–fetal circulatory interactions have been insufficiently explored. The objective of this review is to critically synthesize contemporary evidence regarding the physiological mechanisms, determinants, and management strategies underlying hemodynamic adaptation following SA in CS. This narrative review was conducted through a comprehensive literature search across major electronic databases, including PubMed, Google Scholar, and the Cochrane Library, focusing on studies that address hemodynamic changes and management strategies associated with SA during CS. It examines the mechanisms and determinants of SA-induced hypotension, including maternal positioning, body mass index, and drug effects (oxytocin, propofol, thiopental, opioids, and local anesthetics). Furthermore, it discusses preventive and management strategies, including vasopressors, mechanical measures, and optimized fluid therapy, with special consideration for pre-eclampsia. In conclusion, hemodynamic adaptation following SA is multifactorial. It requires an individualized, multimodal management approach to preserve maternal cardiovascular stability and optimize fetal outcomes, and future research should focus on establishing standardized, evidence-based preventive strategies. Early identification of high-risk patients and optimized vasopressor-based management strategies may improve maternal hemodynamic stability and fetal outcomes during CS delivery under SA.

Keywords: Cesarean section, hemodynamic adaptation, post-spinal hypotension, spinal anesthesia.

According to the most recent National Institute for Health and Care Excellence (NICE) guidelines, neuraxial anesthesia is the standard treatment for women having a cesarean section (CS). Spinal

anesthesia (SA) is generally preferred over general anesthesia (GA) because it reduces the risk of pulmonary aspiration or failed endotracheal intubation. Other benefits include facilitating immediate bonding between the mother and her neonate, rapid onset of action, higher efficacy, faster recovery, reduced toxicity, and a lower risk of systemic toxicity.⁽¹⁾ A CS is a surgical procedure that entails the incision in the abdominal and uterine walls to deliver the infant and extract the placenta and amniotic fluid.⁽²⁾ In the field

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of medicine, there are two categories of causes that necessitate surgery: those that involve the mother and those that involve the fetus. A variety of fetal causes, including an abnormally large infant, fetal distress, placental issues, anomalies in the umbilical cord, or the presence of twins, may result in pregnancy complications. Maternal factors encompass numerous variables, including age, the number of children the mother had, anomalies in the birth canal, abnormalities in the contractions during delivery, premature rupture of membranes, and pre-eclampsia. The fear of giving birth in pain, the incapacity to push, traumatic experiences from previous pregnancies, and the belief that the time and date of their child's birth determine their intimate relationships during a vaginal delivery contribute to the rising incidence of CSs.⁽³⁾ For elective CSs, SA is the method of choice worldwide. This type of anesthesia is fast-acting and simple to administer, offering superior maternal and neonatal safety compared with GA. When compared with GA, which involves airway manipulation and the potential for failed intubation and aspiration complications, SA mitigates these risks and minimizes maternal and fetal exposure to intravenous anesthetic agents. SA allows the mother to remain conscious during childbirth, facilitating an immediate bonding experience with the infant. These advantages have firmly established its status as the gold standard for CS delivery. Although SA provides numerous advantages, it also introduces various potential complications. Maternal hypotension is the most critical and recurring issue among the numerous potential adverse effects, as it occurs in approximately 70.0% – 80.0% of cases.⁽⁴⁾ The most severe form of hypotension, which results in the manifestation of maternal symptoms such as nausea, vomiting, and vertigo, is represented by the loss of consciousness. SA, which is employed during CS surgery, offers various advantages, including rapid drug action, profound sensory and motor blocking, uncomplicated procedures, minimal impact on the neonate, and a modest risk of anesthetic drug toxicity. One of the many risks that must be considered when SA is used during surgery is the possibility of hemodynamic abnormalities in the mother.⁽⁵⁾ SA brings on blood pressure fluctuations and other hemodynamic changes in the cardiovascular system. The body's reaction to a drop in systemic vascular resistance is an increase in cardiac output (CO), which causes these changes. Aortocaval suppression during pregnancy can substantially reduce CO.⁽⁶⁾ However, because there is a compensatory process that involves

an increase in vascular tone, the suppression of the aortocaval area does not always result in an increase in blood pressure. Maternal hypotension is a notable adverse consequence of SA in women who undergo CS. It has a substantial effect on the well-being of the mother and fetus, highlighting the need for effective management strategies.⁽⁷⁾ The management strategies employed vary from prophylactic measures, such as maternal repositioning and leg wrapping, to more extensive interventions, including fluid administration, vasopressors, and anesthetic dose adjustment.⁽⁸⁾ Maternal conditions such as diabetes, pre-eclampsia, and chronic kidney disease further influence the management approach, as the factors that contribute to blood pressure variations in these conditions dictate the management of hypotension. The optimal strategy is determined by factors such as the degree of hypotension, maternal comorbidities, and the balance between the benefits and risks of the selected method. The most frequently employed method is SA due to its rapidity, reliability, and ease of achieving appropriate anesthesia.⁽⁹⁾ Despite the widespread use of SA for CS delivery and the extensive body of literature describing its clinical benefits and associated complications, several important gaps remain in the current understanding of optimal strategies for the prevention and management of SA-induced maternal hypotension. Current studies have primarily focused on isolated preventive interventions such as fluid preloading, vasopressor administration, or maternal positioning. In contrast, comprehensive analyses integrating these strategies and evaluating their combined effects on maternal hemodynamic stability and neonatal outcomes remain limited. Furthermore, heterogeneity in study populations, anesthetic techniques, and outcome assessment methods has resulted in inconsistencies in the available evidence. Consequently, there is a growing need for a comprehensive synthesis of recent literature to clarify the mechanisms underlying SA-induced hypotension and to critically evaluate the effectiveness of the current management approaches. Therefore, the present review aims to systematically examine contemporary evidence regarding the incidence, pathophysiological mechanisms, and management of hypotension associated with SA in women undergoing CS. The objective of this review is to consolidate existing knowledge on preventive and therapeutic strategies, identify persistent research gaps, and provide directions for future investigations to improve maternal hemodynamic stability and optimize fetal outcomes.

Materials and methods

This study was conducted as a narrative review and did not follow a formal systematic review protocol. A structured literature search was performed using electronic databases including PubMed, Google Scholar, HINARI, and the Cochrane Library. Relevant articles published between 2010 and 2025 were identified using keywords such as “spinal anesthesia,” “cesarean section,” “hemodynamic changes,” and “post-spinal hypotension.” Boolean operators (AND, OR) were applied to refine the search strategy. Studies focusing on hemodynamic alterations, risk factors, and management strategies associated with SA during CS delivery were included. Clinical trials, observational studies, and relevant review articles were considered. Non-English articles, duplicate studies, and studies not directly related to the topic were excluded. Article selection was based on relevance, methodological quality, and contribution to the understanding of the subject.

Anesthesia in CS

The CS and the patient's asthmatic respiratory status determines the selection of anesthesia for CS. The elimination of the need for intubation, which can affect the airway and potentially reduce the incidence of bronchospasm from airway manipulation, is a benefit of SA for patients with asthma. SA may be harmful to people with uncontrolled asthma in the case of a high motor block because it reduces ventilatory capacity. Even though a drop in blood pressure is a normal reaction to SA, a substantial drop may be considered critical and require management depending on the patient's clinical status. Hemorrhage or inadequate fluid replacement can reduce circulating plasma volume, contributing to perioperative hemodynamic instability. In addition, intraoperative insensible fluid losses, particularly evaporative losses from exposed tissues, may further exacerbate intravascular volume depletion, and these losses tend to increase with the size and exposure of the surgical incision.⁽¹⁰⁾ Furthermore, a lowered heart rate (HR) contributes to a postoperative drop in blood pressure. In CS, the most frequent cause of maternal morbidity and mortality is complications from anesthesia. Intubation failure and pulmonary aspiration of stomach contents are the most frequent complications in procedures performed under GA. High levels of neural block and local anesthetic toxicity are the primary

causes of death in regional anesthesia. Since the advent of regional anesthesia, the rates of maternal mortality associated with anesthesia in CS operations have declined. Regional anesthesia provides various advantages, including a decreased risk of aspiration due to the preservation of airway reflexes and spontaneous respiration, a reduced risk of neonatal resuscitation, an earlier initiation of breast-feeding, improved postoperative analgesia, less postoperative vomiting, and an earlier recovery of gastrointestinal motility. The development of maternal hypotension during surgery may be attributed to bradycardia, decreased venous return, and systemic vascular resistance because of a higher level of block and medicinal sympathectomy.⁽¹¹⁾ It is essential to prevent maternal hypotension and stabilize maternal hemodynamic status in expectant patients during SA. To mitigate maternal hypotension, vasoactive substances and intravenous crystalloid infusions have been implemented preoperatively and intraoperatively.

