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Literature Review

Effects of TCI Propofol on Maternal and Fetal Outcomes in VP-Shunt Surgery during the First Trimester of Pregnancy: A Narrative Review

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Abstract

Neurosurgical procedures during pregnancy, particularly ventriculoperitoneal (VP) shunt placement in the first trimester, pose substantive challenges for anesthetic practice. Drug selection must protect both mother and fetus while accommodating pregnancy-related alterations in pharmacokinetics and pharmacodynamics. Propofol administered via Target Controlled Infusion (TCI) has become a preferred option in neuroanesthesia because it enables rapid reduction in intracranial pressure and precise titration. Reports from neuro-obstetric practice, including VP shunt operations, indicate that TCI propofol maintains stable anesthetic depth with fewer hemodynamic fluctuations than inhalational techniques. In pregnant patients, dosing is individualized using the Marsh model, typically targeting a plasma concentration of 2–4 µg/mL with an induction dose of 1–2 mg/kg. Although propofol readily crosses the placenta, contemporary data show fetal concentrations remain low and are rapidly cleared. Moreover, recent studies have not associated appropriately dosed, closely monitored propofol with increased rates of miscarriage, major congenital anomalies, or reduced live births. Accordingly, for first-trimester neuroanesthesia, TCI propofol is a safe and effective choice that supports maternal cerebral protection while minimizing fetal exposure. When combined with vigilant physiologic monitoring, titration to effect, and adherence to neuro-obstetric best practices, maternal and fetal outcomes are comparable to those achieved with inhalational anesthesia. These findings support the judicious adoption of TCI propofol for VP shunt surgery in early pregnancy, emphasizing individualized dosing and multidisciplinary perioperative coordination to optimize safety and efficacy. This review synthesizes current evidence and offers pragmatic dosing guidance for clinicians, aligned with contemporary neuroanesthesia and obstetric anesthesia standards.

Keywords: Neuroanesthesia, pregnancy, TCI propofol, hydrocephalus, maternal outcomes

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Introduction

Pregnancy requiring neurosurgical intervention, such as ventriculoperitoneal (VP) shunt placement during the first trimester, presents unique challenges in anesthetic practice. In such conditions, the choice of anesthetic agents must not only ensure maternal safety but also fetal security. Propofol administered with Target-Controlled Infusion (TCI) is increasingly used in neuroanesthesia procedures, owing to its rapid onset of action, ability to reduce intracranial pressure, and precise dose titration, all crucial factors in neurosurgical management during early pregnancy.[1,2] Nevertheless, since propofol readily crosses the placental barrier, its use in the first trimester raises specific concerns, particularly regarding potential maternal hemodynamic complications and their impact on intracranial pressure, as well as fetal risks such as miscarriage, congenital anomalies, and neonatal survival.[3]

Hydrocephalus, one of the main indications for VP-shunt placement, remains a global issue with

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a notably high incidence in developing countries. Recent meta-analyses estimate the incidence of congenital hydrocephalus at 79 to 123 per 100,000 live births, a figure likely similar or even higher in Indonesia, in line with high birth rates and limited access to definitive health care.4 In daily clinical practice, an increasing number of women of childbearing age are living with VP shunts, resulting in more frequent cases of pregnancy requiring revision or new shunt placement.[5] Although data on hydrocephalus incidence specifically in pregnant women are limited, available evidence indicates that approximately 1–2% of pregnancies may be complicated by pre-existing or newly diagnosed hydrocephalus requiring shunt placement or revision, particularly in the first trimester when maternal physiological adaptation is still unstable.[4,5]

The complexity of anesthetic management in this group is further compounded by physiological changes during pregnancy and the potential for neurological complications.[2] This narrative review discusses the use of propofol with the TCI technique for neurosurgical procedures in pregnant women with hydrocephalus, particularly during the first trimester of pregnancy. Accordingly, this paper aims to narratively evaluate the latest scientific evidence regarding the use of TCI propofol in VP-shunt procedures during early pregnancy, examine maternal and fetal safety aspects both intraoperatively and postoperatively, map potential short- and long-term complications that may arise, and provide a scientific basis for the development of more standardized clinical recommendations for similar cases in the future.[6]

Thus, the findings of this review are expected to provide a significant contribution as a reference for developing anesthetic guidelines for pregnant patients requiring neurosurgery, given the limited international consensus in this field. The novelty of this review lies in its specific focus on TCI propofol technique, rather than general intravenous anesthesia, in the context of VP-shunt surgery during the first trimester of pregnancy. In addition to providing a comprehensive overview of maternal complications such as hemodynamic instability and increased intracranial pressure, this paper also critically highlights fetal outcomes including the risk of congenital anomalies, miscarriage, and live birth rates based on the most recent evidence from the past decade. Through an evidence-based systematic approach, this review aims to fill the existing knowledge gap, strengthen clinical decision-making, and serve as a foundation for future research to optimize the management of pregnant patients requiring neurosurgery.

