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Original Article

Effect of iPACK block versus femoral nerve block on postoperative movement pain and muscle strength in patients undergoing total knee replacement

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Abstract: Objectives: Postoperative pain and quadriceps weakness hinder rehabilitation following total knee arthroplasty (TKA), creating a dilemma when using motor-blocking femoral nerve blocks (FNB). This study compared the effect of the motor-sparing infiltration popliteal artery-knee capsule (iPACK) block relative to FNB on analgesia and functional recovery. Methods: This retrospective cohort study analyzed patients undergoing unilateral TKA under spinal anesthesia between June 2022 and October 2025, grouped by received block (iPACK or FNB). Resting and activity pain were assessed at 2, 6, 12, and 24 hours, and 2 weeks postoperatively. Quadriceps strength, range of motion (ROM), straight leg raise, and Timed Up and Go (TUG) test were evaluated on postoperative days 1 and 2. The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) and Knee Society Score (KSS) were collected preoperatively and at 8 weeks. Results: Of 156 patients, 82 received iPACK and 74 received FNB. The iPACK group showed significantly reduced pain scores across all time points (activity pain at 6 hours: 5.11 vs. 5.93, P=0.003) and reduced 48-hour morphine consumption (18.18 vs. 24.31 mg, P<0.001). The iPACK group also showed superior quadriceps strength (day 2: 3.79 vs. 3.61 kg, P<0.001), ROM (day 2: 100.24° vs. 97.18°, P=0.002), and faster TUG times (day 2: 5.87 vs. 8.33 seconds, P<0.001). At 8 weeks, WOMAC and KSS were significantly better in the iPACK group. Conclusions: For TKA patients, the iPACK block provides more effective analgesia, superior quadriceps strength preservation, and accelerated functional recovery compared to FNB.

Keywords: Total knee arthroplasty, iPACK block, femoral nerve block, postoperative pain, quadriceps strength, functional recovery

Introduction

Total knee arthroplasty (TKA) is a definitive surgical intervention for treating end-stage knee osteoarthritis, significantly relieving pain and restoring joint function [1]. This condition involves painful, progressive joint degeneration, stiffness, and severe functional impairment [2]. Although TKA effectively alleviates pain and corrects deformities, the postoperative period is often marked by intense pain and quadriceps weakness, which hinder early rehabilitation and increase the risk of complications such as venous thrombosis and prosthesis loosening [3, 4]. Various analgesic strategies have been investigated to optimize postoperative pain management following knee surgery, including intra-articular morphine injection for pain control after knee arthroscopy [5]. However, for more invasive procedures such as TKA, more effective analgesic techniques are required to manage the greater postoperative pain burden. Modern analgesia emphasizes multimodal strategies, in which regional nerve blocks play a crucial role [6, 7]. Femoral nerve block (FNB) has been a cornerstone of post-TKA analgesia, but it has a notable drawback: it often causes quadriceps weakness, increasing the risk of falls and delaying ambulation [8]. This creates a critical clinical dilemma between achieving profound analgesia and preserving motor function. Therefore, identifying an analgesic technique that preserves motor function is imperative.

The pursuit of optimal perioperative analgesia stems from an understanding of the physiologic

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response to surgical trauma [9]. Tissue injury during TKA triggers a cascade of inflammatory mediators and neuronal sensitization, leading to both resting and movement-evoked pain [10, 11]. Furthermore, surgical manipulation and postoperative pain reflexively inhibit alpha motor neurons, resulting in arthrogenic muscle inhibition, particularly of the quadriceps [12, 13]. This phenomenon impairs voluntary muscle activation, independent of nerve injury [14]. By targeting the knee's posterior capsular region, supplied by sciatic branches and obturator nerves, the infiltration between the popliteal artery and the capsule of the knee (iPACK) block provides effective posterior knee analgesia without compromising motor function [15].

The present study sought to perform a comprehensive retrospective comparison of iPACK block versus femoral nerve block in TKA recipients. By assessing postsurgical movement pain and muscle strength, the present investigation sought clinical proof supporting the superiority of the iPACK block in balancing analgesia and functional preservation. The innovation of this study lies in its holistic approach to comparing these two techniques, going beyond mere analgesia to encompass key determinants of successful rehabilitation. By investigating whether the iPACK provides non-inferior analgesia while promoting superior protection of quadriceps strength and accelerating functional recovery, this study aimed to provide evidence that may help refine clinical protocols and improve patient outcomes after TKA.

