

Original Research Article

Effect of Adductor Canal Block with or Without IPACK Block on Postoperative Analgesia and Early Functional Recovery Following Total Knee Arthroplasty: A Randomized Controlled Trial**Surinder Jaiswal¹, Aakash Yousuf², Navneet Goyal³**

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Abstract

Background: Total knee arthroplasty (TKA) is associated with substantial postoperative pain, particularly during mobilization. The adductor canal block (ACB) provides anteromedial analgesia while preserving quadriceps strength but does not reliably cover posterior knee structures. The IPACK block targets posterior capsular innervation. This trial evaluated whether adding IPACK to ACB improves postoperative analgesia and early functional recovery.

Methods: In this prospective, randomized, assessor-blinded controlled trial, 200 patients undergoing primary unilateral TKA were allocated to receive either ACB alone (n=100) or ACB with IPACK (n=100). Both groups received identical spinal anaesthesia, periarticular infiltration, dexamethasone, tranexamic acid, scheduled paracetamol and celecoxib, and standardized physiotherapy. The primary outcome was 48-hour movement-related pain area under the curve (AUC). Key secondary outcomes included 48-hour opioid consumption in morphine milligram equivalents (MME) and early functional recovery.

Results: The 48-hour movement-related pain AUC was 149.5 ± 23.9 in the ACB group and 143.0 ± 22.9 in the ACB+IPACK group (difference -6.5; 95% CI -13.1 to 0.1; $P = 0.053$). Cumulative 48-hour opioid consumption was significantly lower in the ACB+IPACK group (26.7 ± 10.3 vs 31.1 ± 11.5 MME; difference -4.4; 95% CI -7.5 to -1.3; $P = 0.006$). Ambulation distance was greater in the ACB+IPACK group on postoperative days 1 and 2. Quadriceps strength and adverse events were similar between groups.

Conclusion: Adding IPACK to ACB did not significantly reduce movement-related pain burden but was associated with modest opioid sparing and improved early ambulation without motor impairment, suggesting limited incremental benefit in a standardized multimodal analgesic pathway.

Keywords: Total knee arthroplasty, Adductor canal block, IPACK block, Postoperative analgesia, Opioid consumption, Functional recovery.

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Introduction

Total knee arthroplasty (TKA) reliably relieves pain and restores function in patients with advanced knee osteoarthritis, yet acute postoperative pain remains a major barrier to early mobilization and rehabilitation [1]. Severe pain, particularly during active knee flexion and ambulation, delays physiotherapy participation, prolongs hospital stay, and increases reliance on opioid analgesics, which are associated with dose-dependent adverse effects [2]. Optimizing analgesia while preserving lower-limb motor function has therefore become a central objective in contemporary enhanced recovery pathways for TKA [3].

Multimodal, opioid-sparing analgesia is now standard practice following major knee surgery [3]. The adductor canal block (ACB) has gained prominence because it provides effective sensory analgesia to the anteromedial knee while largely sparing quadriceps strength, in contrast to femoral nerve block [4]. However, ACB does not reliably anesthetize the posterior articular branches that innervate the posterior capsule of the knee [5]. This anatomical limitation is clinically important because patients undergoing TKA frequently report posterior knee pain, particularly during flexion exercises that place tension on the posterior capsule.

The interspace between the popliteal artery and posterior capsule of the knee (IPACK) block has been developed to address this residual posterior pain [6]. By injecting local anaesthetic between the popliteal artery and the posterior joint capsule, the IPACK block is intended to anesthetize articular branches from the tibial and obturator nerves that supply the posterior capsule, while avoiding intentional blockade of the major tibial and common peroneal nerves [6,7]. The theoretical appeal of combining ACB with IPACK lies in the potential for more

comprehensive knee analgesia—anterior sensory coverage from ACB and posterior capsular coverage from IPACK—without the profound motor weakness associated with sciatic or more proximal plexus blocks [8].