Hypotension in SA

SA is administered into the epidural space, thereby inhibiting sympathetic output and enhancing parasympathetic activity. This leads to vasodilation, reduced venous return, and reduced CO. Furthermore, the gravid uterus's aortocaval compression further diminishes venous return, which results in the development of hypotension.⁽¹²⁾ Maternal baseline physiological parameters, such as systolic blood pressure (SBP), HR, low maternal gestational weight gains (<11 kg), and multiparity with a prior history of SA-induced hypotension, are predictors of hypotension risk. The supine stress test and other conservative methods have demonstrated promising sensitivity (55.0% – 60.0%) and specificity (80.0 %–90.0%) for predicting hypotension. Other potential determinants include the velocity time integral, inferior vena cava collapsibility index, pleth variability index, and perfusion index.⁽¹³⁾ Furthermore, it has been determined that the corrected blood flow time of the carotid artery is a reliable indicator of hypotension induced by SA. The hypotension predictive index, a machine-learning-based metric, has also been suggested as a tool for predicting maternal hypotension. Mothers who had infants weighing ≥ 4 kg were at a 5-fold higher risk than those who had newborns weighing ≤ 2.4 kg. Moreover, the risk of hypotension was 2-fold when the sensory block was present above T6.⁽¹⁴⁾ Hypotension may be identified by maternal vertigo,

vomiting, and an extended recovery period and is defined as a stay in the recovery room for a minimum of 45 min following an elective CS. It may result in more severe repercussions, including maternal bradycardia, unconsciousness, and subsequent pulmonary aspiration. Biomarkers such as oxypurines and lipid peroxides are elevated in the umbilical vein, which suggests that the newborn experienced ischemia-reperfusion injury. This was particularly important if the hypotension lasted longer than 2 min. Hypotension, which is defined as a drop in mean arterial blood pressure of more than 30.0% within 10 min of the action or a drop in SBP of more than 10.3% within the first 30 min, is the outcome of SA induction.⁽¹⁵⁾ Bradycardia- and tachycardia-related hypotension are the two types of hypotension that occur during SA. Ephedrine is used as a vasopressor, and most anesthesiologists use fluid therapy or phenylephrine together with patient position changes to control hypotension during SA. Hemodynamic changes include mean arterial pressure, pulse frequency, and hypotension. A hypotensive state is indicated by a mean arterial pressure of < 70 mmHg. Patients undergoing a CS may experience hemodynamic alterations, including increased pulse frequency and decreased mean arterial pressure, diastolic pressure, and systolic pressure, when SA methods are used. This can lead to severe complications, such as hypotension. Fredy FM, *et al.*

demonstrated that patients' hemodynamics were altered following CS with SA.⁽¹⁶⁾ The uteroplacental system is incapable of autoregulation because of the complete dilation of the placental blood vessels. The sole determinant of uteroplacental perfusion is maternal blood pressure, and the lowest blood pressure limit that can be compensated to ensure adequate human uteroplacental perfusion has not been established. To protect the mother and neonate, it is essential to identify and address a substantial decrease in maternal blood pressure. Low blood pressure reduces APGAR scores. Infant acidosis may be alleviated by brief hypotension (not exceeding 2 min), but neurobehavioral consequences are unaffected.⁽¹⁷⁾ The key risk factors and their underlying mechanisms associated with post-spinal hypotension are summarized in **Table 1**.

Induction position

It is recommended that patients sit with one leg hanging over the edge of the bed and keep their spines bent to support the opening of the intervertebral space. The lateral position is characterized by the patient lying on their side, with a pillow strategically positioned along their back, potentially along their buttocks, and a pillow between their flexed legs to prevent hip adduction and internal rotation. This may enhance patient comfort and hemodynamic status, reduce gastroesophageal reflux, facilitate drainage of respiratory secretions, and

Table 1. Risk factors and mechanisms of post-spinal hypotension in cesarean section.

Risk factor	Underlying mechanism	Clinical impact
Maternal supine position	Aortocaval compression reduces venous return and cardiac output	Increased risk of hypotension and fetal hypoperfusion
High spinal block (above T6)	Extensive sympathetic blockade leading to vasodilation and reduced systemic vascular resistance	Severe and rapid drop in blood pressure
Increased BMI (obesity)	Elevated intra-abdominal pressure and enhanced aortocaval compression	Higher incidence and severity of hypotension
Large fetal size	Increased uterine compression of major vessels	Reduced cardiac output and placental perfusion
Baseline low blood pressure	Limited physiological reserve to compensate for sympathetic blockade	Greater susceptibility to hypotension
Use of vasodilatory drugs	Direct vascular smooth muscle relaxation and reduced systemic vascular resistance	Exacerbation of hypotensive episodes
Oxytocin administration	Peripheral vasodilation and transient decrease in systemic vascular resistance	Sudden drop in blood pressure
Rapid onset of spinal anaesthesia	Abrupt sympathetic blockade causing sudden vasodilation	Acute hemodynamic instability

BMI, body mass index.

improve arterial blood oxygenation. The maternal position influences hemodynamics by altering the diffusion of local anesthetics. Research on various maternal positions has produced inconsistent results regarding the rapidity of block onset and hemodynamic stability. The diffusion of local anesthetic can influence the hemodynamic consequences, the rapidity of onset of the sensory block, and the position. SA complications are classified as minor or major based on their position. The distribution of local anesthetics is affected by the patient's posture, block height, and volume status, all of which influence the degree of hypotension.⁽¹⁸⁾ The maternal position can influence the pace of hemodynamic effects. According to recent research, intraoperative nausea and vomiting are a common occurrence during CSs performed under SA, accounting for up to 80.0% of cases. Pregnant women are more susceptible to nausea and vomiting due to their pregnancy and position.⁽¹⁹⁾ According to Obasuyi BI, *et al.*, the incidence of hypotension was 56.0% in the recumbent group and 34.0% in the lateral group.⁽²⁰⁾ In the lateral group, Manouchehrian N, *et al.* reported a rate of 24.5%, while the rate was 57.7% in the seated group.⁽²¹⁾ Coppejans HC, *et al.* reported that the patients in the seated position experienced substantially fewer technical challenges during the initial identification of the intrathecal space.⁽²²⁾ The traditional position is outweighed by the overall benefit of the lateral position over the seated position. To preserve hemodynamic status, SA should be administered in the lateral rather than the seated position.

Body mass index (BMI)-induced hypotension

Hypotension in obstetric patients is concerning because, in addition to occurring more frequently, it can have serious maternal–fetal consequences, such as a higher incidence of nausea and vomiting, fetal hypoxia brought on by changes in utero-placental blood flow and resulting fetal acidosis. Post-regional anesthetic hypotension can be defined in various ways, including a drop in SBP to below 100 mmHg.⁽²³⁾ As there is a lack of research comparing the complications of SA in pregnant women with increased weight to those of eutrophic patients for CS, including hypotension, this analysis is necessary given the high prevalence of obesity among pregnant women. A substantial rise in the incidence of obesity in the general population is what the World Health Organization defines as a pandemic. According to

Brazilian research, obstetric patients have exhibited a similar trend, with a frequency of approximately 5.5% throughout pregnancy.⁽²⁴⁾ Hartmann B, *et al.* assessed the risk variables for post-SA hypotension in the general population and found that individuals with a history of hypertension, persistent alcohol addiction, and an elevated BMI were more vulnerable.⁽²⁵⁾ Certain modifications that are associated with pregnancy subject the cardiovascular system of expectant women to stress, which is exacerbated by obesity. In the immediate aftermath of labor, CO experiences a substantial increase, surpassing pre-pregnancy levels by as much as 75.0%, and in patients with obesity, it is further intensified. As obesity increases peripheral vascular resistance during pregnancy, the patient with obesity has a reduced degree of afterload reduction. These individuals originally had left ventricular hypertrophy due to increased volemia.⁽²⁶⁾ The persistent increase in blood pressure caused by the hypervolemic condition caused the heart to gradually dilate, which sometimes resulted in systolic dysfunction. An increase in CO and basal HR may exacerbate pregestational hypertension and result in diastolic dysfunction. Hypoxemia, sleep apnea, and supine posture may aggravate this clinical presentation. These individuals have higher rates of morbidity and mortality due to the possibility of supine hypotension syndrome. Increased vascular inflammation, endothelial dysfunction, and dyslipidemia are all effects of obesity. This endothelial dysfunction raises the risk of hypertension during pregnancy. The high prevalence of comorbidities such as obesity, hypertension, and diabetes increases perioperative risk and complicates anesthetic management by amplifying cardiovascular instability. The likelihood of problematic airways is elevated by the combination of obesity and pregnancy, which is a frequent source of concern in the emergency department. The reason for this is that obesity is linked to a delayed rate of gastric evacuation. If a single dose is administered to these patients, the level of spinal blockade is typically more unpredictable and exaggerated than in an expectant woman without obesity.⁽²⁷⁾ During a typical pregnancy, hypotension is almost always present in conjunction with SA, but in expectant women, aortocaval compression may be more pronounced. Because volume expansion based on total weight can be beyond maximum cardiac compliance, the possibility of hypervolemia in pregnant women who are extremely obese leads to a reevaluation of volemia expansion based on patient

weight. The physiology of hypotension is influenced by an imbalance between endogenous vasoactive chemicals, and decreases in angiotensin II, as well as increases in prostaglandins and nitric oxide, are more critical than sympathetic blockade and aortocaval compression.⁽²⁸⁾ Patients with pre-eclampsia are subject to the same variables and are less likely to experience hypotension episodes. Because of decreased concentrations of local anesthetics and reduced need for pharmacologic treatment, SA has demonstrated a decrease in the frequency and severity of hypotension. As an alternative to regional anesthesia in this patient population, sequential blockades and other combined anesthetic techniques have been suggested in numerous studies. In addition to eliminating the method's temporal constraints, this approach enables administration of lower intrathecal concentrations of local anesthetics. To avoid the dire circumstance of conversion to GA, the blockade should be evaluated and enhanced before the surgical incision. There has been a noticeable increase in maternal obesity. New prospective studies that use the neuroaxis's integrated sequential anesthetic approaches are necessary to induce and administer anesthesia in those individuals and to establish safe and effective doses.⁽²⁹⁾ Prioritizing the particular therapy of those patients is essential for the safety of the mother and fetus.