Patients and methods

Research design and grouping

This was a retrospective cohort study aimed at evaluating the effects of iPACK block versus FNB on postoperative analgesia and early functional rehabilitation among those receiving TKA. The study included patients who underwent elective unilateral TKA surgery under spinal anesthesia at The First Hospital of Yulin between June 2022 and October 2025. Participants were divided into the iPACK Block group or the FNB group depending on the type of regional anesthesia adjunct they received during surgery. The block technique was selected by the attending anesthesiologist based on their individual expertise and proficiency. Both techniques are routinely used anesthesia protocols in the department.

All patients underwent spinal anesthesia under standard monitoring in the operating room. The surgical team and postoperative rehabilitation process at our center remained relatively fixed and standardized over the study period. For patients in the FNB group, the procedure was carried out in a sterile environment and with real-time ultrasound guidance. A high-frequency linear probe was used to locate the femoral nerve in the inguinal region. After verifying the ideal needle tip location and no blood aspiration, 20 ml of 0.25% bupivacaine was administered subfascially. For patients in the iPACK block group, the block was performed after the spinal anesthesia took effect but before the surgery began, while the patient remained supine with the knee slightly flexed. An ultrasound probe was used to identify the posterior femoral cortex and popliteal artery in a transverse section at the popliteal region. Employing an in-plane method, the needle was advanced to ensure its tip reached the muscle gap between the popliteal artery and the posterior femoral cortex. After confirming no blood aspiration, 20 ml of 0.25% bupivacaine was injected near the medial edge of the popliteal artery. Postoperatively, both groups of patients received a unified analgesic regimen as background treatment and were provided rescue analgesia with intravenous patient-controlled analgesia (PCA) pumps as needed.

Ethical statement

This study protocol has been reviewed and approved by The First Hospital of Yulin's Ethics Committee. Given the retrospective nature of the study, which involved only the collection and analysis of existing electronic medical record data, it did not interfere with patients' established treatment plans and did not implement any additional intervention. During the study, all patients' personal identification information was strictly anonymized and de-identified to maximize the protection of patient privacy. After review by The First Hospital of Yulin's Ethics Committee, obtaining written informed consent from patients for this study was waived.

Inclusion and exclusion criteria

Inclusion criteria: Patients qualified if they satisfied the subsequent criteria: age greater than 18 years; underwent elective unilateral TKA under spinal anesthesia; had an American

Society of Anesthesiologists (ASA) physical status classification of I-III [16]; and had complete medical record data.

Exclusion criteria: Exclusion criteria included: presence of contraindications to intraspinal anesthesia or regional nerve blocks, such as coagulation disorders, pre-existing lower limb neuromuscular diseases, local infection at the puncture site, or systemic infections; allergies or contraindications to the drugs involved in the study; mental or cognitive impairments that affect assessment; ASA classification of IV or higher; and those with missing key outcome data.

Data collection

Baseline characteristics and surgical information: Baseline data in this study were obtained by reviewing patients' electronic medical records. Patient age, gender, body mass index (BMI), operative side, history of diabetes, and current alcohol consumption status were extracted directly from the medical records. The ASA classification was assessed and recorded by anesthesiologists during preoperative visits based on the patient's overall health status. Preoperative resting pain and mobilization pain were assessed using the Visual Analog Scale (VAS), a straight ruler delineated by a scale ranging 0-10, with 0 signifying no discomfort and 10 denoting the worst possible pain. Patients mark on the scale to indicate their pain intensity [17]. Resting pain refers to the pain experienced by patients lying flat in bed without performing any active movements. Activity pain is measured immediately during specific standardized functional activities, defined as the maximum pain intensity reported during a single active knee flexion movement to a predetermined angle (90 degrees) assisted by healthcare professionals.

Quadriceps muscle strength was quantitatively assessed using a calibrated handheld digital dynamometer. Subjects were positioned supine while both the hip and knee joints flexed at 90 degrees. The dynamometer sensor pad was placed anteriorly on the distal tibial tuberosity. Patients performed a maximal effort knee extension against the dynamometer resistance for 3-5 seconds, and the peak force value was recorded.

Intraoperative and early postoperative key indicators were collected through a systematic review of anesthesia records, operating room notes, post-anesthesia care unit (PACU) records, and inpatient nursing electronic medical records. Mean arterial pressure values at admission to the PACU, 2 hours post-operation, and 6 hours post-operation were sourced from vital signs recorded by monitors (model, manufacturer, country) at those time points. Surgical duration was defined as the interval starting from the first skin incision to the completion of wound dressing, with this timing automatically recorded and verified by the operating room timing system. The time of first morphine administration was determined by reviewing postoperative PCA pump records or nurse medication administration records, calculating the time from surgery completion to the first demand for analgesia and subsequent morphine injection. The total morphine consumption within 48 hours postoperatively was calculated by aggregating precise PCA pump dosing records and additional rescue analgesic doses administered by nurses according to medical orders during the same period.

