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CLINICAL TRIAL REPORT

Preferable Concentration-Volume Combination of Ropivacaine for Femoral Nerve Block in Arthroscopic Meniscoplasty: A Prospective, Double-Blind, Randomized Clinical Trial

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Purpose: This study aimed to determine the preferable combination of ropivacaine balancing analgesic efficacy with minimal motor impairment under fixed total dosage for ultrasound-guided femoral nerve block (FNB) in meniscoplasty patients.

Patients and Methods: In this randomized double-blind trial, 200 patients scheduled for arthroscopic meniscus repair were allocated to four groups receiving ultrasound-guided FNB with equivalent 50 mg ropivacaine doses [$R_{0.17}$: 0.17% (30 mL); $R_{0.20}$: 0.20% (25 mL); $R_{0.25}$: 0.25% (20 mL); $R_{0.33}$: 0.33% (15 mL)]. The primary outcome was area under curve (AUC) of visual analog scale (VAS) pain intensity scores on movement through 24 hours postoperatively.

Results: Statistically significant intergroup differences were observed in the AUC of VAS pain intensity scores on movement through 24 and 48 hours postoperatively ($R_{0.33} < R_{0.20} < R_{0.17}$; $R_{0.25} \approx R_{0.20} < R_{0.17}$). The AUC of VAS scores at rest through 24 hours postoperatively showed: $R_{0.33} < R_{0.25} < R_{0.20} < R_{0.17}$; and at 48 hours: $R_{0.33} \approx R_{0.25} < R_{0.20} < R_{0.17}$. The AUC of sensory block scores through 24 and 48 hours postoperatively showed: $R_{0.33} > R_{0.25} \approx R_{0.20} > R_{0.17}$. In terms of postoperative motor block scores, no significant difference was found between the $R_{0.17}$ and $R_{0.20}$ groups ($P = 0.2233$), but both were significantly lower than the $R_{0.25}$ and $R_{0.33}$ groups ($P < 0.05$). The AUC of quadriceps muscle strength scores through 24 hours postoperatively showed: $R_{0.33} < R_{0.25} < R_{0.20} < R_{0.17}$; and at 48 hours: $R_{0.33} < R_{0.25} < R_{0.20} \approx R_{0.17}$. The number of patients requiring rescue analgesia was significantly higher in the $R_{0.17}$ group than in the other three groups ($P = 0.0013$).

Conclusion: At a dose of 50 mg ropivacaine, 0.20% ropivacaine (25 mL) for FNB provided effective postoperative analgesia for patients undergoing arthroscopic meniscoplasty, while allowing for earlier recovery of muscle strength.

Keywords: ultrasound guidance, femoral nerve block, ropivacaine, sensory block, motor block

Introduction

Arthroscopic meniscoplasty has emerged as the preferred surgical approach for meniscal injuries.[1] Despite its minimally invasive nature with small incisions and reduced trauma, moderate to severe postoperative pain persists in up to 60% of patients,[2] primarily attributed to the dense neural innervation of the joint capsule. Postoperative pain not only compromises clinical outcomes and patient satisfaction but also hinders early functional rehabilitation.[3,4] Early mobilization is critical for postoperative recovery, facilitating joint function restoration, reducing cardiovascular complications, shortening hospitalization, and minimizing healthcare costs while improving patient satisfaction.[5] Consequently, effective pain management constitutes a pivotal component of enhanced recovery protocols for meniscal injury patients.

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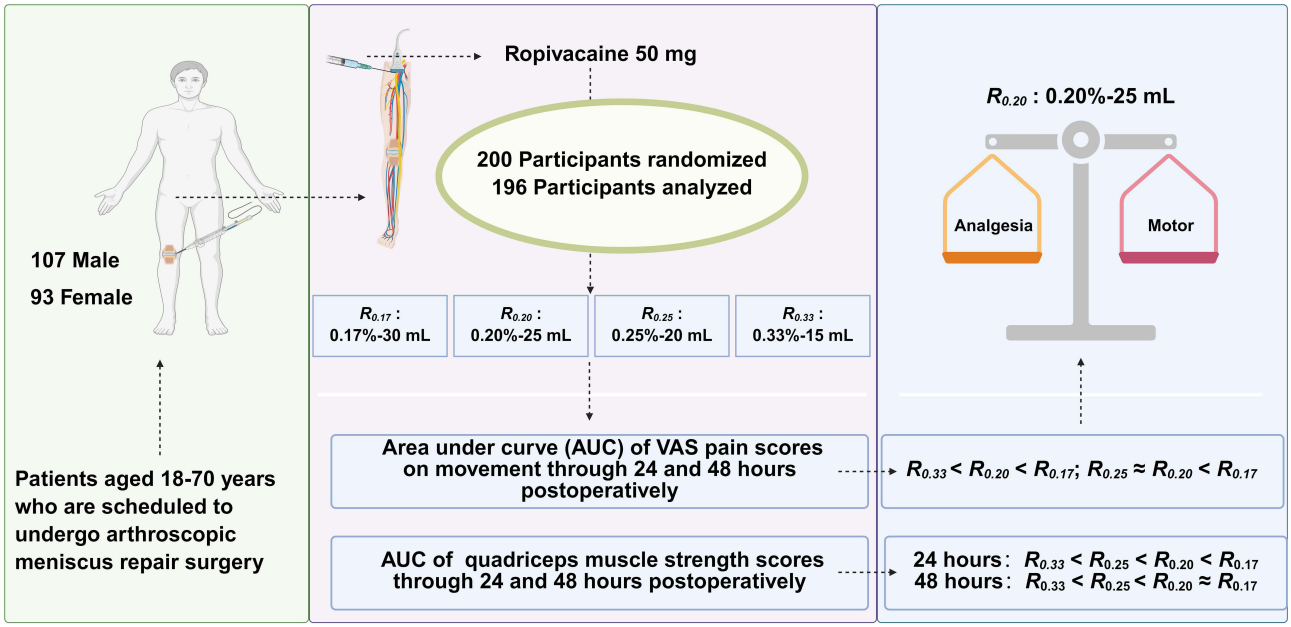
Graphical Abstract



Current analgesic modalities for arthroscopic meniscal surgery include systemic intravenous analgesia, intra-articular drug injection, and nerve blocks. Ultrasound-guided nerve blockade has gained prominence due to its technical maturity, reliable efficacy, high success rate, and favorable safety profile. Preoperative nerve blockade provides preemptive analgesia by interrupting nociceptive transmission pathways, thereby reducing central sensitization. Additionally, it reduces intraoperative general anesthetic requirements, facilitates rapid postoperative recovery, and ensures prolonged postoperative analgesia.

