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A Randomized Controlled Study of Combined Spinal-Epidural Analgesia Using a 25G Fine Needle Single Puncture in Children

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Abstract: *Objective*: To investigate the efficacy and safety of combined spinal-epidural (CSE) anesthesia using a 25G spinal fine needle via a single puncture for lower limb surgery in children. *Methods*: Sixty pediatric patients scheduled for surgery were randomly divided into two groups, with 30 patients in each. The control group received subarachnoid anesthesia with 2–2.5 mL of 0.33% ropivacaine. The experimental group received the same ropivacaine dose, followed by withdrawal of the needle to the epidural space and administration of 0.1 mg hydromorphone diluted to 5 mL. The anesthetic and analgesic effects, incidence of complications, and postoperative family satisfaction were observed in both groups. *Results*: Compared with the control group, the experimental group showed a higher anesthesia success rate, a shorter onset time, and a longer maintenance time of anesthesia ($p < 0.05$). Postoperative analgesia at various time points was significantly better in the experimental group ($p < 0.05$). The total incidence of complications was lower in the experimental group, though the difference was not statistically significant ($p > 0.05$). Family satisfaction was significantly higher in the experimental group ($p < 0.05$). *Conclusion*: CSE anesthesia using a 25G fine needle via a single puncture for pediatric lower limb surgery is safe and effective. It can significantly improve surgical outcomes and is worthy of clinical promotion.

Keywords: 25G fine needle single puncture; Children; Combined spinal-epidural anesthesia; Hydromorphone

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1. Introduction

The management of anesthesia for pediatric surgery has always been a critical focus in clinical practice. Currently, in clinical practice in China, fine needle spinal anesthesia is commonly used for lower limb surgeries in children, with postoperative analgesia often relying on intravenous methods [1]. However, intravenous analgesia is often unsatisfactory, presenting issues such as unstable analgesic effects, suboptimal alertness, and incomplete pain relief. The combined spinal-epidural (CSE) anesthesia approach integrates the rapid onset of spinal anesthesia

with the advantage of epidural anesthesia for postoperative pain management. However, the traditional "needle-through-needle" technique requires initial puncture of the epidural space with a larger Tuohy needle, which has significant drawbacks including greater puncture trauma, risk of post-dural puncture headache, and a higher risk of catheter misplacement into the subarachnoid space [2].

In recent years, both domestic and international research has explored improved implementation methods. Among these, the technique using a 25G fine needle for a single puncture to simultaneously achieve intrathecal drug administration and epidural catheter placement shows promising prospects. This technique significantly reduces complication risks associated with traditional methods through a minimally invasive approach while perfectly retaining the flexibility for continuous postoperative epidural analgesia, providing an ideal solution for postoperative pain management [3]. Therefore, how to effectively achieve ideal anesthetic effects and practically solve postoperative pain problems has become an important issue urgently needing to be addressed. This study aims to use a 25G fine needle single puncture technique to achieve CSE anesthesia in children and evaluate its clinical efficacy and safety.

2. Materials and methods

2.1. General information

Sixty pediatric patients scheduled for surgery in our hospital from June 2024 to December 2025 were selected as subjects. The 60 patients were randomly divided into two groups using a random number table, with 30 patients in each group. The study was approved by the hospital ethics committee (Ethics Approval No.: 2025-KY-18).

2.1.1. Inclusion criteria

(1) Age 3–14 years, weight 10–40 kg
(2) Scheduled for lower limb surgery (e.g., lower limb fracture reduction and fixation, circumcision, etc.)
(3) Indicated for CSE anesthesia, ASA physical status I–II
(4) Informed consent obtained from the family and informed consent form signed

2.1.2. Exclusion criteria

(1) Cardiac diseases (e.g., congenital heart disease with cardiac dysfunction, acute myocarditis), liver diseases (e.g., cirrhosis, cholestatic liver disease), kidney diseases (e.g., chronic kidney insufficiency, acute kidney injury), neurological diseases (e.g., status epilepticus, spinal cord lesions)
(2) Allergy to ropivacaine or hydromorphone
(3) Contraindications to lumbar puncture (e.g., lumbar deformity, infection at puncture site, coagulation disorders)
(4) Concurrent systemic/local infectious diseases, or inability to cooperate with positioning (Blinding method to be added)

2.2. Methods

2.2.1. Preoperative preparation

Ten minutes preoperatively, children received an intravenous injection of dexmedetomidine (0.35 μg/kg) based on body weight (reference common pediatric preoperative sedation dose 0.5–1 μg/kg, providing sedation for anxiety

reduction and mild analgesia). Upon entering the operating room, a peripheral intravenous line was established, and the patient was connected to a multi-function monitor for continuous monitoring of heart rate, blood pressure, oxygen saturation, and respiratory rate.