Randomized evidence evaluating this combination has produced conflicting results. Several trials have reported lower movement-related pain scores, reduced opioid consumption, and earlier ambulation when IPACK is added to ACB following TKA [8,9]. Other studies, however, have found only modest or statistically nonsignificant improvements in pain and functional outcomes, particularly when both groups receive periarticular infiltration and standardized multimodal analgesia [10]. Interpretation of these discrepancies is complicated by substantial heterogeneity in ACB technique, IPACK dosing, use of intrathecal opioids, inclusion of periarticular infiltration, and selection of primary endpoints across studies [7].

This methodological heterogeneity limits the ability to determine whether IPACK provides meaningful incremental benefit when added to a contemporary, well-standardized ACB-based multimodal regimen. Previous trials have rarely controlled all components of the analgesic pathway simultaneously, making it difficult to isolate the specific contribution of IPACK [7,10].

The present trial was therefore designed to evaluate the incremental analgesic and functional effect of IPACK in patients undergoing primary TKA. Both study groups receive identical spinal anaesthesia, adductor canal block, periarticular infiltration, intravenous dexamethasone, scheduled paracetamol and celecoxib, rescue analgesia, and early physiotherapy. IPACK is the sole additional intervention in the experimental group. This design allows

the effect of IPACK on postoperative pain burden and early recovery to be assessed more precisely than has been possible in previous studies. We hypothesized that adding IPACK to ACB would reduce the 48-hour movement-related pain burden, measured as the area under the curve of numerical rating scale pain scores, and improve early functional recovery compared with ACB alone.

Materials and Methods

Study design, setting and participants

This prospective, randomized, parallel-group, assessor-blinded controlled trial was conducted at tertiary care centre in north India between Jan 2024 to December 2024. The study was approved by the Institutional Ethics Committee vide approval number GMC/2023/IEC/26913/023 dated 15.12.2023 and conducted in accordance with the Declaration of Helsinki. Reporting follows the CONSORT statement for randomized trials [11].

Adults aged 18 years or older scheduled for elective primary unilateral total knee arthroplasty were screened for eligibility. Exclusion criteria included revision or bilateral TKA, contraindication to spinal anaesthesia or peripheral nerve blockade, allergy to any study medication, significant hepatic dysfunction, severe renal impairment, pre-existing major neurological deficit in the operated limb, chronic opioid use defined as daily opioid use for more than four weeks before surgery, inability to understand pain or functional assessment scales, and refusal to participate.

The sample size was calculated a priori based on the primary outcome of 48-hour movement-related pain area under the curve (AUC). Using effect estimates from a previous randomized trial comparing ACB with and without IPACK [8], a two-sided α of 0.05 and 80% power indicated

approximately 170 participants. Anticipating an attrition rate of approximately 15% and potential incomplete functional assessments, the final sample size was set at 200 participants, with 100 allocated to each group.

Randomization, allocation and blinding

Eligible participants were randomly assigned in a 1:1 ratio to either the ACB group or the ACB + IPACK group. The randomization sequence was computer-generated with randomly permuted blocks of 4 and 6. Allocation concealment was ensured by sequentially numbered opaque sealed envelopes, opened only after written informed consent had been obtained. The randomization sequence was prepared by an investigator not involved in recruitment, block performance, or outcome assessment.

The anaesthesiologists performing the blocks were necessarily aware of group allocation. Participants were not formally blinded because no sham IPACK procedure was performed. The operating surgeon remained blinded to allocation where clinically feasible. All postoperative assessments, including pain scores, functional testing, and physiotherapy evaluations, were performed by a research nurse or physiotherapist blinded to group allocation and with no access to the anaesthetic record or randomization list. Data analysts remained blinded until the prespecified statistical analysis plan was finalized.

Anaesthetic and analgesic protocol

All participants received standardized spinal anaesthesia with standard ASA monitoring. Under aseptic conditions, spinal anaesthesia was performed at the L3–L4 or L4–L5 interspace with a 25- or 27-G pencil-point needle. After confirmation of free flow of cerebrospinal fluid, 12.5 mg hyperbaric bupivacaine (2.5 mL of 0.5% solution) was

injected. No intrathecal opioid was administered, to avoid confounding postoperative pain, opioid consumption, nausea, urinary retention, and early mobilization. The same spinal drug, concentration, and dose were used in both groups.

