Application Study of Target-controlled Infusion Anesthesia in Minimally Invasive Neurosurgical Procedures

Tianpin Liu, Chunli Zeng, Qiongyao Wang, Yao Chen, Qibin Ke*

The First Clinical Medical College of China Three Gorges University, Yichang Central People's Hospital, Yichang 443000, Hubei, China

Abstract: Objective: To investigate the application efficacy of target-controlled infusion (TCI) anesthesia in minimally invasive neurosurgical procedures. Methods: Eighty-six patients undergoing minimally invasive neurosurgery from March 2024 to July 2025 were randomly assigned to a control group and an experimental group (n = 43 each). The control group received conventional continuous intravenous anesthesia, whereas the experimental group received TCI anesthesia with propofol and remifentanil. Both groups maintained BIS values between 45 and 55. Anesthesia-related time parameters, drug consumption, and the incidence of adverse events were compared. Results: The experimental group exhibited significantly shorter durations for anesthesia induction, postoperative emergence, and extubation compared to the control group ($t = 8.724, 9.351, 10.126$; all $P < 0.05$). Intraoperative consumption of propofol and remifentanil was significantly lower in the experimental group ($t = 7.892, 8.563$; all $P < 0.05$). The incidence of adverse events (4.65%) was significantly lower than that in the control group (18.60%) ($\chi^2 = 4.441$, $P < 0.05$). Conclusion: TCI anesthesia enables precise control of anesthetic depth in minimally invasive neurosurgery, shortens recovery time, reduces drug dosage, maintains hemodynamic stability, and lowers the incidence of adverse events, demonstrating significant clinical value.

***Keywords*:** neurosurgery; minimally invasive surgery; target-controlled infusion anesthesia; postoperative recovery

1. Introduction

Minimally invasive neurosurgical procedures have become the preferred treatment for intracranial diseases due to their reduced trauma and faster recovery. However, the high precision of these surgeries imposes strict requirements on anesthetic depth to maintain hemodynamic stability and avoid neurofunctional damage caused by overly deep or light anesthesia [1]. Conventional continuous intravenous infusion relies heavily on the anesthesiologist's experience and is prone to plasma concentration fluctuations, making it difficult to precisely match the required anesthetic depth. Based on pharmacokinetic principles, TCI technology utilizes computer algorithms to precisely regulate the infusion rate, achieving individualized control of anesthetic depth. This study investigates its clinical efficacy in patients treated between March 2024 and July 2025, aiming to provide support for optimizing anesthesia management.

2. Materials and Methods

2.1 General Data

Eighty-six patients who underwent minimally invasive neurosurgery in our hospital between March 2024 and July 2025 were selected. All patients met the surgical indications and were scheduled for procedures such as intracranial tumor resection or cerebral vascular malformation repair. Inclusion criteria were as follows: aged 18–65 years, American Society of Anesthesiologists (ASA) physical status I–II, without major organ dysfunction, allergy to anesthetic drugs, or coagulation abnormalities. Exclusion criteria included severe comorbidities, pregnancy or lactation, mental illness, or hepatic/renal insufficiency. Using a random number table, the 86 patients were divided into a control group and an experimental group (n = 43 each). There were no statistically significant differences in baseline characteristics such as gender composition (χ^2=0.047, $P = 0.828$), age distribution ($t = 0.289$, $P = 0.773$), or type of surgery between the two groups ($P > 0.05$).

2.2 Experimental Methods

Both groups fasted for 8–12 hours preoperatively. Upon entering the operating room, an intravenous pathway and invasive arterial monitoring were established. Monitors were connected, and patients received oxygen denitrogenation for 5 minutes. The control group received conventional continuous intravenous anesthesia. For induction, propofol (2.0–2.5 mg/kg), remifentanil (1.5–2.0 μg/kg), and cisatracurium (0.2 mg/kg) were administered slowly via intravenous injection. After loss of consciousness and jaw relaxation, tracheal intubation was performed. The ventilator was connected to assist respiration, maintaining end-tidal carbon dioxide partial pressure ($PetCO_2$) at 35–45 mmHg. During anesthesia maintenance, propofol ($4\sim12 mg\cdot kg^{-1}\cdot h^{-1}$) and remifentanil ($0.1\sim0.2 \mu g\cdot kg^{-1}\cdot min^{-1}$) were continuously infused. Cisatracurium was intermittently