Femoral nerve block (FNB) and saphenous nerve block (SNB) represent two common regional anesthesia techniques for knee surgeries. SNB is indeed a local analgesic method that preserves motor function. However, compared to SNB, FNB provides more reliable and stronger analgesic effects,[6,7] which is crucial for surgeries involving the patella, meniscus, and anterior cruciate ligament. At the same time, FNB has an advantage in improving the response to tourniquets.[8] Therefore, FNB has its unique clinical application value compared to SNB, but its impact on the strength of the quadriceps muscle remains a major clinical concern.[9] The use of low-concentration ropivacaine enables sensory-motor dissociation blockade.[10] In most studies, the concentration of ropivacaine used for femoral nerve block ranges from 0.1% to 0.5%.[11–14] It was found that 0.1% or 0.2% of ropivacaine can achieve a balance between pain relief and preservation of motor function.[14,15] However, in most studies, when comparing the efficacy of different drug concentrations, the control over the total drug dosage is not strict enough.[16,17]

To provide further evidence, this prospective study investigates patients undergoing elective arthroscopic meniscoplasty under standardized ultrasound-guided FNB with a fixed ropivacaine dose (50mg) administered in varying concentration-volume combinations. Our objective is to identify the appropriate ropivacaine formulation that balances analgesic efficacy with motor function preservation, thereby establishing an evidence-based protocol for perioperative pain management in minimally invasive knee procedures.

Materials and Methods

This study was approved by the Ethics Committee of West China Hospital, Sichuan University (Ethical approval number: 2019–822), and all participants provided written informed consent. The trial was registered prior to patient enrollment at the Chinese Clinical Trial Registry on July 24th, 2020 (ChiCTR2000034895).

Patient Enrollment

Two hundred patients scheduled for unilateral arthroscopic meniscoplasty at the Sports Medicine Center of West China Hospital between August 2020 and October 2021 were consecutively enrolled. Inclusion criteria were: (1) age 18–70 years; (2) body mass index (BMI) 18–34 kg/m^2; (3) American Society of Anesthesiologists (ASA) physical status classification I–III; (4) scheduled for elective arthroscopic meniscoplasty. Exclusion criteria were: (1) contraindications to nerve blocks (coagulation disorders, infection at the puncture site, inability to cooperate with the procedure, local anesthetic allergy, etc).; (2) pregnancy or breastfeeding; (3) inability to cooperate with postoperative follow-up (illiteracy, hearing impairment, mental disorders, etc).; (4) history of substance abuse; (5) diabetes mellitus or peripheral neuropathy; (6) severe hepatic or renal insufficiency; (7) concomitant nerve injury or abnormal muscle strength in the affected limb. Withdrawal criteria were: (1) surgical time exceeding 2 hours; (2) intraoperative conversion to open surgery or extension of the surgical field beyond the knee joint; (3) refusal of postoperative follow-up; (4) ineffective nerve block.

Patient Grouping

A blinded observer used SAS 9.2 software to generate random numbers (1–200) for random group assignment. Patients were assigned to one of four groups (n = 50 per group): Group A ($R_{0.17}$): 30 mL of 0.17% ropivacaine; Group B ($R_{0.20}$): 25 mL of 0.20% ropivacaine; Group C ($R_{0.25}$): 20 mL of 0.25% ropivacaine; Group D ($R_{0.33}$): 15 mL of 0.33% ropivacaine.

Blinding Procedure

Blinding was implemented as follows: (1) Preoperative visits were conducted by designated personnel; patients were enrolled based on inclusion/exclusion criteria, and group assignment was determined after signing the informed consent form. The randomization sequence was generated by an independent statistician using computer software, and the allocation information was placed in sequentially numbered, opaque, sealed envelopes. These envelopes were kept by a research coordinator not involved in patient recruitment or outcome assessment; (2) The preparation and administration of the drugs were performed by an individual who was not involved in any other aspects of the study. Syringes used for drug preparation were of the same model and covered from view, with all relevant details known only to this person; (3) All FNB were performed by the same trained anesthesiologist, who only performs nerve block but is unclear about the concentration and volume of the drugs used; (4) Sensory and motor block levels and onset times were assessed by personnel blinded to group assignment; (5) Intraoperative anesthesiologists, postoperative follow-up personnel, and surgeons were blinded to group assignment; (6) Statistical analysis was performed by statisticians blinded to group assignments.

Perioperative Analgesia and Management

After admission, electrocardiographic monitoring was initiated. Single-injection ultrasound-guided FNB was performed according to group assignment. Briefly, patients were placed in the supine position with the affected limb abducted and externally rotated 15°. After routine disinfection, a portable color ultrasound machine with a high-frequency linear array transducer (6–13 MHz) was used. Using an in-plane approach, the transducer was placed parallel to the inguinal ligament. The femoral nerve, appearing as a round, hyperechoic structure lateral to the femoral artery, between the iliac fascia and iliopsoas muscle, was identified. The needle (22-gauge, 80 mm) was inserted 1 cm lateral to the transducer along its long axis. The needle trajectory was clearly visualized. When the needle tip is below the iliac fascia and close to the femoral nerve, the assigned drug solution was deposited around the femoral nerve, both superficially and deeply, to ensure that the local anesthetic spreads in a circular manner around the nerve. After injection, the needle was withdrawn, and pressure was applied to the puncture site. FNB was performed using this method in all groups. Sensory block level in the anterior thigh and quadriceps muscle strength was assessed and recorded at 2, 4, 6, 8, 10, 15, 25, and 30 minutes post-injection. After confirming the block, general anesthesia was induced.

Anesthesia induction included intravenous administration of sufentanil (0.2 μg/kg), rocuronium (0.1 mg/kg), propofol (2 mg/kg), and midazolam (2 mg). An SLIPA laryngeal mask airway was inserted, and anesthesia was maintained with

1–3% sevoflurane and 50% nitrous oxide. The anesthesiologist adjusted sufentanil, rocuronium, and sevoflurane concentration as needed. At the end of surgery, inhalational anesthetics were discontinued, and the patient was transferred to the post-anesthesia care unit (PACU). Sensory block level in the femoral nerve distribution area, resting and movement-related visual analog scale (VAS) scores (0, no pain; 10, worst pain. 1–3, mild; 4–6, moderate; 7–10, severe), quadriceps muscle strength, incidence of adverse events, and rescue analgesia use (100 mg intramuscular tramadol if the patient experienced unbearable pain upon awakening) were recorded upon PACU discharge and within 48 hours of returning to the ward.