Comparison of postoperative analgesic effects: Resting and activity pain assessments were performed at four acute phase time points: 2 hours after admission to the PACU, 6 hours post-operation, 12 hours post-operation, and 24 hours post-operation, as well as at a short-term follow-up point two weeks post-operation.

Comparison of early postoperative functional recovery: Early postoperative functional recovery was assessed on the first and second postoperative days by experienced rehabilitation therapists at the bedside.

Range of motion (ROM) was assessed with a conventional long-arm goniometer. Patients were placed in a supine position and then instructed to voluntarily perform maximum knee flexion. The degree indicated by the moving arm at this point was recorded as the active range of motion.

Patients were placed in a supine position with both legs naturally extended and the trunk relaxed. The physical therapist stood on the affected side of the patient, holding the ankle with one hand and supporting the knee with the other to ensure that the knee remained

straight during leg elevation and to prevent excessive external rotation of the hip joint, which could lead to measurement errors. The examiner then gently and passively raised the patient's leg. As the hip joint flexed, the patient would feel tension in the hamstring muscles. When the leg was raised to a certain angle, the patient typically reported pain along the back of the lower leg. At the moment the patient felt pain, the examiner used a goniometer to measure the angle between the thigh and the horizontal plane. If the patient experienced pain when the thigh was raised to approximately 45 degrees from the ground, the test result was considered positive.

For knee extension assessment, the physician placed their hand under the patient's knee and applied upward resistance, asking the patient to extend the knee against resistance. For hip adduction assessment, the physician placed their palm on the outer side of the patient's knee and applied outward resistance, asking the patient to adduct the lower limb against resistance. Based on the patient's ability to overcome gravity and resist the applied force, muscle strength was recorded according to standardized grading (Grade 3, Grade 4). Grade 3 indicates the ability to overcome gravity but not resistance (raising the leg while lying supine). Grade 4 indicates the ability to resist some force but is slightly weaker than Grade 5 (full resistance against maximum force) [18].

Before conducting the Timed Up and Go (TUG) test and the 10-meter walk test, the procedures were explained to the patients, and a rehabilitation therapist stood by to prevent falls. During the TUG test, the patient sat on a standard-height chair with armrests. Upon hearing the start command, the patient had to stand up, walk as quickly and safely as possible to a marked line 3 meters away, turn around, return, and sit down again. The rehabilitation therapist used a stopwatch to record the total time from when the patient's back left the chair back to when their buttocks touched the seat again. For the 10-meter walk test, a 20-meter long corridor was measured, with only the middle 10 meters used for official timing. The ends were reserved for acceleration and deceleration buffers. The patient started walking from behind the starting line and began timing when they crossed the timing start line. Timing stopped when they crossed the end line 10 meters away, recording the time taken to cover this distance. The test allowed patients to use any required assistive devices (such as walkers).

Mid-term postoperative functional evaluation: The mid-term evaluation of postoperative knee joint function was conducted using the internationally recognized Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) questionnaire and the American Knee Society Score (KSS) system at two time points: preoperatively and 8 weeks postoperatively.

The WOMAC questionnaire represents a self-reported instrument for evaluating the functional condition of individuals suffering from hip or knee osteoarthritis [19]. The questionnaire consists of 24 items covering three core dimensions: pain, stiffness, and difficulty in performing daily physical activities. Patients answer based on their actual experiences over the past 48 hours, with every item scored on a scale of 0 (no difficulty/no pain) to 4 (extreme difficulty/extreme pain). The aggregate score is derived by adding up all individual item scores, spanning from 0 to 96. Higher scores indicate more significant pain, more severe joint stiffness, greater limitations in daily activities, and poorer overall health status.

The KSS system consists of two parts, the knee score and the function score [20]. The knee score is assessed by a clinician, focusing on the degree of knee pain, range of motion, and stability. Points are deducted for deformities such as flexion contracture or malalignment. This part has a maximum score of 100, where a higher score reflects superior knee joint condition. The function score evaluates the patient's activity level, including walking distance and the ability to ascend and descend stairs. Points are deducted for the use of assistive devices. This part also has a maximum score of 100, with higher scores representing better functional performance and activity levels.