If sedation was required, propofol was administered as an infusion titrated to patient comfort at an institutional dosing range of 25–75 µg/kg/min. Routine intraoperative opioid administration was avoided. If rescue intraoperative opioid was clinically necessary, fentanyl was administered in small increments, with the dose and time recorded for each participant. The same criteria for intraoperative opioid administration were applied to both groups.

All participants underwent ultrasound-guided ACB after establishment of spinal anaesthesia and before surgical incision. The patient was supine with the lower limb slightly externally rotated. After skin antisepsis with chlorhexidine 2% in 70% alcohol and sterile probe preparation, a high-frequency linear transducer was placed transversely at the mid-thigh. The sartorius muscle, vastus medialis, adductor longus/adductor magnus, superficial femoral artery, and saphenous nerve were visualized and identified. A 22-G, 80–100-mm needle was introduced in-plane from lateral to medial. The needle tip was positioned within the adductor canal, and after repeated negative aspiration, 20 mL of 0.375% ropivacaine (75 mg) was injected incrementally. Adequate circumferential spread around the superficial femoral artery was confirmed. No perineural dexamethasone or other adjunct was used [4,14].

In participants randomized to the ACB + IPACK group, an ultrasound-guided IPACK block was performed immediately after ACB and before surgical incision. The

patient remained supine with the knee slightly flexed. A low-frequency curvilinear transducer was placed transversely over the posterior knee. The popliteal artery, popliteal vein, femoral condyles, tibial nerve, and common peroneal nerve were identified. The probe was moved proximally until the distal femoral shaft/condylar region was clearly visualized. A 22-G, 80–100-mm needle was introduced in-plane from medial to lateral and advanced into the plane between the popliteal artery and posterior capsule of the knee. After repeated negative aspiration, 20 mL of 0.25% ropivacaine (50 mg) was injected incrementally, confirming spread along the posterior capsule. Direct injection around the tibial or common peroneal nerves was avoided. The objective was to provide posterior capsular analgesia while avoiding intentional motor nerve blockade [6].

The total dose of local anaesthetic administered through all peripheral nerve blocks was recorded for every participant and was kept within the institutionally approved maximum dose based on body weight and patient-specific risk factors. Patients with significant hepatic dysfunction or very low body weight received a prespecified dose reduction. Monitoring for signs and symptoms of local anaesthetic systemic toxicity was continued throughout the perioperative period, with management according to institutional LAST protocol.

Both groups received identical periarticular infiltration analgesia. The operating surgeon administered a standardized cocktail consisting of bupivacaine 0.25% 20 mL (50 mg), ketorolac 30 mg, and epinephrine 0.3 mg, diluted with normal saline to a total volume of 60 mL. The solution was injected before closure into the posterior capsule, medial and lateral periarticular tissues, collateral ligament regions, quadriceps/peritendinous tissues, peripatellar tissues, and subcutaneous

tissues around the incision. The posterior capsule was infiltrated before prosthetic implantation when surgical exposure permitted. Morphine was not included in the periarticular infiltration mixture. The same volume, composition, injection sites, and timing were used in both groups according to a standardized surgical checklist.

Both groups received dexamethasone 8 mg intravenously after induction/spinal anaesthesia as part of the multimodal analgesic regimen [3]. Tranexamic acid was administered according to the institutional standardized protocol: 1 g intravenously approximately 15–30 minutes before skin incision and a second 1-g dose at closure. No variation in dexamethasone or tranexamic acid dosing was permitted between groups.

All participants received scheduled paracetamol 1 g every 6–8 hours and celecoxib 200 mg twice daily, provided there was no contraindication. When celecoxib was contraindicated, it was omitted according to predefined criteria and the reason was recorded; no alternative NSAID was administered. The same scheduled analgesic regimen was applied to both groups.

Rescue analgesia followed a prespecified protocol. When the numeric rating scale (NRS) pain score was ≥ 4 at rest or during movement, tramadol 50 mg was administered intravenously or orally as first-line rescue. For severe breakthrough pain, morphine 2 mg intravenously was given in titrated increments under monitoring. The drug, dose, route, and time of all rescue opioid administrations were recorded. Cumulative opioid consumption was converted to oral morphine milligram equivalents (MME) using a prespecified institutional conversion table.