Sensory block level was assessed using a pinprick test in the anterior thigh (femoral nerve distribution area) and compared to the contralateral side.[18] The scoring system was: 0, no difference from pre-block; 1, slight hypoesthesia with mild pain; 2, marked hypoesthesia without pain; 3, complete anesthesia. A score ≥ 2 was considered a successful sensory block.

Quadriceps muscle strength was assessed using the Lovett grading system.[19] The patient was asked to lift their lower leg while the examiner lifted the thigh. The scoring system was: 0, no muscle contraction; 1, slight muscle contraction without joint movement; 2, Complete range of motion (ROM) of the joint can be achieved, but only when gravity is eliminated; 3, Complete ROM of the joint can be achieved against gravity; 4, Complete ROM of the joint can be achieved against gravity and moderate resistance; 5, Complete ROM of the joint can be achieved against gravity and strong resistance. A score < 3 post-injection was considered a successful motor block. Postoperative recovery was defined as ≥ 3.

Outcome

Primary outcome: area under curve (AUC) of VAS pain scores on movement through 24 hours postoperatively.

Secondary outcomes: (1) Sensory block level and quadriceps muscle strength at 2, 4, 6, 8, 10, 15, 25, and 30 minutes post-injection; (2) Sensory block level, quadriceps muscle strength, resting and movement-related VAS pain scores, and corresponding AUCs at PACU discharge and 2, 4, 8, 12, 24, and 48 hours postoperatively; (3) Total consumption of midazolam, sufentanil, rocuronium, and propofol, and maximum sevoflurane concentration during surgery; (4) Vital signs upon admission, incision, and 10, 30 minutes and the end of the surgery; (5) Number of patients requiring rescue analgesia.

Statistical Analysis

A pilot study of 20 patients showed AUCs of VAS pain scores on movement through 24 hours postoperatively were 115.20 ± 10.80 ($R_{0.17}$), 92.11 ± 7.50 ($R_{0.20}$), 87.33 ± 9.41 ($R_{0.25}$), and 79.01 ± 11.25 ($R_{0.33}$). Based on this pilot study, PASS 11.0 software (NCSS Statistical Software, Kaysville, UT, USA) was used to calculate a minimum sample size of 40 patients per group (two-sided $\alpha = 0.05$, power = 90%). To account for potential withdrawals and loss to follow-up, 50 patients were recruited per group.

Quantitative data are presented as mean ± standard deviation. AUCs were calculated and compared using GraphPad Prism version 7 (GraphPad Software Inc., San Diego, CA, USA). Other data were analyzed using SAS 9.2. Primary outcomes were tested first at a pre-specified alpha level of 0.05. Only if a primary outcome showed statistical significance did we proceed to test secondary outcomes within that domain, thereby controlling the family-wise error rate. Comparisons of quantitative data among the four groups were performed using analysis of variance or the Kruskal–Wallis test. Multiple testing was performed using Tukey's test or Dunn's test. Qualitative data are presented as counts and percentages; comparisons among the four groups were performed using the χ^2-test or Fisher's exact test. Repeated measures data were analyzed using mixed-effects models, which provides some protection against inflation of type I error. A P value <0.05 was considered statistically significant.

Results

Patient Characteristics

Based on the inclusion and exclusion criteria, a total of 200 patients were enrolled. One patient was excluded due to an operative time exceeding 2 hours, and three patients were excluded due to changes in surgical approach. Finally, 196

patients were included in the analysis: 48 in the $R_{0.17}$ group, 49 in the $R_{0.20}$ group, 50 in the $R_{0.25}$ group, and 49 in the $R_{0.33}$ group (Figure 1).

There were no significant differences in age, sex, BMI, surgical side, ASA status, operative time, or anesthetic time among the four groups of patients (Table 1).

Sensory and Motor Blockade within 30 minutes After Femoral Nerve Block

The onset time of sensory blockade (score ≥ 2) showed a decreasing trend with increasing concentration. The score showed an increasing trend over time. The $R_{0.33}$ group showed the fastest increase and the highest peak (2.65 ± 0.48), while the $R_{0.17}$ group showed the slowest increase and the lowest peak (2.27 ± 0.76). The $R_{0.20}$ (2.39 ± 0.61) and $R_{0.25}$ (2.56 ± 0.50) groups were intermediate (Figure 2A). There was a statistically significant difference among the four groups ($P = 0.0058$). Specifically, the sensory blockade scores in the $R_{0.17}$ and $R_{0.20}$ groups were significantly lower than those in the $R_{0.25}$ and $R_{0.33}$ groups ($P < 0.05$).