Drug-induced hypotension

Vasopressors such as mephentermine, phenylephrine, and norepinephrine, except ephedrine, are better for managing hypotension, with low rates of reactive hypertension or rhythm changes.

Oxytocin

The timing of oxytocin administration during the pre-labor CS to prevent postpartum hemorrhage varies across studies and may even be initiated before fetal delivery to induce uterine contraction. During early labor, uterine contractions increase HR and induce autotransfusion (300–500 mL) from the uterus to the systemic circulation with each contraction. Women who underwent pre-labor CS at term under SA and initiated oxytocin after fetal delivery experienced a substantially higher incidence of hypotension than those who initiated it at skin incision.⁽³⁰⁾ The women's cumulative oxytocin and phenylephrine concentrations were also reduced, and the preoperative administration of oxytocin enhanced CO and SBP, which aided in

the maintenance of hemodynamic status following SA. Various regimens have been reported for the timing, dosing, and rate of oxytocin administration during CS. Doses ranging from 0.5 to 10 U have been reported to maintain uterine tone and reduce blood loss, even during non-elective CS. Torloni MR, *et al.* conducted an observational study in which oxytocin was initiated preoperatively, resulting in a smaller blood pressure drop and a smaller increase in HR compared with initiation after fetal delivery.⁽³¹⁾ Preoperative administration of prophylactic oxytocin may induce uterine contractions, which could lead to autotransfusion from the uterus to the maternal circulation and a subsequent rise in SBP and CO. This is likely to assist patients in maintaining a more stable hemodynamic state, as evidenced by a less severe drop in blood pressure and a reduced need for vasopressors. The response to the same dose may vary by individual, and the effect of synthetic oxytocin depends on the expression of the uterine oxytocin receptor. Clinical factors, including parity, gestational age, and BMI, may also influence this. Giorgione V, *et al.* observed an increase in cardiac index resulting from increased venous return and stroke volume.⁽³²⁾

Propofol

Propofol is a short-acting intravenous hypnotic agent with rapid onset and context-sensitive clearance that has intricate and dose-dependent cardiovascular effects that necessitate meticulous consideration in parturients undergoing CS under SA. The hemodynamic milieu of SA is primarily characterized by sympathetic blockade, which results in arterial and venous vasodilation, decreased systemic vascular resistance, reduced venous return, and, subsequently, hypotension. Propofol's intrinsic vasodilatory properties, attenuation of baroreceptor reflex sensitivity, and negative inotropic influence on myocardial contractility may exacerbate cardiovascular depression within this physiologic framework.⁽³³⁾ Propofol induces smooth muscle relaxation by modulating intracellular calcium dynamics and enhancing nitric oxide-mediated vasodilation. Furthermore, it centrally suppresses sympathetic outflow, thereby enhancing the sympathectomy induced by neuraxial blockade.⁽³⁴⁾ These effects are of particular clinical importance in obstetric patients because of pregnancy-associated physiological changes, such as increased blood volume, reduced systemic vascular resistance, aortocaval compression,

and increased sensitivity to anesthetic agents. Low-dose propofol infusions may offer maternal comfort without substantial respiratory depression when used for sedation during SA in CS delivery. It is critical to exercise caution during titration to prevent the exacerbation of spinal-induced hypotension. When neuraxial sympathectomy and propofol-mediated vasodilation are combined, the mean arterial pressure may drop considerably, thereby potentially jeopardizing uteroplacental perfusion if vasopressors such as phenylephrine or ephedrine are not immediately administered.⁽³⁵⁾ Furthermore, propofol's rapid redistribution and clearance render it favorable for controlled sedation; however, its effect on maternal hemodynamic stability remains dose-sensitive. Emerging evidence suggests that target-controlled infusion techniques may attenuate abrupt hemodynamic fluctuations compared to bolus administration, thereby optimizing cardiovascular stability during CS under SA. Thus, propofol is a valuable adjunct for sedation during CS performed under SA; however, its pharmacodynamic profile requires judicious dosing, vigilant monitoring, and proactive hemodynamic management to preserve maternal cardiovascular stability and fetal well-being.

Thiopental

Thiopental sodium, an ultra-short-acting barbiturate, has historically played a notable role in obstetric anesthesia, particularly as an induction agent in cases requiring conversion from regional to GA during CS. Due to its favorable maternal and neonatal safety profile, SA remains the gold standard technique for elective CS deliveries. However, thiopental becomes clinically relevant when unexpected intraoperative complications, such as profound hypotension, high spinal block, failed block, or acute fetal distress, necessitate the rapid induction of GA.⁽³⁶⁾ From a hemodynamic perspective, thiopental exerts dose-dependent myocardial depressant effects and causes peripheral vasodilation via the direct suppression of sympathetic outflow and attenuation of baroreceptor reflex activity.⁽³⁷⁾ In parturients already experiencing sympathetic blockade secondary to SA, the addition of thiopental may potentiate systemic vascular resistance reduction, thereby exacerbating hypotension. This synergistic vasodilatory effect may compromise uteroplacental perfusion if not meticulously managed with vasopressors,

intravenous fluid optimization, and left uterine displacement to prevent aortocaval compression. Pharmacodynamically, thiopental rapidly crosses the blood-brain barrier due to its high lipid solubility, thus producing expeditious hypnosis within 30–40 s.⁽³⁸⁾ However, its redistribution kinetics, rather than metabolism, primarily determine its short duration of action. In pregnant patients, physiological changes, including increased plasma volume, decreased plasma protein concentration, and enhanced CO, alter the drug distribution and free fraction availability, thereby potentially modifying the drug's hemodynamic impact. Furthermore, thiopental readily crosses the placenta, and although brief exposure during rapid-sequence induction is generally associated with minimal neonatal depression, excessive dosing or prolonged induction-to-delivery intervals may result in transient neonatal respiratory suppression.⁽³⁹⁾ Therefore, careful titration (typically 3–5 mg/kg) and adherence to rapid delivery protocols are crucial to balance maternal hemodynamic stability with fetal safety. Thus, the pharmacological profile of thiopental is crucial in circumstances that require emergency GA, even if it is not commonly utilized in simple SA for CSs. Optimizing maternal hemodynamic adaptation and ensuring positive perinatal outcomes require a comprehensive understanding of the cardiovascular effects of SA, particularly the sympathetically attenuated state it induces.

Fentanyl and morphine

The medical practice of reducing the dosage of local anesthetics and incorporating opioid adjuvants has gained popularity as a method to achieve adequate levels of anesthesia without causing hemodynamic instability. The selection of an appropriate opioid adjuvant (morphine or fentanyl) is a critical factor in the modification of hemodynamic responses during SA administration. The pharmacokinetic and pharmacodynamic properties of fentanyl and morphine are distinct, resulting in different effects on maternal hemodynamic parameters. Lipophilic opioids, including fentanyl, offer clinical benefits such as rapid onset and minimal rostral spread. However, they are linked to the potential for abrupt respiratory depression and muscle rigidity. For postoperative pain treatment, morphine, as a hydrophilic opioid with a long-lasting analgesic effect, is an appropriate choice. However, it may cause hemodynamic instability (hypotension and bradycardia), acute respiratory depression or stoppage,

a biphasic pattern, and considerable rostral spread within the first 24 h. Careful examination and understanding of these distinctions substantially improve the selection of analgesics for SA during CS. The precise effect of these analgesics on maternal blood pressure and cardiovascular function remains undefined, indicating a substantial gap in current research. Because maternal hypotension is common and can have negative consequences on the mother and fetus, a direct comparison of intrathecal fentanyl vs. morphine during SA for CS birth is required. In SA, opioid adjuvants can affect oxygenation by modulating central respiratory control, particularly through the depression of brainstem respiratory centers.⁽⁴⁰⁾ The primary therapy for hypotension induced by SA is ephedrine, a combination α - and β -adrenergic agonist. This is because it can elevate CO and systemic vascular resistance. To address clinically important bradycardia that develops after SA procedures, atropine is administered as a therapeutic measure.

Bupivacaine and ropivacaine

Although bupivacaine (1-butyl-N-(2,6-dimethylphenyl)piperidine carboxamide hydrochloride) is the most commonly used hyperbaric local anesthetic, the recent commercial availability of hyperbaric ropivacaine (2S)-N-(2,6-dimethylphenyl)-1-propylpiperidine-2-carboxamide has garnered interest from the anesthesiology community. Ropivacaine is increasingly considered a safe and effective local anesthetic for SA because of its improved hemodynamic stability and reduced incidence of hypotension compared with conventional agents such as bupivacaine.⁽⁴¹⁾ Hyperbaric bupivacaine is often used because of its potent anesthetic qualities and capacity to deliver dependable SA with a regulated distribution of the anesthetic block. The effectiveness and safety of ropivacaine and bupivacaine for SA in non-obstetrical and obstetrical settings have been compared in research that considers adjuvants and varying concentrations. Although both anesthetics are effective, their block properties, side effects, and patient recovery profiles differ. Numerous studies have examined the relative safety and effectiveness of ropivacaine and bupivacaine in SA. The study by Khalil RS, *et al.* found that bupivacaine had a greater hemodynamic effect, although the incidence of hypotension was much higher in our study.⁽⁴²⁾ Ropivacaine offers better hemodynamic stability, as

seen by the far lower incidence of hypotension, even though bupivacaine is associated with quicker sensory onset and a longer analgesia effect. As a result, it is the recommended choice for individuals with a higher risk of cardiovascular disease. These differences highlight how clinical outcomes are affected by medication choice, administration, and research design. Bupivacaine is the suggested choice for prolonged postoperative analgesia; however, ropivacaine is advised for parturients who are hemodynamically fragile. As a result, the best anesthetic option is patient-dependent.