TCI Propofol in Neuro-Obstetric Procedures: General Overview

The use of TCI propofol in neuroanesthesia, especially in obstetric cases such as VP-shunt, has marked significant progress in the management of neurosurgical anesthesia in pregnant women. TCI systems provide more precise control over anesthetic depth and hemodynamic responses, which is crucial for maintaining stable intracranial pressure in patients at high risk for fluctuations.[7] The main challenge during pregnancy is to protect the maternal brain from secondary injury without endangering the fetus through drug exposure. Several studies have shown that TCI propofol produces more stable anesthetic conditions compared to inhalational anesthesia, reduces blood pressure fluctuations, and accelerates postoperative recovery, thus enabling earlier neurological assessment.[8]

Although specific data in pregnant women remain limited, multiple studies have confirmed the routine use of propofol administered via TCI during pregnancy. The Marsh pharmacokinetic model has been clinically validated within a plasma concentration range of 2–3 µg/mL, demonstrating reliable accuracy and adaptability for individualized dose titration. Furthermore, existing literature and TCI guidelines support its role in enabling tailored dosing strategies to maintain hemodynamic stability and control intracranial pressure.[9,10] Comparative analyses indicate that intravenous anesthesia, particularly using TCI propofol, offers greater hemodynamic stability and smoother control of intracranial pressure compared to inhalational agents such as sevoflurane or desflurane. Several studies have also reported that TCI propofol provides more predictable depth of anesthesia and faster maternal recovery, thus facilitating early postoperative neurological assessment. In addition, general intravenous anesthesia without TCI is often associated with larger fluctuations in drug concentration, whereas the TCI system maintains a steady state more effectively.

Pharmacology of TCI Propofol in Pregnant Women

Pregnancy induces physiological changes that alter propofol handling: expanded maternal blood volume increases its volume of distribution, sometimes necessitating a slightly higher induction dose to achieve the desired effect. Hepatic metabolism and renal clearance are enhanced, while reduced plasma albumin raises the unbound fraction, so adverse effects must be anticipated with careful monitoring.[11,12] These adaptations directly shape pharmacokinetics: increased blood volume, cardiac output, and perfusion of the liver and kidneys promote broader systemic distribution.[1,5,6,11] Concurrent hypoalbuminaemia further elevates the free maternal concentration.[2]

Consequently, a greater proportion of propofol is available to produce clinical effects even when total plasma levels appear lower. Its marked lipophilicity, together with pregnancy-related gains in body fat, also drives deeper tissue uptake and wider distribution.[8,9] This pharmacokinetic shift underscores the need for individualized dosing and titration to effect, balancing efficacy against maternal side-effects and fetal exposure.
In clinical practice, TCI propofol induction doses are usually adjusted based on actual body weight and the mother's hemodynamic response, with extra attention to patients with organ dysfunction. Evidence shows that, compared to inhalational anesthesia, TCI propofol less frequently causes severe hypotension or vasopressor requirements, provided that monitoring and titration are carried out strictly.[13]

Maternal propofol metabolism occurs primarily in the liver via conjugation involving UDP-glucuronosyltransferase (UGT1A9) and, to a lesser extent, CYP2B6. The resulting inactive metabolites are then excreted in urine.[9,12] Increased hepatic blood flow during pregnancy generally accelerates propofol clearance, though individual response varies. This necessitates careful dosing and titration, especially in patients with hepatic or renal impairment.[6,13]

Propofol Pharmacology in the Fetus

Propofol readily crosses the placental barrier via passive diffusion, allowing a portion of the drug to enter the fetal circulation. Clinical studies in caesarean section patients have shown that propofol concentrations in umbilical cord blood range from 30–60% of maternal levels; for example, the ratio of umbilical vein to maternal vein is approximately 0.65, and the ratio of umbilical artery to umbilical vein is around 0.53 at delivery.[14] Animal models using pregnant sheep estimate the fetal-to-maternal concentration ratio to be around 15% during infusion, confirming the rapid distribution and efficient elimination of propofol in the fetus.[15]

Clinically, although propofol can cause mild respiratory depression or decreased muscle tone in neonates if administered close to delivery, large studies have not found any significant negative effects on Apgar scores or long-term infant outcomes.16 Furthermore, there is no strong evidence that first-trimester propofol exposure increases the risk of major or minor congenital anomalies, as long as it is used at clinically appropriate doses and times.[17] Therefore,