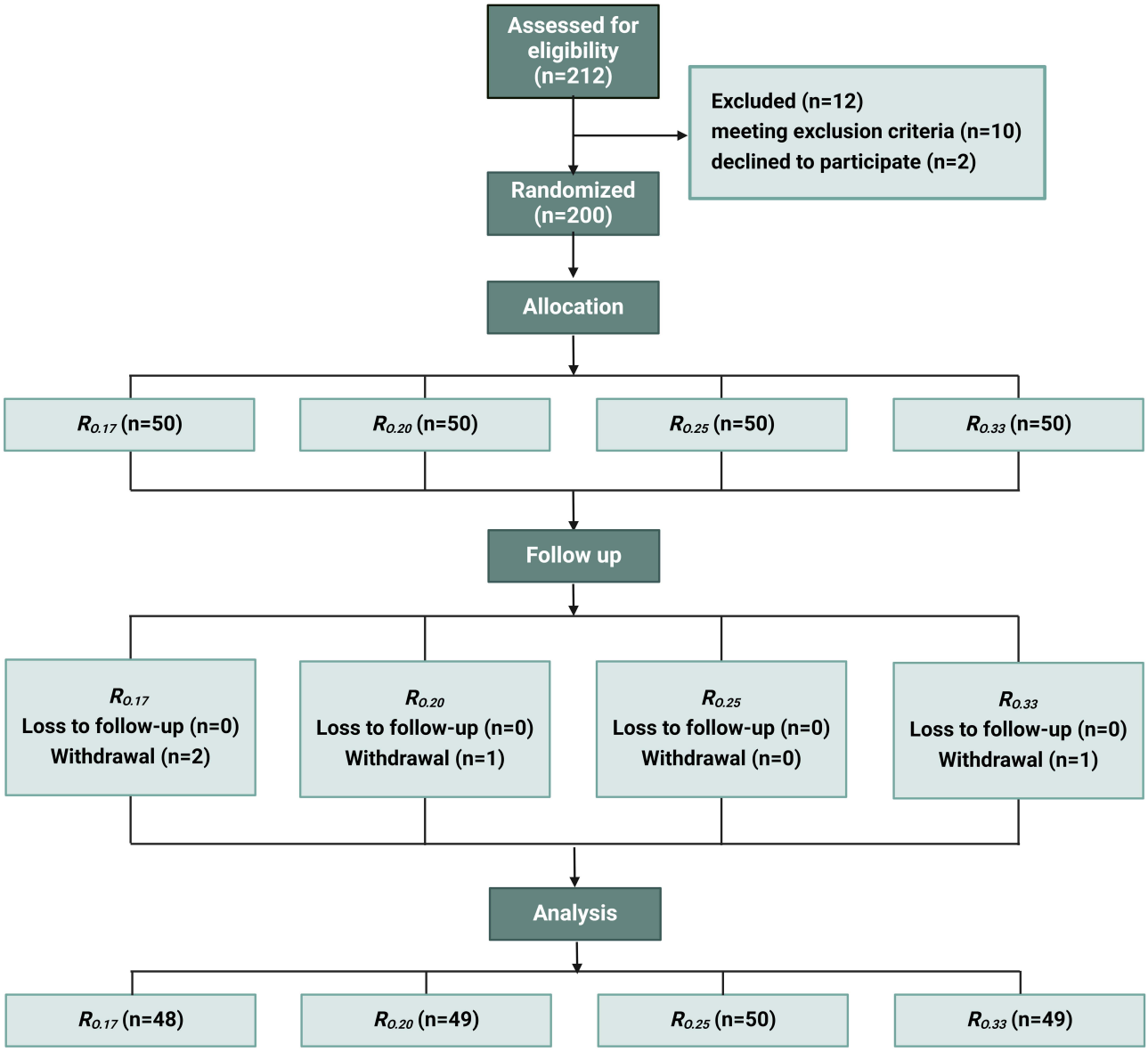


Figure 1 Flow diagram depicting patient selection.
Abbreviations: $R_{0.17}$, 30 mL of 0.17% ropivacaine; $R_{0.20}$, 25 mL of 0.20% ropivacaine; $R_{0.25}$, 20 mL of 0.25% ropivacaine; $R_{0.33}$, 15 mL of 0.33% ropivacaine.

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Table 1 Clinical and Demographic Characteristics

Characteristic	$R_{0.17}$ (n = 48)	$R_{0.20}$ (n = 49)	$R_{0.25}$ (n = 50)	$R_{0.33}$ (n = 49)	*P* value
Age (year)	39.27 ± 11.76	41.84 ± 17.62	41.64 ± 15.24	38.94 ± 15.49	0.6851
Gender					
Male (%)	26 (54.17)	25 (51.02)	24 (48.00)	30 (61.22)	0.5907
Female (%)	22 (45.83)	24 (48.98)	26 (52.00)	19 (38.78)	
Ethnic group					
Han (%)	46 (95.83)	48 (97.96)	49 (98.00)	49 (100.00)	0.5690
Tibetan (%)	1 (2.08)	0 (0.00)	1 (2.00)	0 (0.00)	
Other (%)	1 (2.08)	1 (2.04)	0 (0.00)	0 (0.00)	
Weight (kg)	62.63 ± 9.77	64.42 ± 12.63	61.28 ± 12.71	63.82 ± 11.79	0.5622
Height (cm)	165.13 ± 7.65	165.73 ± 8.91	163.54 ± 8.40	166.69 ± 7.95	0.2834
History of other diseases					
Neurological complications	0/48	0/49	0/50	0/49	–
Cardiovascular system complications	1/47	2/47	4/46	1/48	0.5341
Pulmonary complications	0/48	1/48	0/50	0/49	0.7449
Drinking					
Never (%)	48 (100.00)	48 (97.96)	44 (88.00)	45 (91.84)	0.1379
Recent (%)	0 (0.00)	0 (0.00)	3 (6.00)	2 (4.08)	
Before (%)	0 (0.00)	1 (2.04)	3 (6.00)	2 (4.08)	
Operation time (min)	44.40 ± 15.88	45.41 ± 16.78	47.50 ± 15.61	46.02 ± 16.00	0.8103
Surgery side					0.8552
Left	22	25	20	26	
Right	26	24	27	23	

Abbreviations: $R_{0.17}$, 30 mL of 0.17% ropivacaine; $R_{0.20}$, 25 mL of 0.20% ropivacaine; $R_{0.25}$, 20 mL of 0.25% ropivacaine; $R_{0.33}$, 15 mL of 0.33% ropivacaine.

The onset time of motor blockade (score < 3) showed a decreasing trend with increasing concentration. The score showed a decreasing trend over time. The $R_{0.33}$ group showed the fastest and greatest decrease in quadriceps muscle strength score (1.22 ± 0.80), while the $R_{0.17}$ group showed the slowest and smallest decrease (2.52 ± 0.74). The $R_{0.20}$ (2.39 ± 0.95) and $R_{0.25}$ (1.52 ± 1.11) groups were intermediate (Figure 2B). There was a statistically significant difference among the four groups (P = 0.0117). Specifically, the muscle strength scores in the $R_{0.17}$ and $R_{0.20}$ groups were significantly higher than those in the $R_{0.33}$ group (P = 0.0036 and P = 0.0080, respectively).