Statistical analysis

Data analysis for this study was carried out with R software (version 4.3.2, R Foundation for Statistical Computing, Austria). Continuous variables first underwent normality assessment by the Shapiro-Wilk test. Normally distrib-

Table 1. Patient demographics and preoperative baseline data

Variable	FNB Group (n=74)	iPACK Group (n=82)	t/χ^2	P
Age	58.69 ± 8.53	60.14 ± 9.95	0.970	0.334
Gender (female/male)	49 (66.22%)/25 (33.78%)	50 (60.98%)/32 (39.02%)	0.461	0.497
BMI	26.86 ± 2.32	26.91 ± 2.38	0.141	0.888
ASA classification			1.421	0.491
I	18 (24.32%)	24 (29.27%)		
II	34 (45.95%)	30 (36.59%)		
III	22 (29.73%)	28 (34.15%)		
Operative side (left/right)	30 (40.54%)/44 (59.46%)	40 (48.78%)/42 (51.22%)	1.068	0.301
Preoperative resting pain	3.21 ± 1.53	3.09 ± 1.37	0.546	0.586
Preoperative activity pain	6.80 ± 1.71	6.67 ± 1.83	0.447	0.655
Preoperative Quadriceps muscle strength (kg)	3.95 ± 0.74	3.87 ± 0.83	0.634	0.527
History of diabetes	12 (16.22%)/62 (83.78%)	15 (18.29%)/67 (81.71%)	0.117	0.732
Current alcohol consumption status	21 (28.38%)/53 (71.62%)	25 (30.49%)/57 (69.51%)	0.083	0.773

FNB: femoral nerve blocks; iPACK: infiltration between the popliteal artery and the capsule of the knee; BMI: Body Mass Index; ASA: American Society of Anesthesiologists.

uted data were reported as mean ± standard deviation, and group differences were evaluated by independent-samples t-tests. Non-normally distributed data are expressed as median (first quartile, third quartile), and inter-group comparisons employed the Mann-Whitney U test. Categorical variables were presented as frequencies (percentages), and between-group comparisons were conducted using the chi-square test. A *P*-value <0.05 was defined as significant.

To verify further whether the iPACK block represents a standalone protective predictor of patients achieving good early postoperative functional recovery, patients were reclassified according to the outcomes of the TUG test on postoperative day 1: good recovery (TUG time ≤10 seconds) and slightly poorer recovery (TUG time >10 seconds). On this basis, a multivariate logistic regression model was constructed to control for the impact of key confounding variables. This model included five variables: type of block, patient age, preoperative visual analog scale score for activity pain and preoperative quadriceps muscle strength.

Results

Patient baseline characteristics

Regarding patient demographics and preoperative baseline data, there were no significant differences observed between the FNB group and the iPACK group in terms of age, gender distribution, BMI, ASA classification, surgical side, preoperative pain, preoperative quadriceps muscle strength, medical history, or current alcohol consumption status (all P>0.05; **Table 1**). These findings suggest that the comparisons between the two groups in this study were well-matched.

Perioperative indicators

There were no notable distinctions detected between the FNB group and the iPACK group regarding mean arterial pressure upon entering the PACU, at 2 hours postoperatively, and at 6 hours postoperatively (all P>0.05; **Table 2**). The duration of surgery (P>0.05) also showed no disparity between the two groups. The time to first administration of morphine was significantly later in the iPACK group relative to the FNB group (P=0.002), and the total morphine consumption within 48 hours was significantly lower in the iPACK group relative to the FNB group (P<0.001). These findings imply that, regarding postoperative pain management and reduction of opioid use, the iPACK technique may be more effective than the FNB method.

Comparison of postoperative analgesic effects

The results of postoperative resting pain scores showed that at 2 hours (P=0.030), 6 hours (P<0.001), 12 hours (P=0.001), 24 hours (P= 0.010) and 2 weeks (P=0.015) after surgery,

Table 2. Intraoperative and early postoperative key indicators

Variable	FNB Group (n=74)	iPACK Group (n=82)	t	P
Mean arterial pressure				
Admission to PACU	74.48 ± 5.58	74.61 ± 5.22	0.157	0.876
2 hours post-operation	75.40 ± 5.91	76.18 ± 5.84	0.836	0.404
6 hours post-operation	78.72 ± 5.92	79.56 ± 5.45	0.915	0.361
Duration of surgery (min)	95.66 ± 12.13	92.35 ± 13.46	1.607	0.110
Time to first dose morphine administration (hour)	8.81 ± 2.43	10.14 ± 2.86	3.132	0.002
Total morphine dose in 48 hours (mg)	24.31 ± 6.72	18.18 ± 4.48	6.626	<0.001

PACU: post-anesthesia care unit.