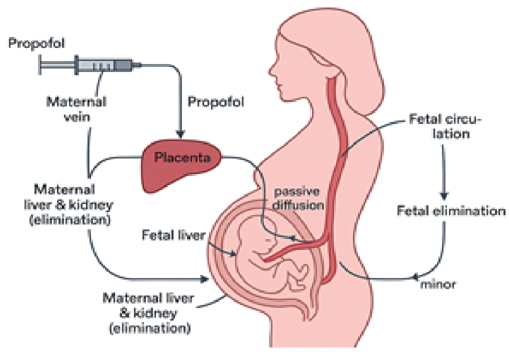

Figure 1. Maternal-Fetal Circulation of Propofol

propofol, particularly with TCI systems, is the preferred option when neurosurgical procedures cannot be delayed during pregnancy, applying the principle of the lowest effective dose and shortest possible duration.

Outcomes and Complications

The use of TCI propofol in neuro-obstetric procedures has proven to be safe and effective, with good maternal outcomes and a low incidence of serious complications. Compared to inhalational techniques, TCI propofol consistently shows lower rates of intracranial pressure complications, hemodynamic instability, and coagulation disturbances.[18] Furthermore, faster postoperative recovery facilitates neurological assessment in the mother and reduces the need for intensive care.[19] For the fetus, most studies and meta-analyses agree that propofol used according to recommended doses and protocols does not increase the risk of miscarriage, congenital anomalies, or reduce live birth rates.[20] The main complication to watch for is neonatal respiratory depression, especially if propofol is given in high doses close to delivery. Therefore, intensive monitoring of both mother and baby is essential, particularly during the peripartum transition. Thus, the use of TCI propofol, both for induction (1–2 mg/kg) and maintenance (plasma target 2–4 µg/mL with Marsh model), can be performed safely in neurosurgical procedures during pregnancy, provided that strict monitoring and individualized dosing are maintained for each patient.

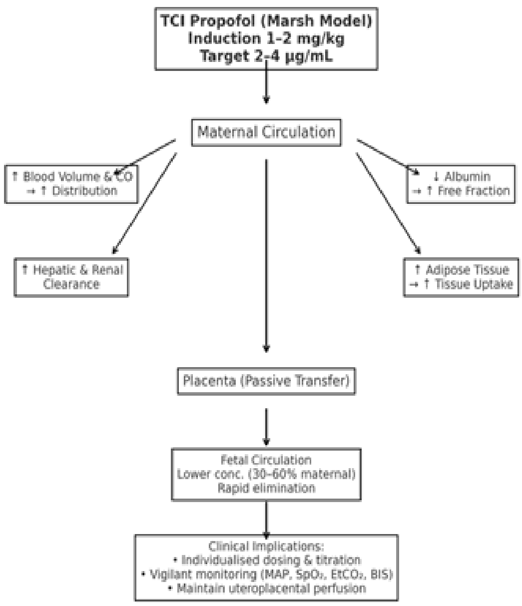

Figure 2. Schematic of TCI Propofol Pharmacology during Pregnancy

Monitoring and Strategies for Preventing Complications during TCI Propofol Anesthesia in Pregnancy

The management of anesthesia using TCI propofol in pregnant women, especially during the first trimester, requires a truly comprehensive monitoring approach. The use of invasive monitoring devices such as an arterial line is highly recommended, as physiological changes during pregnancy can lead to fluctuations in blood pressure at any time. This is crucial to maintain maternal cerebral perfusion and placental blood flow, ensuring both maternal and fetal safety.[6,11] Additionally, monitoring of oxygen saturation and end-tidal CO_2 is mandatory to prevent hypoxemia or hypercapnia, both of which can directly impact maternal and fetal outcomes.[12]

One of the main challenges in the use of propofol is the risk of hypotension due to its systemic vasodilatory effects. Therefore, prevention with adequate preload fluid administration and the preparation of fast-acting vasopressors such as phenylephrine or ephedrine becomes essential. Both drugs have been proven to be relatively safe in pregnancy and effective in maintaining uteroplacental perfusion without increasing the risk of complications in the fetus.[13] Furthermore, the target blood pressure in pregnant women should ideally be maintained slightly higher than in non-pregnant patients to ensure optimal perfusion of vital organs.[2,12] To prevent overdose or even intraoperative awareness, monitoring the depth of anesthesia with the Bispectral Index (BIS) is also highly beneficial. This technology is increasingly becoming standard in many modern neuroanesthesia centers, particularly because drug metabolism in pregnant women can vary greatly.[8] In addition, regular monitoring

Table 1. Perioperative Monitoring Recommendations for TCI Propofol Anesthesia in Pregnancy