Postoperative Pain Scores

The mean resting VAS scores in all four groups were below 5 during the postoperative period (Figure 3A). Significant intergroup differences were observed (P = 0.0006), with the $R_{0.17}$ group demonstrating significantly higher VAS scores compared to the $R_{0.25}$ and $R_{0.33}$ groups (P = 0.0009 and P = 0.0002, respectively). The $R_{0.20}$ group showed significantly elevated scores versus the $R_{0.33}$ group (P = 0.0281). Analysis of AUC of resting VAS pain scores revealed the following patterns: through 24 hours postoperatively, $R_{0.17}$ (80.78 ± 5.09) > $R_{0.20}$ (73.94 ± 7.96) > $R_{0.25}$ (68.54 ± 8.41) > $R_{0.33}$

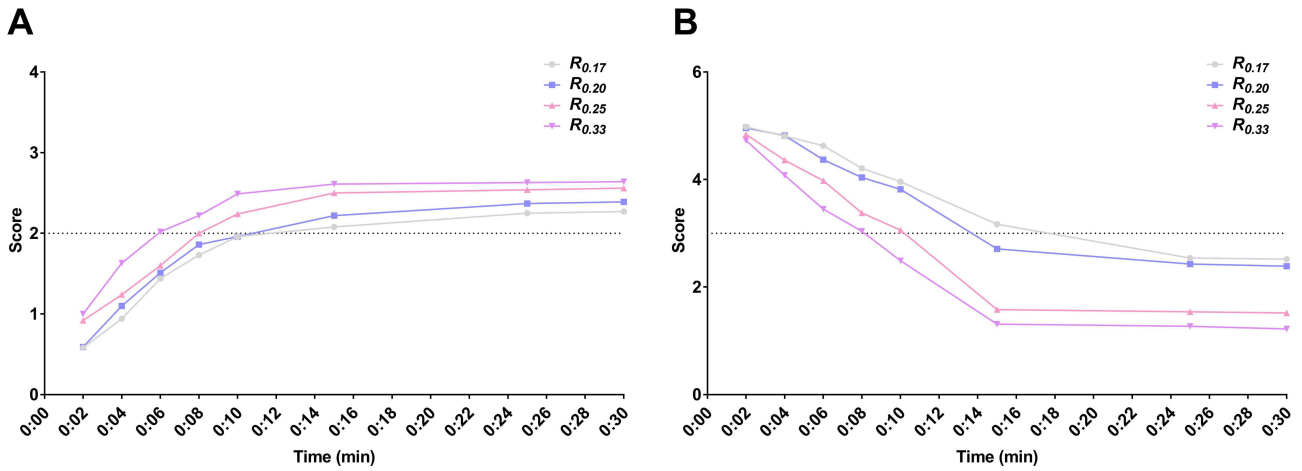

Figure 2 Sensory (**A**) and motor (**B**) blockade scores within 30 minutes after femoral nerve block.
Abbreviations: $R_{0.17}$, 30 mL of 0.17% ropivacaine; $R_{0.20}$, 25 mL of 0.20% ropivacaine; $R_{0.25}$, 20 mL of 0.25% ropivacaine; $R_{0.33}$, 15 mL of 0.33% ropivacaine.

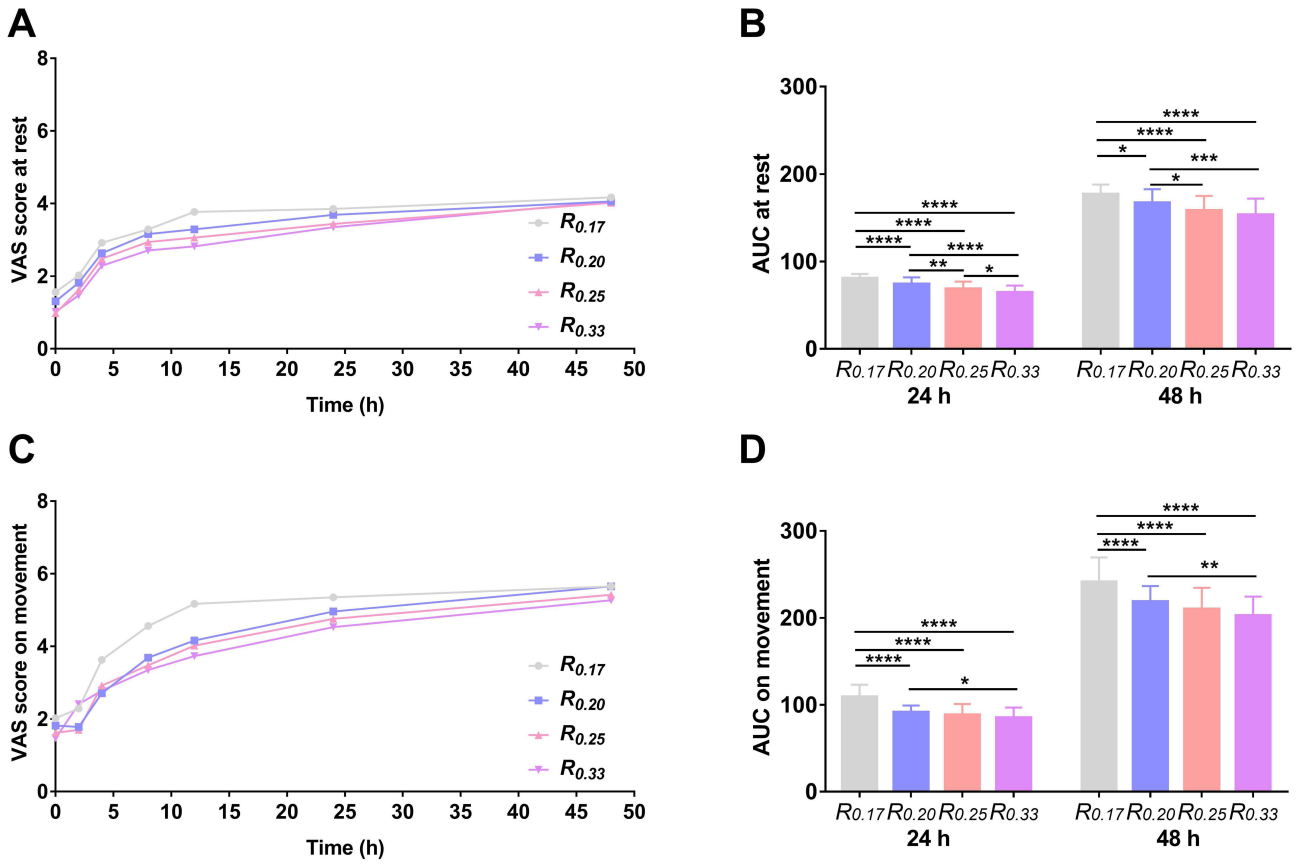

Figure 3 Postoperative VAS pain scores at rest (**A**) and the AUC over time (**B**); postoperative VAS pain scores on movement (**C**) and the AUC over time (**D**).*P<0.05; **P<0.01; ***P<0.001; ****P<0.0001.
Abbreviations: $R_{0.17}$, 30 mL of 0.17% ropivacaine; $R_{0.20}$, 25 mL of 0.20% ropivacaine; $R_{0.25}$, 20 mL of 0.25% ropivacaine; $R_{0.33}$, 15 mL of 0.33% ropivacaine; AUC, area under curve; VAS, visual analog scale.