Norepinephrine and ephedrine

Ephedrine is the initial choice of medication for the prevention of maternal hypotension. It has a stimulant effect on α - and β -adrenoceptors, resulting in positive inotropic and chronotropic effects. However, the vasoconstrictive effect may be diminished with repeated ephedrine administration. In addition, α 1 and β 1 stimulation is induced by norepinephrine, which also maintains maternal blood pressure while having a less detrimental impact on HR. Furthermore, the combined impact of ephedrine and norepinephrine on maternal hemodynamics remains to be investigated. Ephedrine is recognized for its ability to release endogenous norepinephrine. Ephedrine has a longer duration of action and a delayed onset than norepinephrine, and it has the longest duration during surgery. The ephedrine group exhibited a higher number of boluses of vasoactive agents.⁽⁴³⁾ Moreover, the number of hypotensive episodes was correlated with the number of vasopressor boluses. Phenylephrine was the initial treatment option for hypotension that occurred during SA in the past decade. CO may be reduced by phenylephrine-induced baroreceptor-mediated bradycardia. Although phenylephrine is effective, it may reduce CO through reflex bradycardia, underscoring the need for careful, patient-specific use. Due to the potential for impaired uteroplacental blood flow, this is an especially important concern in obstetrics. Kee WD, *et al.* demonstrated that the normalized CO was higher in the norepinephrine group than in the phenylephrine group.⁽⁴⁴⁾ Sharkey AM, *et al.* demonstrated that the number of bradycardia episodes was diminished in a norepinephrine group compared to a phenylephrine group when equipotent concentrations of medications were administered in CS under SA.⁽⁴⁵⁾ Elnabtity AM, *et al.* demonstrated that the norepinephrine group exhibited a lower frequency of bradycardia and tachycardia than the ephedrine group.⁽⁴⁶⁾ The β 1 and mild β 2 stimulatory

effects of norepinephrine may account for these results. Given the close correlation between maternal blood pressure and uteroplacental blood flow, it is important to prevent maternal hypotension and treat it as soon as possible to prevent fetal acidosis. One well-established advantage of ephedrine is its ability to maintain uterine blood flow. However, norepinephrine and other α agonists may impair uteroplacental blood flow. Minzter BH, *et al.* reported that norepinephrine had no discernible effect on fetal perfusion or uteroplacental blood flow.⁽⁴⁷⁾ Kee, *et al.* found that in CS under SA, the incidence of bradycardia events was greater in the phenylephrine group than in the norepinephrine group.⁽⁴⁸⁾ Some studies have suggested that norepinephrine maintains better HR stability compared to phenylephrine, although evidence remains variable. Because it stimulates the fetus's metabolism and β -adrenoceptors, ephedrine may cause acidosis in fetal tissues. Therefore, even though ephedrine is recognized for its ability to safeguard uterine blood flow, it may result in a greater incidence of embryonic acidosis by activating fetal β -adrenoceptors. The longer duration of action and the increased number of ephedrine boluses may be associated with a less pronounced decrease in maternal blood pressure, SBP, and DBP after the midpoint of surgery. The ephedrine group exhibited a consistent decrease in HR from the onset of surgery to its conclusion. Ephedrine is a non-catecholamine sympathomimetic that primarily acts indirectly by stimulating α - and β -adrenergic receptors. The effects of norepinephrine are produced by its release from nerve terminals in the autonomic nervous system. Despite the lack of evidence that it is preferable to other vasopressors, it has long been the preferred vasopressor for obstetric anesthesia. Tachyphylaxis, maternal supraventricular tachycardia, and fetal acidosis are among the intercurrents of epinephrine. According to earlier studies, ephedrine's β -adrenergic effect causes blood pressure to increase, which is linked to the maintenance of placental and uterine blood flow.

Phenylephrine

Phenylephrine is a pure α 1-adrenergic agonist. By encouraging dose-dependent vasoconstriction, which is more noticeable in the venous than in the arterial bed, it improves venous return after sympathetic inhibition during spinal block. Previous studies have shown that phenylephrine is just as efficient as ephedrine in controlling hypotension. Moreover,

it preserves uterine and placental blood flow and reduces the risk of fetal acidosis. A recent study revealed that even high levels were not associated with adverse effects on the fetus, as indicated by APGAR scores and umbilical cord blood gas values.⁽⁴⁹⁾ Regardless of whether they are given as a continuous infusion or bolus, ephedrine and phenylephrine are equally effective in preventing and treating hypotension, according to several studies. Although phenylephrine is less effective at managing blood pressure, no differences in the incidence of maternal adverse effects, such as dizziness, vomiting, and changes in consciousness, were observed, most likely because the drop in blood pressure was not substantial. Early reports have indicated that ephedrine's β -adrenergic effects may interfere with tachyphylaxis and alter fetal metabolism. Metaraminol and phenylephrine are α -agonists that are associated with a low incidence of fetal acidosis.⁽⁵⁰⁾ Furthermore, other clinical studies have demonstrated the superiority of phenylephrine over ephedrine, which contradicts early animal studies that advised against the use of α -agonists in obstetrics.⁽⁵¹⁾ α -Agonists in obstetrics have been the subject of renewed investigation as a result of the availability of clinical data from humans. The use of potent vasoconstrictors, such as phenylephrine, is more physiologically appropriate for treating vasodilatation-induced hypotension in SA than ephedrine, whose action is primarily mediated by ventricular stimulation. The benefits of this method include efficacy, titration simplicity, and the considerable observation that neonatal outcomes were not adversely affected by even the highest dosages ($>2,000 \mu\text{g}$), as determined by APGAR scores and umbilical cord blood gases. Compared with intermittent boluses, infusion treatment was associated with a reduced incidence, frequency, and severity of hypotension, along with a tendency toward decreased nausea and vomiting, relative to phenylephrine given by bolus.⁽⁵²⁾

Bupivacaine with opioids

Bupivacaine is the most frequently used local anesthetic in SA, and the risk of hypotension is increased when the dosage is high. A comparison of the effects of bupivacaine dose on SA-induced hypotension was conducted by Li S, *et al.*⁽⁵³⁾ The results indicated that low-dose bupivacaine (LB) reduces disequilibrium compared with high-dose bupivacaine (HB). However, the motor block and

effective anesthesia duration are less satisfactory. Furthermore, LB in conjunction with the additional intrathecal administration of opioids, including fentanyl and sufentanil, may be sufficient to induce anesthesia. Compared with the conventional HB regimen, LB could reduce the incidence of maternal hypotension; however, it did not provide an adequate intraoperative analgesic effect.⁽⁵⁴⁾ Simultaneously, the LB regimen was associated with decreased hypotension, more consistent analgesia efficacy, and less regurgitation. The presence of LB substantially reduced maternal hypotension. The heterogeneity was investigated in the study by Li M, *et al.*, where the use of 4 mg of bupivacaine was comparatively low compared with other trials, despite the LB regimens decreasing the prevalence of hypotension and achieving a consistent analgesic effect.⁽⁵⁵⁾ This conclusion was corroborated by sensitivity analyses. A reduction in local anesthetic dosage and an increase in analgesia are achieved by incorporating analgesics. The combination of bupivacaine with opioids such as fentanyl, sufentanil, and meperidine was determined by various trials.⁽⁵⁶⁾ Fentanyl is regarded as an optimal opioid in obstetrics due to its liquid solubility, which is superior to that of morphine, and its tendency not to diffuse intrathecally

to the fourth ventricle in quantities sufficient to induce respiratory depression. Compared with the HB regimen, the LB regimen resulted in fewer instances of regurgitation but a higher incidence of complications. Vomiting is contingent upon hypotension, and pruritus was more prevalent in patients treated with the LB regimen and was documented in all trials (**Figure 1**).