2.2.2. Intraoperative procedure and management

(1) Positioning and puncture preparation

Assist the child into the lateral decubitus position with the lumbar intervertebral spaces fully opened. Using the L3–4 interspace as the puncture point, perform routine disinfection and drape with a sterile aperture drape, adhering strictly to aseptic technique.

(2) Puncture and group-specific drug administration

Puncture the subarachnoid space with a 25G fine needle. After observing clear cerebrospinal fluid (CSF) reflux, administer drugs: ① Control group: Inject 2–2.5 mL of isobaric 0.33% ropivacaine (2 mg/mL) (reference pediatric spinal anesthesia dose from the International Guidelines for Pediatric Regional Anesthesia*). ② Experimental group: First inject the same dose of ropivacaine. Then, after withdrawing the needle to the epidural space confirmed by "loss of resistance + aspiration negative for CSF/blood", inject 0.1 mg of hydromorphone (conforming to the pediatric safe dose range of 0.002–0.005 mg/kg), diluted with normal saline to 5 mL, administered in 3 aliquots over 5–8 minutes. This procedure was performed by attending physicians or higher.

(3) Monitoring and complication management

Record vital signs every 5 minutes. Manage complications as follows: ① Respiratory depression (RR < 12 breaths/min or SpO_2 < 90%): Administer oxygen/manual assisted ventilation, intubate if necessary; ② Hypotension: Administer fluid bolus 10–15 mL/kg, use ephedrine 0.1–0.2 mg/kg if ineffective; ③ Agitation: After excluding pain, administer additional dexmedetomidine 0.1–0.15 μg/kg, maintaining Ramsay sedation score 2–3.

2.2.3. Postoperative handover

Monitor vital signs for 30 minutes to 1 hour postoperatively. After confirming the child is awake (responsive to stimuli) and free of acute complications, transfer to the post-anesthesia care unit with a full handover.

2.3. Observation indicators

2.3.1. Assessment of anesthetic effects

Including: Anesthesia success rate (proportion of children meeting all criteria post-puncture

(1) Aspiration of clear CSF

(2) Surgery completed without requiring additional intravenous/local anesthetics

(3) Vital sign fluctuations < 20% of preoperative baseline, no surgery interruption due to inadequate anesthesia)

Anesthesia onset time (time from completion of intrathecal drug injection to the appearance of either:

(1) Loss of pain sensation in the surgical area of the lower limb

(2) Motor blockade in the lower limb.

Anesthesia maintenance time (time from anesthesia onset until effect wanes requiring supplemental medication).

2.3.2. Assessment of analgesic effects

Using the Faces Pain Scale-Revised (FPS-R) to evaluate pain intensity at 1 h, 4 h, 8 h, 12 h, and 24 h postoperatively, where 0 indicates no pain and 10 indicates worst pain [4].

2.3.3. Assessment of safety

Recording the incidence of intraoperative apnea, hypotension, postoperative headache, urinary retention, and puncture-related complications.

2.3.4. Evaluation of family satisfaction

Using a self-designed nursing satisfaction questionnaire on a 100-point scale, categorized as very satisfied (> 90 points), satisfied (75–90 points), and dissatisfied (< 75 points). Total satisfaction is the sum of very satisfied and satisfied cases [5].

2.4. Statistical methods

All data were processed using SPSS 23.0 software. Measurement data conforming to normal distribution are described as mean ± standard deviation, with intergroup comparisons using independent samples t-tests. Count data are presented as frequency and percentage, with differences tested using Chi-square (χ^2) analysis. The significance level was set at $p < 0.05$.

3. Results

3.1. Comparison of general data

As shown in **Table 1**, there were no significant differences in general patient data between the groups ($p > 0.05$).