(64.33 ± 8.15); through 48 hours postoperatively, $R_{0.17}$ (177.00 ± 10.89) > $R_{0.20}$ (166.90 ± 15.76) > $R_{0.25}$ (158.10 ± 16.94) ≈ $R_{0.33}$ (153.30 ± 18.63) (Figure 3B).

For pain on movement, the time to first VAS score > 5 was delayed with increasing ropivacaine concentrations: R0.17 group (12 hours) < other groups (24 hours) (Figure 3C). Significant intergroup differences in VAS scores on movement

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were noted ($P = 0.0491$), with the $R_{0.17}$ group showing significantly higher scores than other groups ($P = 0.0315$ vs $R_{0.20}$; $P = 0.0137$ vs $R_{0.25}$; $P = 0.0258$ vs $R_{0.33}$). No significant differences were observed between the remaining groups ($P > 0.05$). For the primary outcome measure, the AUC of VAS scores on movement through 24 hours postoperatively were 109.20 ± 13.79, 91.31 ± 7.72, 88.42 ± 12.41, and 85.05 ± 11.79 for the $R_{0.17}$, $R_{0.20}$, $R_{0.25}$, and $R_{0.33}$ groups, respectively; through 48 hours postoperatively, these values were 241.20 ± 28.23, 218.60 ± 18.00, 210.00 ± 24.56, and 202.70 ± 21.65 (Figure 3D). Significant intergroup differences in AUC for VAS scores on movement were observed through both 24 and 48 hours postoperatively ($R_{0.33} < R_{0.20} < R_{0.17}$; $R_{0.25} \approx R_{0.20} < R_{0.17}$).

Postoperative Sensory and Motor Block

Time to recovery of sensory block to a score < 2: $R_{0.33}$ group (8 hours postoperatively) > $R_{0.17}$, $R_{0.20}$, and $R_{0.25}$ groups (4 hours postoperatively). The $R_{0.17}$ group recovered to a score of 0 at 24 hours postoperatively, while the other three groups reached a score of 0 at 48 hours postoperatively (Figure 4A). No statistically significant difference was observed among the four groups overall ($P > 0.05$). The AUC of sensory block scores through 24 and 48 hours postoperatively for the R0.17, $R_{0.20}$, $R_{0.25}$, and $R_{0.33}$ groups were 19.52 ± 4.07, 23.77 ± 5.12, 25.32 ± 6.16, and 31.86 ± 7.38, respectively (24 hours); and 19.52 ± 4.07, 24.73 ± 6.13, 27.72 ± 8.19, and 36.54 ± 10.65, respectively (48 hours) (Figure 4B). Statistically significant differences in the AUC of sensory block scores were observed at both 24 and 48 hours postoperatively ($R_{0.33} > R_{0.25} \approx R_{0.20} > R_{0.17}$).

The time to recovery of motor function (score ≥ 3) showed a trend of prolongation with increasing concentration: $R_{0.17}$ group (4 hours postoperatively) < $R_{0.20}$ group (8 hours postoperatively) < $R_{0.25}$ group (12 hours postoperatively) < $R_{0.33}$ group (24 hours postoperatively) (Figure 4C). Statistically significant differences were observed among the four

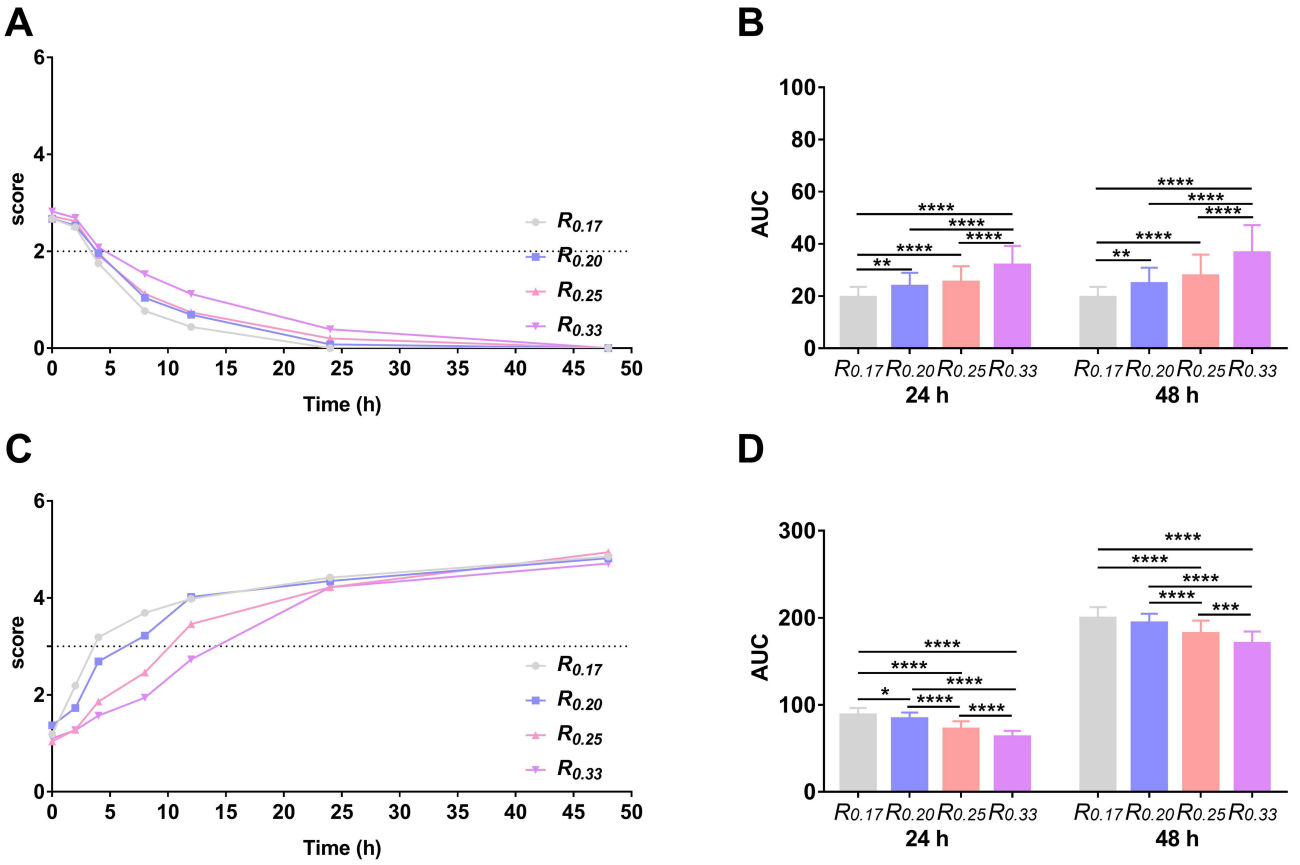

Figure 4 Postoperative sensory block scores (**A**) and the AUC over time (**B**); postoperative motor block scores (**C**) and the AUC over time (**D**). *P<0.05; **P<0.01; ***P<0.001; ****P<0.0001.