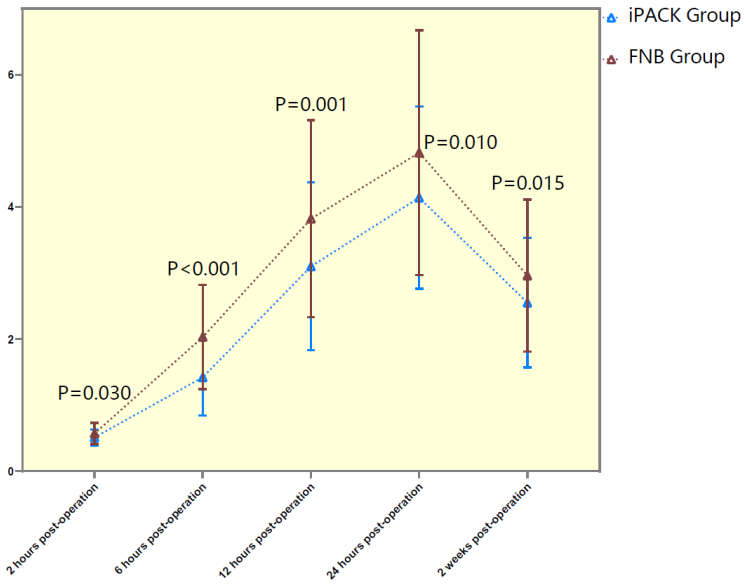

Figure 1. Postoperative resting pain scores. FNB: femoral nerve blocks; iPACK: infiltration between the popliteal artery and the capsule of the knee.

Table 3. Postoperative activity pain scores

Variable	FNB Group (n=74)	iPACK Group (n=82)	t	P
2 hours post-operation	3.04 ± 1.45	2.35 ± 1.39	3.042	0.003
6 hours post-operation	5.93 ± 1.78	5.11 ± 1.63	3.020	0.003
12 hours post-operation	5.43 ± 1.64	4.79 ± 1.56	2.498	0.014
24 hours post-operation	4.63 ± 1.82	3.90 ± 1.25	2.909	0.004
2 weeks post-operation	3.15 ± 1.13	2.68 ± 0.96	2.851	0.005

the pain score in the FNB group was significantly higher than that of the iPACK group (**Figure 1**). These results indicate that at different postoperative time points, the iPACK technique demonstrated superior effectiveness in reducing patients' postoperative resting pain compared to the FNB technique.

The results of the postoperative activity pain score showed that at 2 hours (P=0.003), 6 hours (P=0.003), 12 hours (P=0.014), 24 hours (P=0.004) and 2 weeks (P=0.005) after surgery, the pain score of the FNB group was higher than that of the iPACK group (**Table 3**). These results indicate that at various postoperative time points, the iPACK technique demonstrated superior efficacy in alleviating patients' postoperative activity pain relative to the FNB technique.

Early joint activity and neuromuscular function

Regarding postoperative ROM and straight leg raise ability, on the first postoperative day, the ROM in the iPACK group was significantly higher than that in the FNB group (P=0.007; **Table 4**). Similarly, on the second postoperative day, the ROM in the iPACK group was also significantly better than that in the FNB group (P=0.002). For the straight leg raise test, the results on the first postoperative day demonstrated no significant disparity between the two groups (P=0.066). However, by the second postoperative day, the proportion of negative results (higher straight leg raise ability) in the iPACK group was markedly greater than that of the FNB group (P=0.007). These findings suggest that compared to FNB, the iPACK technique not

Table 4. Range of motion and straight leg raise capability

Variable	FNB Group (n=74)	iPACK Group (n=82)	t/χ^2	P
ROM (degrees)				
Postoperative day 1	89.67 ± 6.24	92.13 ± 4.74	2.752	0.007
Postoperative day 2	97.18 ± 6.57	100.24 ± 5.25	3.233	0.002
Straight Leg Raise				
Postoperative day 1 (positive/negative)	71 (95.95%)/3 (4.05%)	72 (87.80%)/10 (12.20%)	3.375	0.066
Postoperative day 2 (positive/negative)	59 (79.73%)/15 (20.27%)	49 (59.76%)/33 (40.24%)	7.285	0.007

ROM: Range of motion.