Table 1. Comparison of general data between groups [n (%) / ($\overline{x} \pm s$)]

Group	No.	Sex (M/F)	Age (years)	Height (cm)	Weight (kg)	Pre anesthesia SBP (mmHg)	Pre anesthesia DBP (mmHg)	Pre anesthesia heart rate (beats/min)	Pre anesthesia respiratory rate (breaths/min)
Experimental group	30	16/14	7.64 ± 2.75	120.89 ± 15.23	26.57 ± 6.41	94.87 ± 8.02	57.93 ± 6.11	81.92 ± 10.15	18.45 ± 2.43
Control group	30	17/13	7.92 ± 2.61	122.56 ± 14.95	27.23 ± 6.34	95.76 ± 7.78	58.65 ± 5.89	83.67 ± 9.58	18.88 ± 2.31
t value			0.405	0.429	0.401	0.436	0.465	0.687	0.702
p value			0.687	0.670	0.690	0.664	0.644	0.495	0.485

M/F: Male/Female; SBP: Systolic blood pressure; DBP: Diastolic blood pressure

3.2. Comparison of anesthetic effects

As shown in **Table 2**, the experimental group showed a higher anesthesia success rate, a shorter anesthesia onset time, and a longer anesthesia maintenance time compared to the control group ($p < 0.05$).

Table 2. Comparison of anesthetic effects between groups [n (%) / ($\overline{x}$ ± s)]

Group	Number of cases (n)	Anesthesia success rate (n, %)	Anesthesia onset time (min)	Anesthesia maintenance time (min)
Experimental group	30	30 (100.00)	5.78 ± 0.25	98.22 ± 4.23
Control group	30	26 (86.67)	7.24 ± 0.24	78.81 ± 4.42
χ^2/*t* value	-	4.286	23.075	17.377
p value	-	0.038	0.001	0.001

3.3. Comparison of postoperative analgesic effects

As shown in **Table 3**, the experimental group showed significantly better analgesic effects at all postoperative time points compared to the control group ($p < 0.05$).

Table 3. Comparison of postoperative analgesic effects between groups [($\overline{x}$ ± s) / points]

Group	n	1h	4h	8h	12h	24h
Experimental group	30	1.22 ± 0.13	1.79 ± 0.17	2.23 ± 0.22	2.45 ± 0.15	3.37 ± 0.16
Control group	30	2.23 ± 0.14	2.52 ± 0.15	3.24 ± 0.27	3.67 ± 0.13	4.54 ± 0.19
t-value	-	28.956	17.636	15.884	33.665	25.799
p-value	-	0.001	0.001	0.001	0.001	0.001

3.4. Comparison of complications

As shown in **Table 4**, the total incidence of complications post-intervention was lower in the experimental group, but the difference between groups was not statistically significant ($p > 0.05$).

Table 4. Comparison of postoperative complications between groups [n (%)]

Group	n	Apnea	Hypo-tension	Urinary retention	Headache	Puncture-related complications	Total incidence
Experimental group	30	0 (0.00)	0 (0.00)	0 (0.00)	1 (3.33)	0 (0.00)	1 (3.33)
Control group	30	0 (0.00)	1 (3.33)	1 (3.33)	1 (3.33)	1 (3.33)	4 (13.32)
χ^2	-	-	-	-	-	-	1.964
p	-	-	-	-	-	-	0.161

3.5. Comparison of family satisfaction

As shown in **Table 5**, family satisfaction post-intervention was significantly higher in the experimental group ($p < 0.05$).

Table 5. Comparison of family satisfaction between groups [n (%)]

Group	Number of cases (n)	Very satisfied	Satisfied	Dissatisfied	Overall satisfaction
Experimental group	30	18 (60.00)	11 (36.67)	1 (3.33)	29 (96.67)
Control group	30	13 (43.33)	11 (36.67)	6 (20.00)	24 (80.00)
χ^2	-	-	-	-	4.043
p	-	-	-	-	0.044