Abbreviations: $R_{0.17}$, 30 mL of 0.17% ropivacaine; $R_{0.20}$, 25 mL of 0.20% ropivacaine; $R_{0.25}$, 20 mL of 0.25% ropivacaine; $R_{0.33}$, 15 mL of 0.33% ropivacaine; AUC, area under curve.

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groups (P = 0.0010). Compared to the $R_{0.17}$ group, the $R_{0.25}$ and $R_{0.33}$ groups showed significantly prolonged postoperative motor block (P = 0.0389 and P = 0.0272, respectively). Compared to the $R_{0.20}$ group, the $R_{0.25}$ and $R_{0.33}$ groups also showed significantly prolonged postoperative motor block (P = 0.0011 and P = 0.0007, respectively). No statistically significant difference was observed between the $R_{0.17}$ and $R_{0.20}$ groups (P = 0.2233). The AUC of motor block scores through 24 hours postoperatively for the $R_{0.17}$, $R_{0.20}$, $R_{0.25}$, and $R_{0.33}$ groups were 88.26 ± 8.11, 84.04 ± 7.06, 72.02 ± 9.10, and 63.27 ± 6.85, respectively, showing a statistically significant difference ($R_{0.33} < R_{0.25} < R_{0.20} < R_{0.17}$). Through 48 hours postoperatively, the AUC values were 199.50 ± 12.78, 194.10 ± 10.52, 181.90 ± 14.87, and 170.40 ± 13.90, respectively (Figure 4D), showing a statistically significant difference ($R_{0.33} < R_{0.25} < R_{0.20} \approx R_{0.17}$).

Other Indicators

There were no statistically significant differences ($P > 0.05$) in systolic blood pressure, diastolic blood pressure, and heart rate among the four groups of patients at baseline (T0), 10 minutes after the start of surgery (T1), 30 minutes after the start of surgery (T2), and at the end of surgery (T3) (Table 2).

There were no statistically significant differences ($P > 0.05$) in the amount of general anesthetic used intraoperatively among the four groups of patients (Table 3). Postoperatively, the number of patients requiring rescue analgesia in the $R_{0.17}$ group was statistically significantly different ($P < 0.05$) compared to each of the other three groups (Table 3).

Discussion

This study compared the effects of ultrasound-guided FNB using equivalent doses of ropivacaine with different concentration-volume combinations on postoperative sensory and motor blockade in patients undergoing elective arthroscopic meniscoplasty. The objective was to determine the preferable concentration-volume combination. Results

Table 2 Hemodynamic Data

Parameters	$R_{0.17}$	$R_{0.20}$	$R_{0.25}$	$R_{0.33}$
Systolic pressure (mmHg)				
T0	120.06 ± 11.32	128.33 ± 16.48	126.88 ± 15.89	123.65 ± 17.74
T1	101.79 ± 10.21	102.06 ± 11.42	105.88 ± 14.54	103.02 ± 16.94
T2	110.29 ± 12.75	114.61 ± 13.91	113.06 ± 15.07	115.78 ± 17.75
T3	114.25 ± 13.76	119.02 ± 14.66	117.70 ± 14.91	119.82 ± 16.60
Diastolic pressure (mmHg)				
T0	82.38 ± 10.67	83.90 ± 10.52	81.58 ± 10.69	85.82 ± 11.61
T1	69.31 ± 8.66	67.94 ± 7.57	67.46 ± 8.77	67.12 ± 8.60
T2	74.63 ± 9.81	69.98 ± 9.71	68.98 ± 9.01	73.69 ± 10.79
T3	74.17 ± 13.00	73.20 ± 9.62	72.40 ± 9.22	73.63 ± 10.32
Heart rate (beats/min)				
T0	79.31 ± 7.22	77.61 ± 10.85	79.56 ± 12.50	80.80 ± 11.93
T1	62.48 ± 4.67	58.69 ± 6.34	62.04 ± 8.39	59.88 ± 6.21
T2	67.21 ± 7.39	66.29 ± 8.27	69.00 ± 13.28	69.35 ± 8.48
T3	72.69 ± 9.37	72.41 ± 7.70	72.76 ± 9.55	72.24 ± 8.21

Abbreviations: T0, baseline; T1, 10 min after the start of surgery; T2, 30 min after the start of surgery; T3, at the end of the operation; $R_{0.17}$, 30 mL of 0.17% ropivacaine; $R_{0.20}$, 25 mL of 0.20% ropivacaine; $R_{0.25}$, 20 mL of 0.25% ropivacaine; $R_{0.33}$, 15 mL of 0.33% ropivacaine.

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Table 3 The Dosage of Anesthetic Drugs Used During the Operation and the Number of Patients with Postoperative Relief Analgesia

Parameters	$R_{0.17}$	$R_{0.20}$	$R_{0.25}$	$R_{0.33}$	P
Sufentanil (μg)	14.84 ± 4.14	15.46 ± 4.20	16.75 ± 5.03	15.81 ± 3.99	0.1820
Cisatracurium (mg)	5.02 ± 2.56	5.82 ± 3.35	6.03 ± 3.89	7.04 ± 4.22	0.0510
Propofol (mg)	142.08 ± 36.43	136.73 ± 50.55	134.00 ± 56.83	130.00 ± 32.66	0.7563
Maximum sevoflurane Concentration (%)	2.42 ± 0.45	2.39 ± 0.43	2.34 ± 0.42	2.40 ± 0.41	0.8004
Number of patients with relief analgesia	13/48	5/49*	3/50*	2/49*	0.0013

Notes: * $P<0.05$ vs $R_{0.17}$.
Abbreviations: $R_{0.17}$, 30 mL of 0.17% ropivacaine; $R_{0.20}$, 25 mL of 0.20% ropivacaine; $R_{0.25}$, 20 mL of 0.25% ropivacaine; $R_{0.33}$, 15 mL of 0.33% ropivacaine.

demonstrated that higher concentrations provided superior postoperative analgesia but caused more pronounced motor blockade. Both 0.2% (25 mL) and 0.25% (20 mL) regimens achieved comparable overall analgesic efficacy, however, the 0.2% (25 mL) group exhibited significantly reduced motor blockade with better functional recovery at 8 hours postoperatively, meeting clinical requirements for early mobilization. Among the four tested combinations, the 0.2% ropivacaine (25 mL) protocol balanced effective postoperative analgesia with earlier motor function recovery, facilitating early rehabilitation and enhanced recovery.