Table 5. Postoperative quadriceps muscle strength assessment

Variable	FNB Group (n=74)	iPACK Group (n=82)	t/χ^2	P
Quadriceps muscle strength (kg)				
Postoperative day 1	3.43 ± 0.19	3.51 ± 0.12	2.989	0.003
Postoperative day 2	3.61 ± 0.26	3.79 ± 0.21	4.800	<0.001
Knee extension				
Postoperative day 1 (grade 3/grade 4)	60 (81.08%)/14 (18.92%)	54 (65.85%)/28 (34.15%)	4.584	0.032
Postoperative day 2 (grade 3/grade 4)	54 (72.97%)/20 (27.03%)	46 (56.10%)/36 (43.90%)	4.814	0.028
Hip adduction				
Postoperative day 1 (grade 3/grade 4)	57 (77.03%)/17 (22.97%)	53 (64.63%)/29 (35.37%)	2.873	0.090
Postoperative day 2 (grade 3/grade 4)	49 (66.22%)/25 (33.78%)	44 (53.66%)/38 (46.34%)	2.548	0.110

only promotes early postoperative ROM recovery but also improves patients' straight leg raise ability.

Early quantitative and qualitative assessment of muscle strength

Findings from the postoperative quadriceps muscle strength assessment showed that on the first postoperative day (P=0.003) and the second postoperative day (P<0.001), the quadriceps muscle strength in the iPACK group exhibited significantly superior values than in the FNB group (**Table 5**). Additionally, for knee extension capability, on the first postoperative day (P=0.032) and the second postoperative day (P=0.028), the percentage of patients reaching grade 4 was significantly higher in the iPACK group compared to the FNB group, indicating that the iPACK technique helps better maintain or restore quadriceps muscle strength and knee joint function. However, there were no significant differences in hip adduction capability across the two groups on the first postoperative day (P=0.090) or the second postoperative day (P=0.110).

Early functional mobility

Findings from the postoperative mobility assessment revealed no notable disparity between the two groups before operation (TUG Test, P=0.398, as shown in **Figure 2**). However, on the first postoperative day (P=0.003) and the second postoperative day (P<0.001), the completion time of the iPACK group was significantly less than that of the FNB group. In the 10-meter walking evaluation, there was no disparity between the two groups prior to surgery (P=0.593). However, on the first postoperative day (P=0.043) and the second postoperative day (P=0.010), the time required in the iPACK group was significantly shorter than in the FNB group. Therefore, compared with the FNB method, iPACK can help patients recover their ability to move after surgery more quickly and improve their walking speed.

Mid-term postoperative functional evaluation

Preoperative WOMAC scores, KSS knee scores, and KSS function scores (all P>0.05) showed no significant differences between the FNB group and the iPACK group (**Table 6**). At 8 weeks postoperatively, the WOMAC score in the iPACK group was significantly lower than that in the FNB group (P=0.012), indicating better performance in postoperative knee function and symptom improvement in the iPACK group. Additionally, at 8 weeks postoperatively, both the KSS knee score (P=0.011) and the KSS function score (P=0.012) were markedly great-

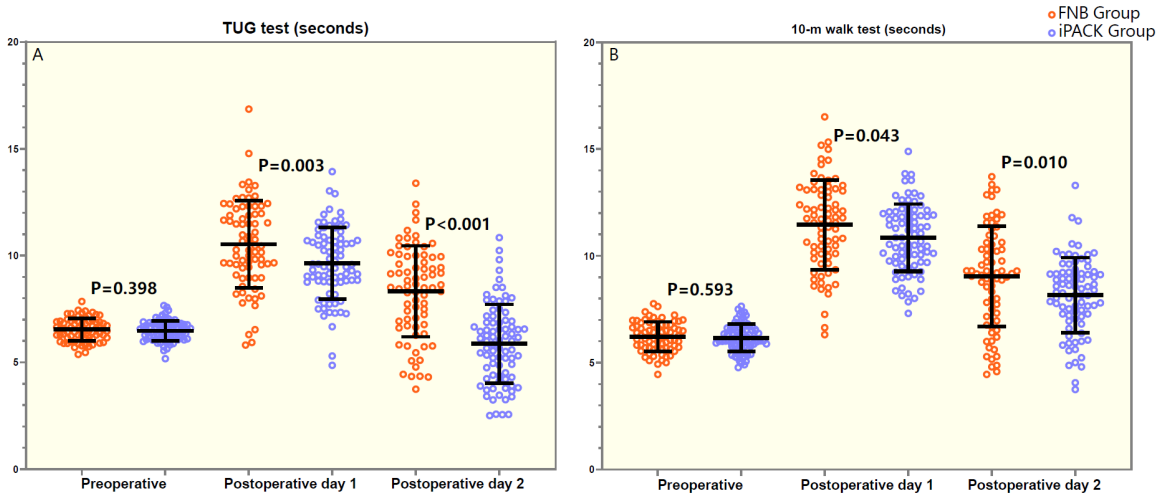

Figure 2. Postoperative mobility tests. A: TUG test (seconds); B: 10-m walk test (seconds). TUG: Time to go.