Management

To mitigate and prevent hypotension following SA, it is possible to prehydrate with colloids or crystalloids and angle the uterus to the left. The Trendelenburg posture may be employed to address hypotension, administer vasopressor medications, place intravenous catheters for fluid administration, and administer oxygen therapy.⁽⁵⁷⁾ The incidence of hypotension can be reduced by administering modest concentrations of local anesthetics in conjunction with intrathecal opioids, which can enhance the analgesic potential without increasing the level of sympathetic blockade. Tachycardia is a compensatory response to reduced tension, causing the heart to beat more rapidly to maintain adequate blood volume and blood pressure.⁽⁵⁸⁾ As individuals age, their arteries become stiffer, and

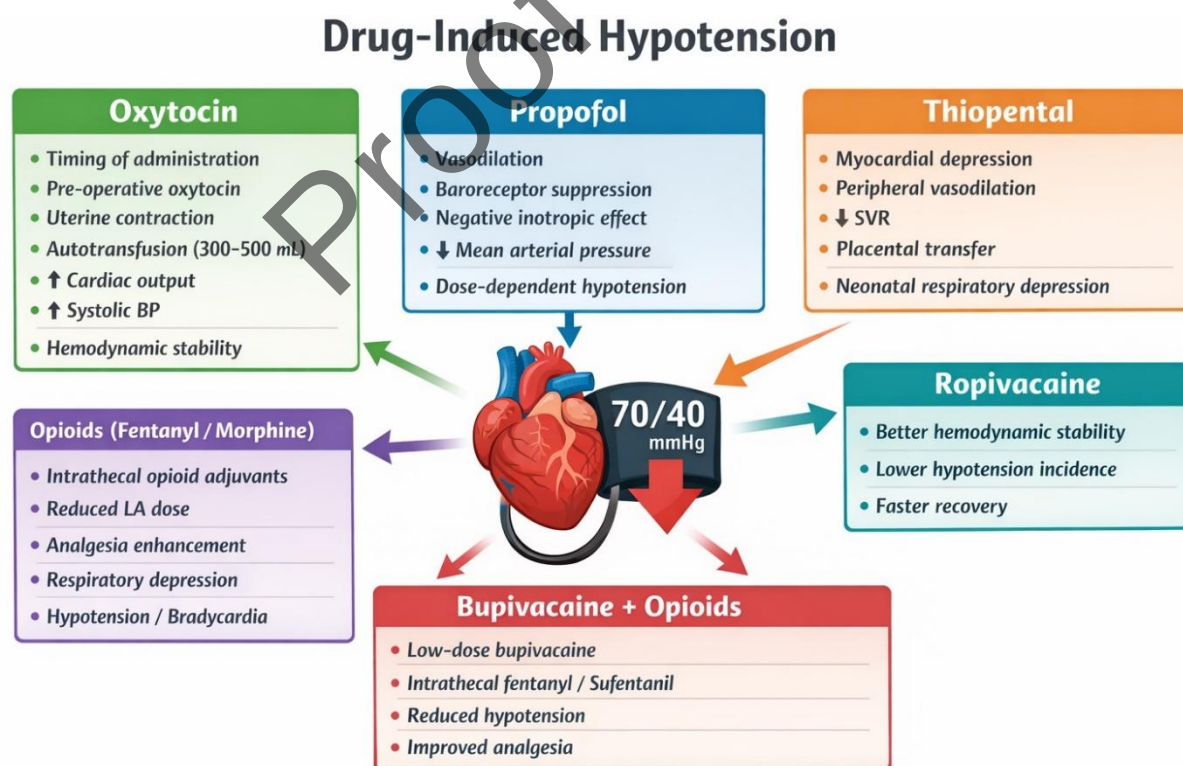


Figure 1. Drug induced hypotension. BP, blood pressure; LA, local anesthesia; SVR, systemic vascular resistance.

their pulse waves accelerate. Blood pressure is typically elevated in response to stimuli that increases HR and decreased in response to stimuli that lower it. The sinoatrial and atrioventricular nodes are innervated by parasympathetic and sympathetic fibers, which affect the pace and frequency of impulse conduction. The autonomic nervous system is predominantly responsible for the extrinsic control of cardiac frequency. Parasympathetic stimulation mediated by vagal efferent fibers reduces the firing rate of the sinoatrial node, thereby decreasing the HR, whereas sympathetic activation enhances pacemaker activity and accelerates cardiac rhythm (Carravieri A, *et al.* 2016).⁽⁵⁹⁾ Prophylactic administration of a titrated dose of phenylephrine infusion from 25 to 50 mcg/min intravenous (IV) concurrent with the spinal drug injection is the primary method of preventing SA-induced hypotension during CS.⁽⁶⁰⁾ The standard vasopressor dose for phenylephrine is 50–100 mg IV bolus or 25–100 mcg/min IV infusion. At the same time, ephedrine is administered in 5–10 mg IV boluses or 1–5 mg/min IV infusion. Norepinephrine has shown potential as an alternative to phenylephrine because of its lower risk of neonatal bradycardia. When norepinephrine is used, an appropriate initial dose is 2.5–4.0 mcg/min, which can be adjusted as needed. Complementing prophylactic and as-needed vasopressor administration, fluid management protocols typically include a rapid intravenous crystalloid infusion during neuraxial anesthesia induction (co-loading). Compression, leg elevation, and maternal repositioning are among the conservative strategies that are also employed. These interventions increase venous return to the heart, thereby increasing central blood volume and reducing the incidence and severity of hypotension.

Leg elevation

Leg elevation is a simple, non-pharmacological strategy used to mitigate hypotension following SA. SA-induced sympathetic blockades lead to venous pooling and reduced preload, contributing to hypotension. Leg elevation above 30° counteracts this effect by promoting autotransfusion and improving central blood volume.⁽⁶¹⁾ The additional benefit of elastic compression likely arises from reduced venous capacitance, further enhancing venous return. These findings suggest that leg elevation directly targets the pathophysiological basis of SA-induced hypotension. However, its effectiveness may depend on individual

patient factors such as intravascular volume status and vascular tone, and it is unlikely to be sufficient as a standalone intervention in high-risk patients.

Leg compression

In patients undergoing CS deliveries, routine implementation of this leg compression practice was recommended due to the uncomplicated, effective nature of encircling the lower extremities in reducing the incidence of hypotension and the need for vasopressors. Repositioning the mother improves venous return and lowers hypotension by reducing aortocaval compression.⁽⁶²⁾ Adopting a full lateral posture is often advised, as it lowers the risk of maternal hypotension more effectively than the supine wedged position. According to Hasanin A, *et al.*, there were no substantial modifications in hemodynamic parameters associated with left lateral tilt before SA administration. However, after SA administration and postpartum, a substantial increase in mean arterial pressure, HR, and CO was observed.⁽⁶³⁾ This position is typically challenging to maintain during surgical procedures in humans, and maternal repositioning merely delays the onset of hypotension. As a result, it is less likely to be used in these situations as a potential management technique. The use of vasopressors in the treatment of SA-induced hypotension has been well studied. Because of their vasoconstrictive properties and ability to increase HR, they effectively manage hypotension by raising blood pressure. Moreover, as they are administered either as a continuous infusion or as intermittent boluses, the latter typically maintains stable hemodynamics more effectively. The predominant vasopressors currently used are phenylephrine and norepinephrine, with phenylephrine preferred. Ephedrine is an α - and β -adrenergic agonist that is administered intramuscularly. It can pass through the placenta and is known to have sympathomimetic effects that cause fetal acidosis. A progressive bolus is less likely to cause neonatal acidosis than a quick bolus. Phenylephrine is an α -agonist that acts immediately. Regional cerebral blood volume and brain oxygenation can be maintained with a preventive phenylephrine infusion at 25 μ g/min. The patient's blood pressure should be taken into account when adjusting the phenylephrine dose. At larger doses (3 mg/min), norepinephrine, as a sympathomimetic, causes a dose-dependent increase in mean arterial pressure by acting on α receptors.⁽⁶⁴⁾ It is advised to provide 6 μ g IV boluses of

norepinephrine intermittently to treat SA-induced hypotension. Norepinephrine and phenylephrine are equally beneficial in preventing and treating hypotension caused by SA. When treating SA-induced hypotension, epinephrine is an effective alternative to norepinephrine. The dose of epinephrine should be determined with caution, as it has severe toxicities, including cerebrovascular incidents, cardiac arrhythmias, and pulmonary edema.⁽⁶⁵⁾ Epinephrine is a potent vasopressor, as evidenced by a study that compared epinephrine and phenylephrine. The results indicated that an epinephrine infusion of 0.1 µg/kg/min was more effective at maintaining SBP at or near baseline levels. Ebru Biricik, *et al.* determined that phenylephrine (25 µg/min) should be the preferred option for the prophylaxis and treatment of hypotension. In addition, norepinephrine can be employed as an alternative due to its reduced CO fluctuation.⁽⁶⁶⁾ Treatment of SA-induced hypotension requires the simultaneous administration of fluids and vasopressors. Preloading with Ringer's lactate alone is less effective at reducing the risk of hypotension than preloading with a combination of hydroxyethyl starch and Ringer's lactate, administered simultaneously with phenylephrine. Phenylephrine is as safe and effective for mothers and newborns as ephedrine when managing maternal hypotension in women undergoing epidurals during CS delivery with anesthesia. According to neurobehavioral criteria and acid–base values, maternal hypotension can be avoided by administering IV boluses of ephedrine, left uterine displacement, and prehydration, thereby preserving the newborn's well-being.⁽⁶⁷⁾ Ephedrine has been the preferred vasopressor for obstetric patients for a long time due to its combined α - and β -mimetic effects. Because α -agonists can affect uterine blood flow, their use has generally been avoided. Furthermore, methoxamine, phenylephrine, angiotensin, and levarterenol failed to maintain uterine blood flow when administered to treat hypotension caused by SA in animal models, leading to fetal hypoxemia.⁽⁶⁸⁾ These problems have prevented phenylephrine, as a pure α -agonist, from being utilized extensively in obstetrics. Wang X, *et al.* compared phenylephrine and ephedrine in the treatment of maternal hypotension brought on by epidural anesthesia and found that they were equally effective in treating maternal hypotension.⁽⁶⁹⁾ The average amount of vasopressor used was not disclosed in the research; however, in an earlier abstract, the mean ephedrine

dose was 15 mg, and the mean phenylephrine dose was 300 µg. Shelke U, *et al.* demonstrated that while the carotid artery vasoconstriction in response to phenylephrine in pregnant guinea pigs did not change, the sensitivity of the uterine artery vasoconstrictive response diminished.⁽⁷⁰⁾

Prophylactic approaches

• Fluids

Another widely adopted strategy for the prevention and management of SA-induced hypotension is the prophylactic administration of intravenous fluids either before anesthesia (preloading) or at the time of induction (co-loading). Crystalloids and colloids are both commonly used for this purpose. Crystalloids such as Ringer's lactate, Hartmann's solution, and normal saline are frequently preferred due to their availability, lower cost, and favorable safety profile. Colloid solutions, including hydroxyethyl starch, dextran, pentastarch, and gelatin, provide a more sustained intravascular volume expansion because of their higher molecular weight and prolonged intravascular retention.⁽⁷¹⁾ Fluid administration helps counteract the sympathetic blockade produced by SA, which leads to vasodilation, decreased systemic vascular resistance, and reduced venous return. By rapidly increasing preload and maintaining CO, fluid therapy supports hemodynamic stability and reduces the incidence and severity of perioperative hypotension. However, excessive fluid administration should be avoided to prevent fluid overload and its associated complications.