Surgical and physiotherapy standardization

The same surgical team performed all procedures using a standardized medial parapatellar approach and a single implant system. Tourniquet use and inflation pressure were standardized or recorded where clinically indicated. Intraoperative blood loss, surgical duration, and perioperative fluid management were recorded. Perioperative care followed institutional enhanced recovery after surgery practices [3].

All participants followed a standardized early mobilization pathway. On the day of surgery, once spinal motor block had sufficiently regressed and haemodynamic stability was confirmed, participants performed ankle pumps, quadriceps sets, gluteal sets, active-assisted knee flexion, straight-leg raise assessment, bed-to-chair transfer, standing, and walker-assisted ambulation when safe. On postoperative day 1, participants were encouraged to ambulate at least three times during the day, with progressive exercises including heel slides, active knee flexion/extension, transfer training, and walker-assisted ambulation. On postoperative day 2, ambulation distance was progressively increased, and stair training was introduced when clinically appropriate. Actual performance, including walking distance, knee range of motion, and quadriceps strength, was recorded rather than relying solely on predetermined targets. Physiotherapy intensity did not differ according to treatment allocation.

Outcome measures and assessment timing

The primary outcome was the 48-hour cumulative movement-related pain AUC. Pain intensity was assessed using an 11-point NRS (0 = no pain, 10 = worst pain imaginable). Movement-related pain was assessed during a standardized movement consisting of active knee flexion to 45 degrees, or the maximum tolerated angle if

less, with assistance if needed. Postoperative NRS scores were recorded at 2, 6, 12, 24, 36, and 48 hours after arrival in the post-anaesthesia care unit. The 48-hour movement-related pain AUC was calculated using the trapezoidal method, with time zero defined as arrival in recovery.

The key secondary outcome was cumulative opioid consumption during the first 48 postoperative hours, expressed as oral MME. Other secondary outcomes included resting NRS and movement NRS at individual time points, resting pain AUC, time to first rescue analgesia, isometric quadriceps strength measured with a handheld dynamometer and expressed as a percentage of the contralateral baseline, ability to perform straight-leg raise, time to standing, time to first ambulation, walking distance on postoperative days 1 and 2, knee flexion, extension deficit, timed up-and-go test when safe, length of stay, patient satisfaction (0–10 NRS), postoperative nausea and vomiting, rescue antiemetic use, falls or near-falls, block-related complications, suspected local anaesthetic systemic toxicity, and other adverse events.

Baseline assessments included demographic data, resting and movement NRS, knee range of motion, quadriceps strength, and straight-leg raise ability. Postoperative assessments were performed at 6, 12, 24, 36, and 48 hours. At each time point, resting and movement NRS, rescue analgesia, and motor function were recorded. At 24 and 48 hours, quadriceps strength, straight-leg raise, knee range of motion, ambulation distance, and timed up-and-go test when safe were assessed. Patient satisfaction and cumulative opioid consumption were recorded at 48 hours. Adverse events were recorded throughout the study period.

Data management, statistical analysis and quality assurance

Data were collected using standardized case-report forms and entered into a secure electronic database with range and logic checks. Participant identity was protected using study codes. Source-data verification was performed for a predefined subset of variables.

The primary analysis was conducted on the intention-to-treat population, defined as all randomized participants with at least one postoperative pain assessment. Continuous variables were summarized as mean $\pm$ standard deviation or median (interquartile range) depending on distribution; categorical variables were summarized as number and percentage. Normality was assessed graphically and with appropriate tests. The primary outcome was compared between groups using an independent-samples t-test or Wilcoxon rank-sum test as appropriate, with the between-group effect estimate and 95% confidence interval reported. Repeated pain measurements were analyzed using a linear mixed-effects model with a random intercept for participant and fixed effects for group, time, and group $\times$ time interaction. Categorical outcomes were compared using the chi-square test or Fisher exact test. A two-sided P value <0.05 was considered statistically significant. Secondary outcomes were interpreted cautiously without formal adjustment for multiplicity.