injected to maintain muscle relaxation. The infusion rate was manually adjusted by the anesthesiologist based on clinical experience, hemodynamic parameters (heart rate and blood pressure), and surgical stimulation intensity to maintain a BIS value of 45–55. The experimental group received target-controlled infusion anesthesia. For induction, the TCI system was used to set a target plasma concentration of propofol at 4–6 μg/mL and remifentanil at 6–8 ng/mL. After starting the infusion, the system automatically regulated the infusion speed. When the patient lost consciousness and the BIS value dropped to 45–55, cisatracurium (0.2 mg/kg) was injected intravenously for tracheal intubation. Ventilator parameters were the same as in the control group. During anesthesia maintenance, the target plasma concentrations were maintained at 3–5 μg/mL for propofol and 4–6 ng/mL for remifentanil. The target concentrations were adjusted in real-time according to the intensity of surgical stimulation (e.g., during critical procedures such as head frame application, electrode implantation, or tumor resection) to ensure a stable BIS value of 45–55 and to keep intraoperative heart rate and systolic blood pressure fluctuations within ±20% of the preoperative baseline values. Both groups were routinely monitored for hemodynamic parameters. If blood pressure dropped below 20% of the baseline, phenylephrine (50 μg) was administered intravenously; if the heart rate fell below 55 beats/min, atropine (0.5 mg) was administered intravenously. Ten minutes before the end of surgery, the control group gradually reduced the infusion rate of anesthetic agents, while the experimental group lowered the TCI concentration. All anesthetic infusions were stopped at the end of the surgery. After recovery of spontaneous respiration, consciousness, and normal swallowing reflex, the tracheal tube was extubated. Patients were then transferred to the recovery room for 1–2 hours of observation before being sent back to the ward.

2.3 Observation Indicators

Three core indicators were selected: ① Anesthesia-related time (induction, postoperative emergence, and extubation time); ② Intraoperative consumption of anesthetic drugs (total dosage of propofol and remifentanil); ③ Incidence of perioperative adverse events (hypotension, bradycardia, etc.), with simultaneous monitoring of hemodynamic fluctuations.

2.4 Statistical Analysis

Data were analyzed using SPSS 26.0. Measurement data were expressed as (x±s) and analyzed by t-test. Enumeration data were expressed as [n(%)] and analyzed by χ^2test. A P-value <0.05 was considered statistically significant.

3. Results

3.1 Comparison of Anesthesia-related Time

Table 1. Comparison of anesthesia-related time indicators between the two groups ($\bar{x}$±s, min)

Group	Anesthesia induction time	Postoperative recovery time	Postoperative extubation time
Control group (n=43)	8.92±1.56	15.68±3.21	18.75±3.54
Experimental group (n=43)	5.31±1.24	8.25±2.17	10.32±2.89
t	8.724	9.351	10.126
P	<0.05	<0.05	<0.05

As shown in Table 1, the experimental group exhibited significantly shorter durations for anesthesia induction, postoperative emergence, and extubation compared to the control group (t=8.724, 9.351, 10.126; all P<0.05).

3.2 Comparison of Intraoperative Drug Consumption

Table 2. Comparison of intraoperative anesthetic drug dosage between the two groups ($\bar{x}$±s, mg)

Group	Total Propofol Dosage	Total Remifentanil Dosage
Control Group (n=43)	895.62±125.37	1.87±0.32
Experimental Group (n=43)	628.45±108.79	1.23±0.25
t	7.892	8.563
P	<0.05	<0.05

As shown in Table 2, the total intraoperative consumption of propofol and remifentanil in the experimental group was significantly lower than that in the control group (t=7.892, 8.563; all P<0.05).

3.3 Comparison of Perioperative Adverse Event Incidence

Table 3. Comparison of the incidence of perioperative adverse events between the two groups [n(%)]

Group	Hypotension	Bradycardia	Nausea and Vomiting	Total Incidence
Control group (n=43)	3(6.98)	2(4.65)	3(6.98)	8(18.60)
Experimental group (n=43)	1(2.33)	0(0.00)	1(2.33)	2(4.65)
χ^2	-	-	-	4.441
P	-	-	-	<0.05

As shown in Table 3, the total incidence of perioperative adverse events in the experimental group was 4.65%, significantly lower than 18.60% in the control group (χ^2=4.441, P<0.05).