Table 6. Preoperative and 8-week postoperative functional scores

Variable	FNB Group (n=74)	iPACK Group (n=82)	t	P
Preoperative WOMAC score	58.82 ± 10.53	57.40 ± 9.32	0.896	0.372
Postoperative 8-week WOMAC score	25.42 ± 7.92	22.46 ± 6.67	2.536	0.012
Preoperative KSS knee score	43.59 ± 7.75	44.68 ± 7.29	0.905	0.367
Postoperative 8-week KSS knee score	78.83 ± 8.41	81.92 ± 6.27	2.580	0.011
Preoperative KSS function score	48.50 ± 6.89	49.06 ± 7.32	0.490	0.625
Postoperative 8-week KSS function score	66.14 ± 9.51	69.82 ± 8.62	2.531	0.012

WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index; KSS: Knee Society Score.

er in the iPACK group compared to the FNB group, further confirming the advantage of the iPACK technique in promoting postoperative knee function recovery.

Multivariate regression analysis of whether TUG was achieved within 10 seconds on postoperative day 1

The multivariate regression analysis of whether TUG was achieved within 10 seconds on postoperative day 1 showed that iPACK, compared to FNB, was a protective factor for achieving TUG within 10 seconds (P=0.005, OR=2.782), meaning that patients using the iPACK technique were more likely to complete the TUG test within 10 seconds on postoperative day 1 compared to those using FNB (**Table 7**). Although age showed a trend as a risk factor, it was not statistically significant (P=0.087, OR=0.954). Preoperative activity pain was a significant risk factor (P=0.024, OR=0.729), indicating that higher preoperative pain levels were associated with a lower likelihood of achieving TUG within 10 seconds, suggesting this factor was detrimental to early postoperative functional recovery. Quadriceps muscle strength was a significant protective factor (P=0.028, OR=1.880), indicating that stronger preoperative quadriceps muscle strength was associated with a higher likelihood of achieving TUG within 10 seconds on postoperative day 1.

Discussion

The results of this comprehensive retrospective analysis provide compelling evidence that in TKA, the iPACK block offers a better balance between analgesia and functional preservation compared to traditional FNB. These data collectively indicate that the iPACK block not only achieves effective postoperative analgesia but also mitigates the adverse effects on quadriceps muscle strength, a key factor for early mobilization and long-term joint function.

The observed superior analgesic properties of the iPACK block, particularly in reducing resting

Table 7. Multivariate regression analysis for whether TUG was achieved within 10 seconds on postoperative day 1

Variable	Coefficient	P	OR	CI Lower	CI Upper
iPACK vs. FNB	1.023	0.005	2.782	1.364	5.673
Age	-0.047	0.087	0.954	0.904	1.007
Preoperative activity pain	-0.316	0.024	0.729	0.555	0.959
Quadriceps muscle strength (kg)	0.631	0.028	1.880	1.069	3.304

TUG: Timed Up and Go; OR: Odds Ratio; CI: Confidence Interval.

and movement-evoked pain, align well with the known innervation patterns of the knee. The posterior capsule of the knee is a major source of post-TKA pain, richly innervated by nerve branches from the tibial, obturator, and occasionally the femoral nerve [21, 22]. Traditional FNB primarily targets the anterior compartment, effectively anesthetizing the femoral nerve but resulting in motor block of the quadriceps [23]. The iPACK directly anesthetizes these terminal articular branches within the interfascial plane between the popliteal artery and the posterior condyle of the femur [24]. This targeted block of posterior nociception more effectively alleviates inflammatory resting pain and movement-evoked pain associated with capsular stretching during knee flexion [25]. Therefore, the delayed interval to first demand for rescue pain relief and the reduced total opioid consumption in the iPACK group are clinical implications of this enhanced analgesic coverage. These findings are consistent with previous literature reporting enhanced analgesic effects of posterior capsule-targeted techniques [26].