In this study, the selection of 50 mg of ropivacaine was determined based on clinical efficacy and safety. The concentration range of ropivacaine in a single femoral nerve block is typically between 0.1% and 0.5%, with an injection volume of 15 to 30 milliliters.[13,14,20] The specific dosage is determined by the need to achieve a balance between sensory and motor block. The total dose of 50 mg falls within the commonly used clinical range, providing effective analgesic effects while minimizing the risk of adverse reactions. It is suitable for the target patient population.

It is worth noting that different research reports have proposed different concentrations of ropivacaine as the superior pain relief solution. Paauwe et al compared the effects of three ropivacaine concentrations (0.025%, 0.05%, and 0.1%) in postoperative analgesia and found that there was no advantage when the concentration was lower than 0.1%.[21] Therefore, under the premise of ensuring the analgesic effect, the concentration of ropivacaine should be set above 0.1%, which supports the scientific nature of our research. Brodner et al concluded that the analgesic effect of 0.1% ropivacaine was insufficient, while the concentrations of 0.2% and 0.3% were comparable.[22] Similarly, in our study, it was confirmed that ropivacaine concentrations of 0.2% and above could provide better analgesic effects. However, we found that the analgesic effect of 0.33% ropivacaine was better than that of 0.2%. The reason for the difference may lie in the fact that the concentration we used in our study (0.33%) was slightly higher than the 0.3% ropivacaine used by Brodner et al, and secondly, in their study, the administration method was infusion, so there would be differences in the efficacy.

Achieving effective analgesia while minimizing postoperative motor weakness remains a critical challenge in regional anesthesia, as highlighted in current clinical practice.[9] Previous studies have demonstrated that ropivacaine concentrations with a low concentration of 0.2% or less induce less motor impairment during femoral nerve and sciatic nerve blockade compared to higher concentrations.[14,15] Consistent with these findings, our results revealed significant intergroup differences in motor blockade profiles. Time to motor recovery (score ≥3) exhibited a concentration-dependent prolongation: $R_{0.17}$ (4 hours postoperatively) < $R_{0.20}$ (8 hours) < $R_{0.25}$ (12 hours) < $R_{0.33}$ (24 hours). Notably, the $R_{0.17}$ and $R_{0.20}$ groups demonstrated superior sensory-motor dissociation, enabling satisfactory motor function recovery within 8 hours postoperatively, thereby facilitating early postoperative rehabilitation.

Regarding postoperative pain assessment, the 0.17% ropivacaine (30 mL) group exhibited significantly higher movement-associated VAS scores and greater demand for rescue analgesia compared to other regimens. Although early motor recovery was observed in this group, persistent pain on movement significantly restricted patient mobility, ultimately compromising rehabilitation outcomes. This aligns with Yao et al's findings that 0.2% ropivacaine provides superior analgesic efficacy compared to lower concentrations (0.12%-0.18%).[15] Tai et al reported a median effective

concentration (EC_{50}) of 0.124% for ropivacaine, providing effective sensory blockade while preserving motor function.[19] This suggests that the ropivacaine concentration should be maintained at or below approximately 0.25%. In our study, the 0.33% (15 mL) regimen induced prolonged motor blockade. Analysis of the AUC of pain and motor blockade scores revealed comparable overall analgesic efficacy between 0.2% (25 mL) and 0.25% (20 mL) regimens, with the former demonstrating significantly reduced motor impairment. Integrating these findings, the 0.2% ropivacaine (25 mL) regimen balanced sustained analgesia with early motor recovery. This conclusion is supported by Singh et al's randomized controlled trial in femoral neck fracture patients, where 0.2% ropivacaine (15 mL) achieved lower postoperative VAS scores.[23] However, conflicting evidence from Veneziano et al suggested better analgesia and earlier discharge with 0.5% ropivacaine in pediatric arthroscopy.[17] This discrepancy may stem from population-specific differences: pediatric patients typically require more intensive analgesia due to lower pain tolerance, whereas our adult-focused study focused on early functional recovery—a parameter not addressed in Veneziano's investigation.

This study has several limitations: (1) The study population consisted solely of patients undergoing arthroscopic meniscoplasty, a procedure with relatively minor trauma. The generalizability of these findings to other lower extremity surgeries requires further investigation. (2) Postoperative functional recovery was not assessed using parameters such as joint flexion angle, time to first ambulation, walking distance, and Knee Society Score. Future studies should incorporate these measures. (3) Variations in surgical technique among surgeons and differences in the extent and location of meniscal injury among patients may have introduced bias. (4) Since there is no clear definition or basis for the minimum clinical difference of the AUC of VAS pain scores, it is unknown whether the statistical differences in the study represent clinical differences.

Conclusion

Ultrasound-guided FNB is a safe and effective analgesic technique for patients undergoing arthroscopic meniscoplasty. At equivalent dosages, concentration and volume influence the efficacy of the block. The 0.2%-25 mL formulation effectively provides pain relief while allowing for earlier muscle strength recovery, and represents a reasonable balance between analgesia and motor preservation in this specific setting.

Data Sharing Statement

The original data analyzed in this study are included in the article; further inquiries can be directed to the corresponding author.

Ethics Approval and Consent to Participate

This trial was approved by the Ethics Committee of West China Hospital, Sichuan University (Ethical approval number: 2019-822), and all participants provided written informed consent. The trial was registered prior to patient enrollment at the Chinese Clinical Trial Registry on July 24th, 2020 (ChiCTR2000034895). Written informed consent was obtained from all participants. The study protocol followed the CONSORT guidelines. The study protocol was performed in accordance with the Declaration of Helsinki and clinical practice guidelines.

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Disclosure

The authors report no conflicts of interest in this work.

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