• Crystalloids

The prophylactic administration of crystalloids is an important strategy for preventing hemodynamic instability, including bradycardia and hypotension, in patients undergoing CS, particularly when SA is used. SA can cause sympathetic blockade, leading to vasodilation, reduced venous return, and decreased CO, which may subsequently induce maternal hypotension and reflex bradycardia.⁽⁷²⁾ The preloading or co-loading of isotonic crystalloid solutions such as normal saline or Ringer's lactate helps maintain intravascular volume and improves venous return to the heart.⁽⁷³⁾ This fluid expansion supports CO and stabilizes maternal blood pressure during the perioperative period. Several clinical studies have demonstrated that administering crystalloids

immediately before or during SA substantially reduces the incidence and severity of hypotension and associated bradycardia in patients undergoing CS delivery. Furthermore, maintaining adequate maternal hemodynamics is crucial for preserving uteroplacental perfusion and ensuring optimal fetal oxygenation. Although crystalloids alone may not eliminate hypotension, they remain a fundamental component of multimodal prophylactic management strategies in obstetric anesthesia and are often combined with vasopressors to enhance hemodynamic stability.

- **Colloids**

Colloids are intravenous fluids that contain large molecules, remain within the intravascular space, and help maintain blood volume. During SA for CS, sympathetic blockades cause vasodilation and decreased venous return, which can lead to maternal hypotension. Administering colloid solutions before or during SA helps expand the plasma volume and improve venous return to the heart, thereby supporting CO and stabilizing blood pressure. Commonly used colloid solutions include hydroxyethyl starch, gelatin, and albumin.⁽⁷⁴⁾ Because of their larger molecular size, colloids remain in the circulation longer than crystalloids and are more effective in maintaining intravascular volume. This helps reduce the incidence and severity of hypotension following SA. Maintaining stable maternal blood pressure is important to ensure adequate uteroplacental blood flow and fetal oxygenation. Therefore, colloid preloading or co-loading is often used as part of the strategies employed to prevent hypotension during CS delivery. There were no discernible differences between colloid preload and co-load, according to a meta-analysis of nine randomized controlled trials. However, the incidence of hypotension was substantially reduced with 15 mL/kg of colloid administered as preload.⁽⁷⁵⁾ Because of the lower vasopressor dose, longer-lasting intravascular volume expansion, and decreased risk of intraoperative nausea and vomiting, colloid preloading is advised. The fluid and vasopressor requirements following SA administration were lower with colloids than with crystalloids. Administering no fluids at all was equivalent to administering crystalloid preload in terms of its ability to mitigate hypotension and its subsequent adverse effects. The absence of fluid preload and the superiority of colloids over crystalloids have been demonstrated, and the timing of fluid administration has been investigated.

One method is co-loading, which involves administering fluids while anesthesia is being administered, or preloading, which involves administering fluids before anesthesia is administered. It has been shown that crystalloid preloading of 500–1,500 mL is less effective due to rapid redistribution.⁽⁷⁶⁾ A brief 10-min co-load of 20 mL/kg of Ringer's lactate effectively reduced the incidence of hypotension in a study comparing crystalloid preloading and co-loading. Crystalloid volumes of 500–1,000 mL are sufficient to achieve the desired hemodynamic effects. They offer greater flexibility, as they can be administered as either a preload or a co-load, with comparable benefits. While glycopyrrolate may have some benefits in managing hemodynamics during CS under SA, its effects are limited and do not substantially influence the overall incidence of hypotension. Moreover, it did not impact the incidence of bradycardia and reduced the need for vasopressors. It is important to weigh the potential adverse effects and individual patient factors against the modest benefits of glycopyrrolate in reducing vasopressor requirements and its effect on maternal HR when deciding whether to use it prophylactically.⁽⁷⁷⁾

- **In pre-eclampsia**

Because GA causes a hypertensive reaction during intubation, SA is thought to be a safe anesthetic technique for women with pre-eclampsia undergoing CS delivery. As bupivacaine causes severe hypotension at even low doses, ropivacaine is the preferred anesthetic drug for SA in these patients.⁽⁷⁸⁾ Severe spinal hypotension is less common in pre-eclamptic individuals without comorbidities. However, other differential diagnoses, such as hypovolemia, valvular heart disease, and, in rare instances, systolic dysfunction, should be considered if such an occurrence is noted. Phenylephrine and norepinephrine are effective treatments for post-spinal hypotension in pre-eclamptic individuals. Those who received norepinephrine experienced hypotension more frequently than those who received phenylephrine. Because SA can cause sudden, severe hypotension, continuous epidural anesthesia has been the favored technique for patients with severe pre-eclampsia who require CS birth.⁽⁷⁹⁾ Variability in clinical practice has been reported in the pharmacological management of severe pre-eclampsia, particularly regarding the administration of magnesium sulfate for seizure prophylaxis and the selection of antihypertensive

agents such as labetalol, hydralazine, or nifedipine, reflecting differences in institutional protocols, practitioner experience, and resource availability.⁽⁸⁰⁾ Numerous retrospective and prospective investigations have demonstrated that patients with severe pre-eclampsia who receive either SA or continuous epidural anesthesia for CS do not have a poorer incidence, severity, or treatment capacity for maternal hypotension. However, variability in findings among patients with pre-eclampsia highlights the need for further targeted research.

Conclusion

SA remains the most widely preferred anesthetic technique for CS due to its rapid onset, reliable neural blockade, and improved maternal safety. However, substantial hemodynamic alterations, particularly hypotension, remain a major clinical challenge in obstetric anesthesia. The present review highlights the multifactorial nature of SA-induced hypotension, emphasizing the influence of factors such as induction position, maternal BMI, and drug-induced cardiovascular effects. Pharmacological agents, including oxytocin, propofol, thiopental, fentanyl, and morphine, and local anesthetics such as bupivacaine and ropivacaine, can substantially modulate maternal hemodynamic responses. In addition, vasopressors such as norepinephrine, ephedrine, and phenylephrine play a pivotal role in maintaining cardiovascular stability during CS delivery. The review also emphasizes the importance of non-pharmacological and prophylactic strategies, including leg elevation, leg compression, and optimized fluid therapy using crystalloids and colloids. Special consideration is required in high-risk conditions such as pre-eclampsia, where altered vascular physiology further complicates hemodynamic management. By integrating evidence from diverse studies, this review provides a comprehensive understanding of the mechanisms, risk factors, and management approaches associated with hemodynamic adaptation following SA in CS. From a clinical perspective, individualized risk assessment, vigilant hemodynamic monitoring, and early use of appropriate vasopressors, combined with optimized fluid and positioning strategies, are essential to effectively prevent and manage maternal hypotension. Future research should focus on developing standardized, evidence-based protocols and conducting large-scale comparative studies to determine optimal management strategies across diverse patient populations.

Author contributions

AD, KPB, MAK, SD, RKV, and KG contributed substantially to the conception and design of the review, literature search, and interpretation of the findings. AD, KPB, and SD were involved in collecting and screening relevant studies. AD and MAK contributed to drafting the manuscript. RKV and KG critically revised the manuscript for important intellectual content. KG supervised the overall work and acted as the corresponding author. All authors approved the final version of the manuscript and take responsibility for the integrity of the work.

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Conflict of interest statement

The authors declare no conflict of interest.

Data sharing statement

The present review is grounded in the referenced literature, with all data generated or analyzed incorporated within this article and its cited sources. Additional details, interpretative insights, and expert perspectives may be obtained from the corresponding author upon reasonable request.

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References

1. Baron EL, Katz D. Neuraxial techniques and medications for cesarean delivery. In: Kaye AD, Urman RD, editors. *Obstetric Anesthesia Practice*. Oxford: Oxford University Press; 2021. p. 203–13.
2. Betran AP, Ye J, Moller AB, Souza JP, Zhang J. Trends and projections of caesarean section rates: global and regional estimates. *BMJ Glob Health* 2021;6:e005671.