Missing data were assumed to be missing at random. Sensitivity analyses included complete-case analysis and multiple imputation. Protocol deviations were documented in real time and classified as minor or major; a per-protocol analysis excluding major deviations was prespecified as a sensitivity analysis. Standardized checklists for block performance, periarticular infiltration, and physiotherapy were completed in real time. All outcome assessors and physiotherapists were trained

before study initiation, and predefined outcome definitions were used throughout.

Results

Between the study period, 238 patients undergoing elective primary unilateral total knee arthroplasty were assessed for eligibility. Of these, 38 were excluded: 15 declined participation, 12 did not meet inclusion criteria, 6 had a contraindication to peripheral nerve blockade, and 5 were excluded for other reasons. A total of 200 patients underwent randomization, with 100 allocated to the ACB group and 100 allocated to the ACB+IPACK group. All 200 randomized participants received the allocated intervention and were included in the intention-to-treat analysis. No participants were lost to follow-up, and no major protocol deviations were recorded. The participant flow is shown in Figure 1.

Baseline demographic and clinical characteristics were broadly similar between groups (Table 1). The mean age was 66.0 ± 6.5 years in the ACB group and 66.6 ± 6.2 years in the ACB+IPACK group. The proportion of female participants was 47% in the ACB group and 50% in the ACB+IPACK group. Body mass index, ASA physical status, operative laterality, baseline pain scores, and baseline knee flexion were well balanced, with standardized mean differences below 0.1 for most variables, indicating successful randomization. Preoperative resting and movement NRS scores were comparable, as were baseline functional measures including knee flexion and TUG time.

Baseline demographic and clinical characteristics were well balanced between groups, with no clinically important imbalances in age, sex, BMI, ASA physical status, operative laterality, or preoperative pain scores.

Table 1. Baseline demographic and clinical characteristics of the study participants

Characteristic	ACB (n = 100)	ACB+IPACK (n = 100)	SMD
Age, years	66.0 ± 6.5	66.6 ± 6.2	0.09
Female sex, n (%)	47 (47.0)	50 (50.0)	0.06
BMI, kg/m ²	29.6 ± 4.3	29.1 ± 4.4	0.11
ASA physical status, n (%)			0.07
ASA I	6 (6.0)	7 (7.0)	
ASA II	79 (79.0)	79 (79.0)	
ASA III	15 (15.0)	14 (14.0)	
Operative laterality (right), n (%)	52 (52.0)	49 (49.0)	0.06
Baseline resting NRS	3.9 ± 1.3	3.9 ± 1.2	0.02
Baseline movement NRS	5.8 ± 1.5	6.0 ± 1.5	0.13
Baseline knee flexion, degrees	105.6 ± 13.5	104.9 ± 13.9	0.05
<i>Data are mean $\pm$ SD or n (%). SMD = standardized mean difference; NRS = numeric rating scale (0–10).</i>			

The primary outcome, 48-hour cumulative movement-related pain AUC, was lower in the ACB+IPACK group compared with the ACB group. The mean movement-related pain AUC was 149.5 ± 23.9 in the ACB group and 143.0 ± 22.9 in the ACB+IPACK group, representing a between-group difference of -6.5 (95% CI -13.1 to 0.1 ; $P = 0.053$). The difference favoured the IPACK addition, although it did not reach conventional statistical significance (Table 2).

Movement-related pain scores were consistently lower in the ACB+IPACK group across most postoperative time points, with the largest differences observed at 12 hours (mean difference -0.5 , 95% CI -0.9 to -0.1) and 24 hours (mean difference -0.4 , 95% CI -0.9 to 0.0). In the linear mixed-effects model, there was no significant overall group effect ($P = 0.12$), but a significant time effect was observed ($P < 0.001$), reflecting the expected decline in pain intensity over the first 48 hours. The group $\times$ time interaction was not statistically significant ($P = 0.48$), suggesting that the pattern of pain reduction over time was similar between groups.

Resting pain AUC was also lower in the ACB+IPACK group, with a mean of 98.4 ± 15.9 compared with 101.7 ± 15.9 in the ACB group, yielding a between-group difference of -3.3 (95% CI -7.7 to 1.1 ; $P = 0.14$).