4. Discussion

In pediatric surgery, the choice of anesthesia regimen is directly linked to surgical safety and postoperative recovery quality. Children's physiological functions are not yet fully developed, and their metabolic capacity for anesthetic drugs, pain tolerance, and sensitivity to adverse reactions differ significantly from adults. Therefore, ensuring anesthetic efficacy while minimizing trauma and complication risks remains a core direction in clinical anesthesia research [6]. In recent years, fine needle neuraxial anesthesia techniques have gained attention due to their minimally invasive advantages. In this study, CSE anesthesia was achieved using a 25G fine needle single puncture, breaking through the limitations of traditional techniques and demonstrating significant clinical value. The core innovation of this study lies in the 25G fine needle single puncture technique, which overcomes the traditional "needle-through-needle" two-puncture model. Its feasibility can be verified from two aspects: First, regarding technical safety, the diameter of the 25G needle is only 0.5mm, causing less damage compared to the traditional Tuohy needle [7]. Second, regarding epidural space localization, the dual judgment method of "loss of resistance + aspiration test" was used, sudden loss of resistance upon needle withdrawal combined with aspiration negative for CSF or blood, alongside the operator's experience, preventing the risk of drug misplacement [8].

In this study, the selection of ropivacaine strictly followed evidence-based guidelines and pediatric physiological characteristics: 0.33% isobaric ropivacaine at a dose of 2 mg/mL was chosen based on the following rationale: According to guidelines, for pediatric epidural regional anesthesia, the ropivacaine dose should be controlled at 2 mg/mL, with a maximum dose of 2.5 mg/kg, and a concentration of 0.25–0.5% is appropriate [9]. The 0.33% concentration falls within this range, ensuring adequate block strength while avoiding prolonged motor block due to high concentration and preventing insufficient analgesia from low concentration. Compared to relevant foreign studies, which used 0.33% ropivacaine 0.7 mg/kg for simple spinal anesthesia in pediatric lower limb surgery with an anesthesia maintenance time of about 75 minutes, the experimental group in this study, due to the combination with hydromorphone, had an extended maintenance time to (98.22 ± 4.23) minutes, indicating that combined medication can prolong analgesic duration [10]. Additionally, the faster onset time in the experimental group is speculated to be related to the synergistic effect of hydromorphone on the local anesthetic, as hydromorphone can inhibit pain signal transmission in the spinal dorsal horn, enhancing the blocking effect of ropivacaine.

Furthermore, the FPS-R scores in the experimental group from 1 to 24 hours postoperatively ranged from (1.22 ± 0.13 to 3.37 ± 0.16 points), all lower than those in the control group (2.23 ± 0.14 to 4.54 ± 0.19 points). The primary reason is the continuous inhibitory effect of hydromorphone on spinal pain signals, compensating for the duration limitation of simple spinal anesthesia. In the safety assessment, the total complication incidence in the experimental group was 3.33%, with only one case of headache. The control group had an incidence of 13.32%, including one case each of hypotension and urinary retention, showing some advantage over traditional techniques. Regarding puncture-related complications, traditional large-bore needles have an incidence of 3–5%; in this study, only the control group had one case of mild redness/swelling, which subsided within 24 hours. Regarding circulatory and respiratory aspects, neither group experienced apnea. The control group had one case of hypotension, which normalized after fluid administration, while the experimental group had no hypotension, indicating that preoperative dexmedetomidine and hydromorphone have low cardiovascular depressive effects, jointly ensuring safety [11]. Additionally, family satisfaction, as an important indicator of medical service quality, reached 96.67% in the experimental group, significantly higher than the 80.00% in the control group. In pediatric medical care, the emotional state and cooperation level of family members indirectly impact treatment outcomes.

A positive anesthesia experience helps alleviate family anxiety and improves the efficiency of doctor-patient communication.

5. Conclusion

In summary, CSE anesthesia using a 25G fine needle single puncture (ropivacaine + hydromorphone) for pediatric lower limb surgery demonstrates high success rate, prolonged analgesia, good safety, and possesses clinical promotion value. However, this study has certain limitations: First, the single-center sample size of 60 cases is small, and the lack of double-blinding may introduce bias. Second, follow-up was only 24 hours, not addressing long-term complications. Third, it was limited to the L3–4 interspace and ASA I-II children, not covering populations such as those with obesity or lumbar deformities. Fourth, ultrasound guidance was not used, which might affect puncture accuracy in children with unclear anatomy. Future research could involve multicenter, large-sample double-blind studies; extend follow-up to 72 hours and expand to special populations; combine ultrasound guidance to optimize the procedure and explore hydromorphone dose gradients; and establish standardized protocols to promote grassroots implementation.

Disclosure statement

The authors declare no conflict of interest.

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