Parameter	Monitoring Purpose	Device/Method	Target Range	Clinical Relevance
Invasive blood pressure	Detection of hemodynamic fluctuation	Arterial line	MAP ≥ 70–75 mmHg	Cerebral and uteroplacental perfusion.[6,11]
Oxygen saturation	Prevention of hypoxemia	Pulse oximetry	94–100%	Maternal and fetal oxygenation.[12]
End-tidal CO_2	Control of ventilation and acid-base balance	Capnography	32–36 mmHg	Prevention of hypercapnia.[12]
Bispectral Index (BIS)	Monitoring depth of anesthesia	BIS monitor	40–60	Prevent awareness and overdose.[8]
Acid-base and electrolytes	Detection of acidosis/ electrolyte disturbances	Blood gas analysis, laboratory	7.35–7.45	Metabolic stabilization.[11]
Fetal heart rate (if >20 weeks)	Detection of fetal distress	FHR monitoring	110–160 bpm	Early intervention.[5,6]

of acid-base balance and electrolytes during the procedure is important to detect metabolic acidosis or electrolyte disturbances as early as possible, thus preventing complications that may endanger both mother and fetus.[11] It should be noted that the management of neuroanesthesia cases during pregnancy is ideally performed by a multidisciplinary team, including neonatologists and perinatologists. Through such collaboration, preparation for managing complications in both mother and fetus can be more comprehensive. If possible, intermittent fetal heart monitoring can also be implemented, especially in pregnancies at more advanced gestational ages, to allow early detection of fetal distress.[5,6] All these measures will strengthen safety protocols and ensure that the use of TCI propofol remains within safe limits for both mother and baby. (Table 1)

Limitations of the Literature and Future Research Opportunities for TCI Propofol Anesthesia in Neuro-Obstetrics

Although the literature on the use of TCI propofol in pregnant women is expanding, most of the available evidence still comes from case reports, case series, or observational studies with a limited number of patients.[3,6] This is mainly due to ethical challenges in conducting prospective studies in pregnant women, so the resulting data is often insufficient to form a global consensus. Nevertheless, several meta-analyses and systematic reviews over the past decade have started to demonstrate consistent patterns that TCI propofol is safe when given at low doses and with strict monitoring.[8,20]

Unfortunately, most studies still focus on short-term outcomes, such as live birth, birth weight, and Apgar scores. Meanwhile, the long-term effects on the neurological, cognitive, or behavioral development of children exposed to propofol during the first trimester have not been widely explored.[1,17] Therefore, large cohort studies with long-term follow-up are required to truly determine the effects of propofol use during early fetal development.[1,20] Moreover, studies directly comparing TCI propofol with other anesthetic techniques, such as inhalational or combined regional-general anesthesia, in pregnant women undergoing neurosurgery are still very limited.[7,10] Such head-to-head comparative studies are important to clarify the advantages and disadvantages of each technique, particularly in terms of hemodynamic stability, recovery time, and complication rates in both mother and fetus.[7,10,19] The results would greatly assist in developing practical guidelines at both national and international levels.

Emerging research opportunities also align with technological advancements in anesthesia, such as the use of artificial intelligence-based algorithms for more personalized dose titration. This approach enables more precise adjustment of propofol doses according to individual patient characteristics.[9] With the increasing number of women of reproductive age requiring neurosurgical intervention during pregnancy, multicenter collaborations and national registries are urgently needed to strengthen scientific evidence and expand the scope of clinical recommendations.[5,6]

Conclusion

Recent evidence supports propofol delivered via TCI as a primary neuroanaesthetic option for VP-shunt procedures in the first trimester. Compared with inhalational techniques, TCI enables tighter control of anesthetic depth, limits fluctuations in intracranial pressure and hemodynamics, and can shorten recovery to allow earlier neurological assessment. Because pregnancy alters drug disposition, patient-specific dosing (e.g., Marsh model) and vigilant physiological monitoring are crucial to minimize maternal adverse effects. Although propofol crosses the placenta, appropriately dosed and time-limited exposure has not been linked to increased rates of miscarriage, major congenital anomalies, or reduced live births; neonatal neurological outcomes remain acceptable when high doses near delivery are avoided.

Collectively, these data justify judicious adoption of TCI propofol for urgent neurosurgical indications in pregnancy, contingent on close monitoring and carefully individualized titration to safeguard both maternal and fetal well-being. Overall, when comparing anesthetic modalities, TCI propofol demonstrates superior intraoperative stability and recovery profile relative to inhalational anesthesia. Its application in pregnant women with hydrocephalus during the first trimester should therefore be considered a safe and rational choice under strict multidisciplinary monitoring.

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