3. Elgzar WT, Alshahrani MS, Ibrahim HA. Mode of delivery preferences: the role of childbirth fear among nulliparous women. *Front Psychol.* 2023;14:1221133.
4. Chen Y, Guo L, Qin R, Xi N, Wang S, Ma Y, Ni X. Dose-response study of norepinephrine infusion for maternal hypotension in preeclamptic patients undergoing cesarean delivery under spinal anesthesia. *Clin Pharmacokinet* 2024;63:847–56.
5. Hassabelnaby YS, Hasanin AM, Shamardal M, Mostafa M, Zaki RM, Elsherbiny M, Refaat S. Epinephrine vs phenylephrine infusion for prophylaxis against maternal hypotension after spinal anesthesia for cesarean delivery: a randomized controlled trial. *J Anesth* 2024;38:500–7.
6. Kinsella SM, Carvalho B, Dyer RA, Fernando R, McDonnell N, Mercier FJ, et al; Consensus Statement Collaborators. International consensus statement on the management of hypotension with vasopressors during caesarean section under spinal anaesthesia. *Anaesthesia* 2018;73:71–92.
7. Massoth C, Töpel L, Wenk M. Hypotension after spinal anaesthesia for CS: approach to iatrogenic sympathectomy. *Curr Opin Anaesthesiol* 2020;33:291–8.
8. Mathew M, Manah YM, Ahuja P, Shetty AR, Taye TE, et al. Managing spinal anaesthesia-induced hypotension in CS: a narrative review. *Ann Med Surg (Lond)* 2025;87:7338–46.
9. Babul A, Ashraf S, Desai J, Free L, Hussain M, Babul N. Intraoperative hypotension after neuraxial anaesthesia: systematic review of vasopressors. *Cureus* 2025;17:e94900.
10. Lorente JV, Hervías Sanz M, Ripollés-Melchor J, Hahn RG. Perioperative fluid therapy in adults and children: a narrative review. *Front Med (Lausanne)* 2025 ;12:1607670.
11. Mohamed S, Befkadu A, Mohammed A, Neme D, Ahmed S, Yimer Y, Girma T. Effectiveness of prophylactic ondansetron in preventing spinal anesthesia induced hypotension and bradycardia in pregnant mother undergoing elective cesarean delivery: A double blinded randomized control trial, 2021. *Int J Surg Open* 2021;35:100401.
12. Chen S, Wu L, Jiang X. Aortocaval compression resulting in sudden loss of consciousness and severe bradycardia and hypotension during cesarean section in a patient with subvalvular aortic stenosis. *BMC Anesthesiol* 2019;19:116.
13. Kim HJ, Choi YS, Kim SH, Lee W, Kwon JY, Kim DH. Predictability of preoperative carotid artery-corrected flow time for hypotension after spinal Anaesthesia in patients undergoing caesarean section: a prospective observational study. *Obstet Anesth Dig* 2022;42:44–5.
14. Shitemaw T, Jemal B, Mamo T, Akalu L. Incidence and associated factors for hypotension after spinal anesthesia during cesarean section at Gandhi Memorial Hospital Addis Ababa, Ethiopia. *PLoS One* 2020;15:e0236755.
15. Lorato SS, Agide FD, Getahun GK, Seid K, Wondimagne YA, Desalegn M, Rundasa DT, et al. Incidence and predictors of post spinal anesthesia-induced hypotension for cesarean section in Ethiopia: A systematic review and meta-analysis. *Perioper Care Oper Room Manag* 2025;40:100541.
16. Kee WD. Prevention of maternal hypotension after regional anaesthesia for caesarean section. *Curr Opin Anaesthesiol* 2010;23:304–9.
17. Basso L, Lacassie HJ. Vasoactive drugs for the management of maternal arterial hypotension after spinal anesthesia for cesarean section. an updated integrative narrative review. *Trends Anaesth Crit Care* 2024;58:101491.
18. Huang Q, Wen G, Hai C, Zheng Z, Li Y, Huang Z, et al. A height-based dosing algorithm of bupivacaine in spinal anesthesia for decreasing maternal hypotension in cesarean section without prophylactic fluid preloading and vasopressors: a randomized-controlled non-inferiority trial. *Front Med* 2022;9:858115.
19. Jelling Y, Klein C, Harlander T, Eberhart L, Roewer N, Kranke P. Preventing nausea and vomiting in women undergoing regional anesthesia for cesarean section: challenges and solutions. *Local Reg Anesth* 2017;10:83–90.
20. Bajwa SP, Hussain A, Akram M, Shahzad S, Khan U. Comparison of hemodynamic effects and patient satisfaction between lateral versus sitting maternal positions for cesarean deliveries in spinal anesthesia. *Pak Armed Forces Med J* 2024;74:965.
21. Manouchehrian N, Moradi A, Torkashvand L. Comparative study of effect of spinal anaesthesia in sitting and lateral positions on onset of sensory block and hemodynamic condition in CS: a randomized clinical trial. *Anesth Pain Med* 2021;11:e111483.
22. Samuel S, Kasahun B, Demeke T, Reshad S, Shemsu N, Kedir A, et al. Impact of lateral versus sitting position for spinal anesthesia on maternal hemodynamic variability and timing of hypotension among cesarean section patients: a prospective cohort study. *Ann Med Surg* 2025;87:62–9.
23. Šklebar I, Bujas T, Habek D. Spinal anesthesia-induced hypotension in obstetrics: prevention and therapy. *Acta Clin Croat* 2019;58 Suppl 1:90–5.
24. Abadi KK, Jama AH, Legesse AY, Gebremichael AK. Prevalence of hypothyroidism in pregnancy and its associations with adverse pregnancy outcomes: a cross-sectional study. *Int J Womens Health* 2023;15:1481–90.
25. Algarni RA, Albakri HY, Albakri LA, Alsharif RM, Alrajhi RK, Makki RM, et al. Incidence and risk factors of spinal anesthesia-related complications after elective cesarean section: a retrospective cohort study. *Cureus* 2023;15:e34198.

26. Nivatpumin P, Lertbunnaphong T, Maneewan S, Vittayaprechapon N. Comparison of perioperative outcomes and anesthetic-related complications of morbidly obese and super-obese parturients delivering by cesarean section. *Ann Med* 2023;55:1037–46.
27. Lawson J, Howle R, Popivanov P, Sidhu J, Gordon C, Leong M, et al. Gastric emptying in pregnancy and its clinical implications: a narrative review. *Br J Anaesth* 2025;134:124–67.
28. Oliveira-Paula GH, Pinheiro LC, Ferreira GC, Garcia WNP, Lacchini R, Garcia LV, et al. ACE inhibitors enhance hypotensive effects of propofol via nitric oxide. *Free Radic Biol Med* 2018;115:10–7.
29. Pozza DH, Tavares I, Cruz CD, Fonseca S. Spinal cord injury and complications related to neuraxial anaesthesia: a systematic review. *Int J Mol Sci* 2023;24:4665.
30. Jeevan R, Kundra P, Mishra S, Maurya DK, Keeranasseril A. Effect of preoperative oxytocin infusion on haemodynamics in elective CS under spinal anaesthesia. *Indian J Anaesth* 2025;69:343–9.
31. Torloni MR, Siaulyis M, Riera R, Cabrera Martimbiano AL, Leite Pacheco R, Latorraca CD, et al. Timing of oxytocin to prevent post-partum hemorrhage in women delivered by cesarean section: a systematic review and metaanalysis. *PLoS One* 2021;16:e0252491.
32. Giorgione V, O'Driscoll J, Coutinho CM, Di Fabrizio C, Sharma R, Khalil A, et al. Peripartum echocardiographic changes in women with hypertensive disorders of pregnancy. *Ultrasound Obstet Gynecol* 2022;59:365–70.
33. Saugel B, Bebert EJ, Briesenick L, Hoppe P, Greiwe G, Yang D, et al. Mechanisms contributing of hypotension after anesthetic induction with sufentanil, propofol, and rocuronium: a prospective observational study. *J Clin Monit Comput* 2022;36:341–7.
34. Küçük RS, Uzman S. A comparison of propofol and etomidate for anesthesia induction in patients with diabetic autonomic neuropathy. *Injector* 2023;2:16–22.
35. Belin O, Casteres C, Alouini S, Le Pape M, Dupont A, Boulain T. Continuous infusion of phenylephrine or norepinephrine for maintenance of blood pressure during spinal anesthesia for cesarean delivery: a randomized study. *Anesth Analg* 2023;136:540–50.
36. Hedawy S, Labeeb EE, Aldalahmeh S, Elswaf A, AlManaseer GM, Shehab MA, et al. Hypnotics as induction agents for general anaesthesia in cesarean section patients: updated systematic review and meta-analysis of randomized controlled trials. *J Anesth* 2025;39:948–75.
37. Taware M, Sonkusale M, Kuthe S. Comparison of hemodynamic effects of intravenous etomidate versus thiopentone during induction and intubation using entropy-guided hypnosis levels in coronary artery bypass surgery cases. *J Datta Meghe Inst Med Sci Univ* 2021;16:704–10.
38. Abd-Elseyed A, editor. Basic anaesthesia review. Oxford: Oxford University Press; 2024.
39. Norman E, Westrin P, Fellman V. Placental transfer and pharmacokinetics of thiopentone in newborns. *Arch Dis Child Fetal Neonatal Ed* 2010;95:F277–82.
40. Hao X, Yang Y, Liu J, Zhang D, Ou M, Ke B, et al. The Modulation by anesthetics and analgesics of Respiratory Rhythm in the Nervous System. *Curr Neuropharmacol* 2024; 22:217–40.
41. Sorout D, Mahajan N, Singh RK, Saiyad SS, Sharma M. Lower limb orthopedic anaesthesia: randomized trial comparing ropivacaine and bupivacaine for sensory-motor block and hemodynamic stability. *Cureus* 2025; 17:e84377.
42. Khalil RS, Mehmud A, Banerjee R, Malhotra R, Banerjee A. Intrathecal ropivacaine versus bupivacaine in a non-obstetric population: meta-analysis and trial sequential analysis. *Indian J Anaesth* 2024;68:129–41.
43. Manouchehtian N, Jeyraee N, Hoseini S. Intravenous norepinephrine vs ephedrine for prevention of post-spinal hypotension in cesarean section: randomized double-blind trial. *Maedica (Bucur)* 2022;17:833–39.
44. Kee WD, Lee SW, Ng FF, Tan PE, Khaw KS. Norepinephrine vs phenylephrine for maintaining blood pressure during spinal anaesthesia for cesarean delivery. *Surv Anesthesiol* 2015; 59:267–8.
45. Sharkey AM, Siddiqui N, Downey K, Ye XY, Guevara J, Carvalho JC. Comparison of intermittent intravenous boluses of phenylephrine and norepinephrine to prevent and treat spinal-induced hypotension in cesarean delivery: randomized controlled trial. *Anesth Analg* 2019; 129:1312–8.
46. Elnabtity AM, Selim MF. Norepinephrine versus ephedrine to maintain arterial blood pressure during spinal anaesthesia for cesarean delivery: a prospective double-blinded trial. *Anesth Essays Res* 2018;12: 92–7.
47. Minzter BH, Johnson RF, Paschall RL, Ramasubramanian R, Ayers GD, Downing JW. The diverse effects of vasopressors on the fetoplacental circulation of the dual perfused human placenta. *Anesth Analg* 2010;110:857–62.
48. Ngan Kee WD, Khaw KS, Tam YH, Ng FF, Lee SW. Performance of a closed-loop feedback computer-controlled infusion system for maintaining blood pressure during spinal anaesthesia for caesarean section: a randomized controlled comparison of norepinephrine versus phenylephrine. *J Clin Monit Comput* 2017;31:617–23.
49. Abdus Samad A, Allah Dad MS, Saeed Z. Assessing Neonatal Apgar Scores Following Propofol and Thiopental Induction in Cesarean Sections: A Systematic Review. *Cureus* 2025;17:e89548.
50. Chao E, Sun HL, Huang SW, Liao JH, Ma PL, Chen HC. Metaraminol use during spinal anaesthesia for cesarean section: a meta-analysis of randomised controlled trials. *Int J Obstet Anesth* 2019;39:42–50.