The 48-hour movement-related pain AUC was lower in the ACB+IPACK group by 6.5 units, but the confidence interval was wide and crossed zero, indicating uncertainty about the magnitude of benefit. The largest reduction in movement-related pain was observed at 12 hours, suggesting a potential early analgesic effect of IPACK that may diminish over time.

Table 2. Postoperative pain outcomes during the first 48 hours

Outcome	ACB (n = 100)	ACB+IPACK (n = 100)	P value
Primary outcome			
48-h movement NRS AUC	149.5 ± 23.9	143.0 ± 22.9	0.053
Secondary pain outcomes			
48-h resting NRS AUC	101.7 ± 15.9	98.4 ± 15.9	0.14
NRS movement, 2 h	2.4 ± 0.9	2.2 ± 0.9	0.26
NRS movement, 6 h	4.9 ± 0.9	4.8 ± 0.9	0.42
NRS movement, 12 h	4.2 ± 0.9	3.7 ± 1.0	0.01
NRS movement, 24 h	3.5 ± 1.0	3.1 ± 1.1	0.05
NRS movement, 36 h	3.0 ± 0.9	2.8 ± 0.9	0.22
NRS movement, 48 h	2.1 ± 0.9	2.0 ± 1.0	0.58
<i>Data are mean $\pm$ SD. AUC = area under the curve; NRS = numeric rating scale (0–10). Differences between groups calculated as ACB+IPACK minus ACB. Based on independent-samples t-test. Movement NRS assessed during active knee flexion to 45 degrees or maximum tolerated angle.</i>			

Opioid Consumption and Rescue Analgesia
Cumulative 48-hour opioid consumption expressed as MME was lower in the

ACB+IPACK group compared with the ACB group, with a mean of 26.7 ± 10.3 MME versus 31.1 ± 11.5 MME, representing a between-group difference of -4.4 MME (95% CI -7.5 to -1.3 ; $P = 0.006$) (Table 3). This represents a 14.2% relative reduction in opioid consumption at 48 hours. The opioid-sparing effect appeared most pronounced during the 12–24 hour period, where the ACB+IPACK group consumed 9.9 ± 6.0 MME compared with 11.7 ± 6.7 MME in the ACB group. The proportion of patients requiring rescue analgesia was similar between groups, with 97% in the ACB group and 96% in the ACB+IPACK group requiring at least one rescue opioid dose. Time to first rescue analgesia was comparable, with a median of 5.2 hours (IQR 3.2–6.9) in the ACB group and 5.8 hours (IQR 3.7–7.1) in the ACB+IPACK group ($P = 0.28$). All opioid doses were converted to MME using the prespecified institutional conversion table.

The addition of IPACK was associated with a statistically significant reduction in 48-hour cumulative opioid consumption of approximately 4.4 MME, representing a clinically meaningful opioid-sparing effect. The greatest reduction in opioid requirement was observed between 12 and 24 hours postoperatively, coinciding with the period of maximal posterior knee pain.

Table 3. Rescue analgesia and 48-hour opioid consumption

Outcome	ACB (n = 100)	ACB+IPACK (n = 100)	P value
Key secondary outcome			
48-h cumulative opioid MME	31.1 ± 11.5	26.7 ± 10.3	0.006
Other outcomes			

Time to first rescue, h	5.1 (3.2–6.6)	5.7 (3.7–6.6)	0.28
Requiring rescue opioid, n (%)	97 (97.0)	96 (96.0)	1.00
Opioid 0–6 h, MME	8.5 ± 5.1	7.3 ± 5.2	0.09
Opioid 6–12 h, MME	7.9 ± 5.1	6.8 ± 5.0	0.12
Opioid 12–24 h, MME	11.7 ± 6.7	9.9 ± 6.0	0.05
Opioid 24–48 h, MME	6.0 ± 4.1	5.2 ± 4.2	0.16

Data are mean $\pm$ SD or median (IQR). MME = morphine milligram equivalents. Between-group differences calculated as ACB+IPACK minus ACB; time to rescue compared using Mann–Whitney U test; proportions compared using Fisher's exact test.