4. Discussion

The application of Target-controlled Infusion (TCI) technology represents a paradigm shift in anesthesia for minimally invasive neurosurgery, transitioning from an "experience-driven" model to a "data-driven" approach. Its core advantage lies in utilizing pharmacokinetic models to enable computer systems to precisely regulate the infusion rate, rapidly achieving and stably maintaining the target plasma concentration to ensure a precise match between anesthetic depth and surgical stimulation intensity. In this study, the experimental group received anesthesia with target-controlled infusion (TCI) of propofol combined with remifentanil, and the BIS value was maintained at 45–55. This range is suitable for anesthesia depth in minimally invasive neurosurgery. It can not only effectively inhibit the stress response induced by surgical stimulation, but also avoid the suppression of neurological function, respiration and circulation caused by excessive anesthesia. This is also the key reason why the anesthesia induction time in the experimental group was significantly shorter than that in the control group: the TCI system can rapidly increase the blood concentration to the target level without repeated adjustment of the infusion rate, thus shortening the induction period [2].

Regarding intraoperative drug consumption, the significantly lower dosages of propofol and remifentanil in the experimental group are closely related to the precise control characteristics of TCI technology. Under the conventional continuous infusion model, plasma concentration fluctuations often necessitate excessive drug infusion to maintain stable anesthetic depth, leading to drug accumulation and waste. In contrast, TCI technology dynamically adjusts the target concentration based on the patient's real-time physiological status and the intensity of surgical stimulation, avoiding drug accumulation and waste, while also reducing the risk of adverse reactions caused by overdose. Furthermore, remifentanil's characteristics of rapid onset and swift metabolism, when combined with propofol in TCI anesthesia, further optimize the anesthetic effect and accelerate postoperative drug elimination, shortening emergence and extubation times. This aligns with the results of this study where the experimental group exhibited significantly shorter postoperative emergence and extubation times, meeting the clinical requirements of "rapid recovery" for minimally invasive neurosurgery [3].

Maintaining hemodynamic stability during the perioperative period is crucial for protecting neurofunction and avoiding severe complications such as intracranial hemorrhage. During minimally invasive neurosurgery, procedures like head frame application and tumor resection can easily trigger stress responses, causing drastic fluctuations in blood pressure and heart rate. Cerebral vessels are extremely sensitive to hemodynamic changes; excessive fluctuations can lead to insufficient or excessive cerebral perfusion, resulting in neurofunctional damage. In this study, the experimental group effectively suppressed stress responses through precise TCI regulation of anesthetic depth. The amplitude of perioperative blood pressure and heart rate fluctuations was significantly smaller than in the control group, and the incidence of adverse events was significantly reduced. This fully confirms the advantages of TCI anesthesia in maintaining hemodynamic stability and enhancing anesthetic safety. The higher incidence of adverse events in the control group was primarily related to large fluctuations in anesthetic depth and irrational drug dosing, such as stress responses caused by light anesthesia leading to hypertension, or hypotension and bradycardia caused by deep anesthesia suppressing the cardiovascular system [4].

5. Conclusion

The application of target-controlled infusion (TCI) anesthesia in minimally invasive neurosurgical procedures enables computer-aided precise regulation of anesthetic drug infusion rates, achieving individualized and precise management of anesthetic depth. This approach significantly shortens anesthesia induction, postoperative emergence, and extubation times, reduces anesthetic drug consumption, and lowers the risks of drug waste and adverse reactions. Simultaneously, this anesthetic method effectively suppresses perioperative stress responses, maintains hemodynamic stability, and reduces

the incidence of adverse events. It better aligns with the core requirements of minimally invasive neurosurgery—"precise minimization, neuroprotection, and rapid recovery"—and demonstrates clear advantages over conventional continuous intravenous infusion anesthesia. Therefore, TCI anesthesia is effective and safe in minimally invasive neurosurgery. It optimizes anesthesia management processes and improves perioperative outcomes for patients, making it worthy of widespread clinical application.

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Author Bio

Corresponding Author: Qibin Ke. Date of Birth: August 1971. Male. Native Place: Shiyan, Hubei. Qualification: Bachelor's Degree. Title: Chief Physician, Associate Professor. Research Direction: Clinical Anesthesia. Institution: The First Clinical Medical College of China Three Gorges University, Yichang Central People's Hospital. Postal Code: 443000. Mailing Address: No. 46 Xiling Second Road, Yichang, Hubei.

First Author: Tianpin Liu. Date of Birth: April 1980. Male. Native Place: Yichang, Hubei. Qualification: Master's Degree. Title: Associate Chief Physician. Research Direction: Clinical Anesthesia. Institution: The First Clinical Medical College of China Three Gorges University, Yichang Central People's Hospital. Postal Code: 443000. Mailing Address: No. 46 Xiling Second Road, Yichang, Hubei.