51. Jain K, Makkar JK, Vp SS, Gander S, Kumar P. A randomized trial comparing prophylactic phenylephrine and ephedrine infusion during spinal anesthesia for emergency cesarean delivery in cases of acute fetal compromise. *J Clin Anesth* 2016;34:208–15.
52. George RB, McKeen DM, Dominguez JE, Allen TK, Doyle PA, Habib AS. A randomized trial of phenylephrine infusion versus bolus dosing for nausea and vomiting during Cesarean delivery in obese women. *Can J Anesth* 2018;65:254–62.
53. Li S, Dai X, Wang Y, Shen L, Hao N. Effect of bupivacaine combined with fentanyl for simultaneous spinal-epidural anesthesia on hemodynamics, and maternal and infant outcomes in patients undergoing cesarean section. *Trop J Pharm Res* 2022;21:193–9.
54. Regmi BD, Deo GP, Shrestha S, Shrestha S, Mishra RT. Low dose hyperbaric bupivacaine with fentanyl in spinal anesthesia in elective cesarean Section. *J Chitwan Med Coll* 2019; 9:79–82.
55. Li M, Xie G, Chu L, Li Y. Efficacy of low-dose hypobaric anesthetics in spinal anesthesia for cesarean delivery: a systematic review and meta-analysis. *J Matern Fetal Neonatal Med* 2025;38:2519655.
56. Jain T. Evaluation of adjunctive analgesia with intrathecal fentanyl along with hyperbaric bupivacaine in spinal anesthesia for elective caesarean section. *Int J Res Med Sci* 2020;8:2924–7.
57. Bhat AD, Singh PM, Palanisamy A. Neuraxial anaesthesia-induced hypotension during cesarean section. *BJA Educ* 2024;24:113–20.
58. Abdali K, Chen X, Ross S, Davis S, Zhou Z, Mallet RT, et al. Mechanisms maintaining cerebral perfusion during systemic hypotension are impaired in elderly adults. *Exp Biol Med (Maywood)* 2023;248:2464–72.
59. Carravieri A, Müller MS, Yoda K, Hayama SI, Yamamoto M. Dominant Parasympathetic Modulation of Heart Rate and Heart Rate Variability in a Wild-Caught Seabird. *Physiol Biochem Zool* 2016;89:263–76.
60. Sahoo SR, Raiguru D, Kakarla A, Das S. Estimation of the effective dose of phenylephrine infusion for preventing spinal anaesthesia-induced hypotension in elective cesarean deliveries: a randomized controlled trial. *Cureus*. 2025;17:e96873.
61. Kinsella SM, Carvalho B, Dyer RA, Fernando R, McDonnell N, Mercier FJ, et al. International consensus statement on the management of hypotension with vasopressors during caesarean section under spinal anaesthesia. *Anaesthesia* 2018; 38:171–2.
62. Park HS, Choi WJ. Use of vasopressors to manage spinal anaesthesia-induced hypotension during cesarean delivery. *Anesth Pain Med (Seoul)* 2024;19:85–93.
63. Hasanin A, Soryal R, Kaddah T, Raouf SA, Abdelwahab Y, Elshafaei K, et al. Hemodynamic effects of lateral tilt before and after spinal anaesthesia during cesarean delivery: an observational study. *BMC Anesthesiol* 2018;18:8.
64. Hirose N, Kondo Y, Maeda T, Matsui M, Matsuda M, Suzuki T. Prophylactic infusion of phenylephrine attenuates decrease in cerebral blood volume and oxygenation during spinal anaesthesia for cesarean section. *Int J Obstet Anesth* 2019;37:36–44.
65. Hans FP, Benning L, Pooth JS, Busch HJ. Unintentional high-dose adrenaline administration in anaphylaxis-induced cardiac arrest: a case report. *Int J Emerg Med* 2024;17:78.
66. Biricik E, Ünlügenç H. Vasopressors for the Treatment and Prophylaxis of Spinal Induced Hypotension during Caesarean Section. *Turk J Anaesthesiol Reanim* 2020;49:3–10.
67. Younis MS, Salman SA, Khamees EN. Ephedrine infusion prevents hypotension and reduces nausea in Cesarean Section under spinal anaesthesia. *Academia Open* 2024;9:10.21070
68. Guo R, Xue Q, Qian Y, Hu Y, Tan J. The effects of ephedrine and phenylephrine on placental vascular resistance during cesarean section under epidural anesthesia. *Cell Biochem Biophys* 2015;73:687–93.
69. Wang X, Mao M, Liu S, Xu S, Yang J. A comparative study of bolus norepinephrine, phenylephrine, and ephedrine for the treatment of maternal hypotension in parturients with preeclampsia during cesarean delivery under spinal anesthesia. *Med Sci Monit* 2019; 25:1093–100.
70. Shelke U, Yadav S, Vardhan V, Vyas V, Sadawarte S, Mulla S, et al. Phenylephrine and ephedrine for prevention of hypotension during CS under spinal anaesthesia: a randomized clinical study. *J Clin Diagn Res* 2023;17:2.
71. Song B, Fu K, Zheng X, Liu C. Fluid resuscitation in adults with severe infection and sepsis: a systematic review and network meta-analysis. *Front Med (Lausanne)* 2025;12:1543586.
72. Ni HF, Liu HY, Zhang J, Peng K, Ji FH. Crystalloid coload reduced the incidence of hypotension in spinal anesthesia for cesarean delivery, when compared to crystalloid preload: a meta-analysis. *Biomed Res Int* 2017;2017:3462529.
73. Zahid TR, Farooq U, Waraich AA, Bashir R, Ali I. Effect of crystalloid administration timing on hypotension in spinal anaesthesia for cesarean delivery: preload versus coload: a study at a Tertiary Care Hospital in Rawalpindi. *Life Sci* 2024;5:06.
74. Widodo K, Isnaini N. The effect of gelatine colloid preloading on hypotension prevention in cesarean section with spinal anesthesia at the central surgery installation of banyumas regional hospital. *Proc Health Med Sci* 2024;5:81–6.

75. Gong RS, Liu XW, Li WX, Zhao J. Effects of colloid preload on hypotension in spinal anaesthesia for CS: a meta-analysis. *Chin Med J (Engl)* 2021;134:1043–51.
76. Marzouk SB, Fouzai B, Dhraief N, Amor FB, Hkiri T, Hamdi H, et al. Cardiac ultrasound-guided crystalloid preloading before spinal anesthesia vs standard coloadng for cesarean delivery: a randomized controlled trial. *Int J Obstet Anesth* 2026;66:104840.
77. Patel SD, Habib AS, Phillips S, Carvalho B, Sultan P. The effect of glycopyrrolate on the incidence of hypotension and vasopressor requirement during spinal anesthesia for cesarean delivery: a meta-analysis. *Anesth Analg* 2018;126:552–8.
78. Dilawar M, Rasool B, Zahra F, Noor I, Adnan M, Siddique S, et al. Comparative analysis of bupivacaine versus ropivacaine in CS surgery. *J Health Wellness Community Res* 2025;5:e228.
79. Simmons SW, Dennis AT, Cyna AM, Richardson MG, Bright MR. Combined spinal-epidural versus spinal anaesthesia for caesarean section. *Cochrane Database Syst Rev* 2019;10:CD008100.
80. Rana S, Lemoine E, Granger JP, Karumanchi SA. Preeclampsia: pathophysiology, challenges, and perspectives. *Circ Res* 2019;124:1094–112.

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