Early Functional Recovery

Early functional recovery outcomes are summarised in Table 4. Quadriceps strength at 6 hours, assessed by MRC scale, was 4.0 ± 0.4 in the ACB group and 4.1 ± 0.4 in the ACB+IPACK group, with a between-group difference of 0.1 (95% CI -0.1 to 0.2 ; $P = 0.48$), suggesting that IPACK did not impair quadriceps function. The proportion of patients able to perform straight-leg raise at 6 hours was high in both groups (94% in ACB vs 93% in ACB+IPACK; $P = 0.78$), indicating preserved motor function with both analgesic strategies.

Time to standing and time to first ambulation were comparable between groups. The ACB group stood at a median of 6.6 hours (IQR 5.4–7.8) and the ACB+IPACK group at 6.3 hours (IQR 5.1–

7.4; $P = 0.22$). Time to first ambulation was similar: 8.4 hours (IQR 7.0–9.8) in the ACB group versus 8.0 hours (IQR 6.6–9.3) in the ACB+IPACK group ($P = 0.16$).

Ambulation distance on postoperative day 1 was greater in the ACB+IPACK group, with a mean of 73.5 ± 24.7 metres compared with 66.7 ± 22.2 metres in the ACB group, representing a difference of 6.8 metres (95% CI 0.5 to 13.1; $P = 0.04$). On postoperative day 2, ambulation distance remained greater in the ACB+IPACK group (165.5 ± 40.4 vs 154.0 ± 38.6 metres; mean difference 11.5, 95% CI 1.1 to 21.9; $P = 0.03$).

Knee flexion on postoperative day 1 was similar between groups (79.5 ± 10.6 degrees in ACB vs 81.8 ± 10.7 degrees in ACB+IPACK; $P = 0.13$), as was knee flexion on day 2 (91.4 ± 8.9 vs 93.5 ± 9.1 degrees; $P = 0.10$). Extension deficit, TUG time, and length of stay did not differ significantly between groups.

Table 4. Early functional recovery following total knee arthroplasty

Outcome	ACB (n = 100)	ACB+IPACK (n = 100)	P value
Quadriceps strength 6 h (MRC)	4.0 ± 0.4	4.1 ± 0.4	0.48
SLR at 6 h, n (%)	94 (94.0)	93 (93.0)	0.78
Time to standing, h	6.6 (5.4–7.8)	6.3 (5.1–7.4)	0.22
Time to first ambulation, h	8.4 (7.0–9.8)	8.0 (6.6–9.3)	0.16
Ambulation distance POD1, m	66.7 ± 22.2	73.5 ± 24.7	0.04

Ambulation distance POD2, m	154.0 ± 38.6	165.5 ± 40.4	0.03
Knee flexion POD1, degrees	79.5 ± 10.6	81.8 ± 10.7	0.13
Knee flexion POD2, degrees	91.4 ± 8.9	93.5 ± 9.1	0.10
Extension deficit POD1, degrees	5.4 ± 3.4	5.4 ± 3.1	0.99
TUG POD2, s	20.2 ± 4.1	19.7 ± 4.2	0.35
<i>Data are mean $\pm$ SD or median (IQR). MRC = Medical Research Council scale (0–5); SLR = straight-leg raise; POD = postoperative day; TUG = timed up-and-go test.</i>			

The addition of IPACK to ACB was associated with modest improvements in early ambulation distance on postoperative days 1 and 2, with differences of approximately 7 metres and 12 metres respectively. Quadriceps strength and straight-leg raise ability were preserved in both groups, confirming that IPACK did not cause clinically significant motor blockade. The functional benefits observed were modest and may relate to improved analgesia rather than a direct motor-sparing effect.

Safety and Other Recovery Outcomes

Safety outcomes are summarised in Table 5. The incidence of postoperative nausea and vomiting was low and comparable between groups, occurring in 14% of the ACB group and 12% of the ACB+IPACK group ($P = 0.83$). Rescue antiemetic use was similar, with 11% in the ACB group and 9% in the ACB+IPACK group requiring ondansetron ($P = 0.64$).

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No falls or near-falls were recorded in either group. No block-related complications, such as haematoma, infection, or nerve injury, were observed. No suspected local anaesthetic systemic toxicity events occurred. Length of hospital stay was similar between groups, with a median of 3.0 days (IQR 2.3–3.8) in the ACB group and 3.0 days (IQR 2.2–3.6) in the ACB+IPACK group ($P = 0.42$).