A principal discovery of this investigation was that iPACK block preserves quadriceps muscle strength, directly addressing a major drawback of FNB. During walking, the femoral nerve innervates the quadriceps, primary knee extensors, and key stabilizers [27]. FNB often leads to quadriceps weakness due to motor fiber blockade, affecting post-TKA rehabilitation [28, 29]. iPACK achieves sensory-motor separation by selectively blocking the posterior capsule sensory nerves of the knee while preserving the motor femoral and sciatic nerve branches [30]. This study shows that the iPACK group performed better in TUG and 10-meter walk tests, indicating that even small improvements in muscle strength can enhance functional abilities like early ambulation and independent walking. Early preservation of muscle strength helps break the pain-immobility-muscle atrophy cycle, enabling earlier and higher-quality participation in rehabilitation. This early advantage may accumulate through positive feedback mechanisms, ultimately improving mid-term functional scores. Thus, although the absolute difference in muscle strength is limited, it has significant initiating value in the overall rehabilitation process. Quantitative muscle testing and manual muscle testing results confirm iPACK's advantages in motor protection from different perspectives.

By maintaining the integrity of the quadriceps, the iPACK translates directly into improved performance in functional activity tests [31]. On the second postoperative day, the iPACK group exhibited greater active ROM and a higher rate of negative straight leg raise tests, indicating less pain or neural tension during hip flexion. In the iPACK group, shorter times were recorded for the TUG test and the 10-meter walk test, highlighting a faster recovery of basic walking function. The ability to stand up from a chair, walk, and turn around more quickly and safely is a key milestone in early rehabilitation and is intrinsically linked to a reduced risk of falls [32]. This is consistent with the study, which found that motor-sparing blocks such as adductor canal block (ACB) or iPACK led to better early ambulation metrics compared to FNB [33].

The interconnection of the observed results warrants discussion. The pathway from a motor-sparing analgesic technique to improved mid-term function may be mediated by several reinforcing mechanisms. Effective analgesia, particularly during movement, can reduce pain-induced arthrogenic muscle inhibition (AMI) [34]. AMI is a reflexive inhibition of muscle tissue surrounding an injured or painful joint, mediated by spinal and supraspinal pathways [35]. By more effectively blocking posterior capsule nociception during movements such

as knee flexion and weight-bearing, the iPACK block may attenuate this inhibitory reflex better than FNB, thereby facilitating better voluntary activation of the quadriceps [36]. Preserved quadriceps strength enables patients to participate in physical therapy with greater confidence and higher quality from the first postoperative day. Patients can perform exercises with greater force and control, potentially accelerating the recovery of neuromuscular control, proprioception, and joint kinematics [37].

This accelerated early rehabilitation creates a positive trajectory that is beneficial in the midterm follow-up. The higher WOMAC and KSS scores observed in the iPACK group at the 8-week evaluation reflect this cumulative benefit. This finding is crucial because it suggests that the choice of regional anesthesia technique can influence patient-reported outcomes after discharge, potentially affecting long-term satisfaction and functional success.

The multivariate regression analysis clearly showed that, after controlling for many potential confounding factors, there was an independent association between iPACK block and achieving early good mobility. The protective effect of iPACK was quantitatively confirmed. This strongly suggests that the recovery benefits of iPACK are not merely due to better preoperative status or fewer opioid side effects but are a direct, positive therapeutic effect resulting from the inherent sensory-motor separation characteristic of this technique. Specifically, iPACK precisely blocks nociceptive afferents from the posterior capsule of the knee while preserving quadriceps muscle function to a large extent.

Several limitations of this study warrant recognition. First, the retrospective and single-center nature of the design introduced possible biases in patient selection, data collection, and unmeasured confounding factors. Although the two groups exhibited good matching regarding recorded initial profiles, and our center's surgical team and postoperative rehabilitation process remained fixed and standardized during the study, unrecorded variables such as surgical technique nuances and patient rehabilitation compliance may have affected the results. Additionally, the choice of block technique was primarily based on the fixed anesthesia team's rotation, which reduced indication bias but did not eliminate potential selection bias due to non-random grouping. Second, the follow-up period for functional scores was extended to 8 weeks, which was an intermediate stage. The long-term sustainability of the observed functional advantages, particularly in terms of implant survival, patient satisfaction, and the incidence of chronic postoperative pain, remains unknown.

Future studies should address these gaps through prospective randomized controlled trials featuring larger cohorts and extended observation windows. Investigating the optimal local anesthetic agent, volume, and concentration for iPACK block, as well as its utility in catheter-based continuous techniques, would be valuable. Finally, a cost-effectiveness analysis that includes not only drug and equipment costs but also metrics such as hospital stay duration, rehabilitation efficiency, and recovery timelines would provide critical data for healthcare systems.

Conclusion

The results of this retrospective study indicated that for patients undergoing total knee arthroplasty, the iPACK block provided a better balance between effective postoperative analgesia and preservation of quadriceps muscle strength compared to femoral nerve block. This advantage not only facilitated earlier and safer functional recovery but was also associated with better patient-reported functional outcome.

Disclosure of conflict of interest

None.

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