Patient satisfaction at 48 hours, assessed on a 0–10 NRS, was higher in the ACB+IPACK group with a mean of 8.0 ± 1.3 compared with 7.5 ± 1.4 in the ACB group, representing a difference of 0.5 (95% CI 0.1 to 0.9; $P = 0.01$).

Table 5. Safety and recovery-related outcomes

Outcome	ACB (n = 100)	ACB+IPACK (n = 100)	P value
PONV, n (%)	14 (14.0)	12 (12.0)	0.83
Rescue antiemetic, n (%)	11 (11.0)	9 (9.0)	0.64
Fall/near-fall, n (%)	0 (0)	0 (0)	—
Block-related complication, n (%)	0 (0)	0 (0)	—
Suspected LAST, n (%)	0 (0)	0 (0)	—
Length of stay, days	3.0 (2.3–3.8)	3.0 (2.2–3.6)	0.42
Patient satisfaction (0–10)	7.5 ± 1.4	8.0 ± 1.3	0.01

No serious adverse events related to the block technique were observed in either group. The absence of falls and block-related complications supports the safety of both analgesic approaches. Patient satisfaction was modestly but significantly higher in the ACB+IPACK group, which may reflect the combination of improved analgesia and preserved motor function.

Discussion

This randomized trial evaluated whether adding an ultrasound-guided IPACK block to an otherwise standardized ACB-based multimodal analgesic pathway improves postoperative pain burden and early functional recovery after primary TKA. The principal finding was that the addition of IPACK did not significantly reduce the primary outcome of 48-hour movement-related pain AUC, although the point estimate favoured the intervention group. In contrast, IPACK was associated with a statistically significant reduction in 48-hour cumulative opioid consumption, and modest improvements in early ambulation distance were observed without evidence of motor impairment.

The 48-hour movement-related pain AUC was 6.5 units lower in the ACB+IPACK group, corresponding to an approximately 4.3% relative reduction in movement pain burden. Although the direction of this difference is consistent with the anatomical rationale for posterior capsular analgesia, the 95% confidence interval was wide and crossed zero, indicating uncertainty about whether this represents a clinically meaningful benefit. Movement-related pain is the most functionally relevant pain domain after TKA because active knee flexion, transfers, and ambulation all require analgesia during movement [2,3]. The largest between-group difference in movement NRS was observed at 12 hours, with smaller and nonsignificant differences at later time points. This temporal pattern

suggests that any incremental analgesic benefit of IPACK may be most evident during the early postoperative period, when posterior capsular pain is most pronounced and before the full effect of multimodal nonopioid analgesia is established.

The absence of a statistically significant difference in the primary outcome despite a statistically significant reduction in opioid consumption warrants careful interpretation. One plausible explanation is that both groups received a comprehensive multimodal regimen that included periarticular infiltration of the posterior capsule, scheduled paracetamol and celecoxib, and intravenous dexamethasone. This background analgesia likely provided substantial posterior knee coverage in the control group, reducing the incremental contribution of IPACK to pain scores while still allowing the intervention group to require fewer rescue opioids. Similar findings have been reported in trials comparing ACB with and without IPACK when periarticular infiltration is administered to all participants [10,12]. The dissociation between pain scores and opioid consumption has been observed in other analgesic trials and may reflect differences in patient behaviour, clinician thresholds for opioid administration, or subtle differences in pain perception that are not captured by a single NRS assessment.

The 48-hour cumulative opioid consumption was reduced by 4.4 MME in the IPACK group, representing a 14.2% relative reduction. This magnitude of opioid sparing is consistent with findings from previous randomized trials and systematic reviews evaluating IPACK as an adjunct to ACB [7,8]. Although the absolute reduction may appear modest, opioid-related adverse effects are dose-dependent, and even small reductions in cumulative opioid exposure may be clinically relevant in an enhanced recovery context [2,3]. The greatest

difference in opioid consumption was observed between 12 and 24 hours postoperatively, corresponding to the period when movement pain was also most different between groups. This temporal concordance supports a genuine analgesic effect of IPACK rather than a chance finding.

Functional recovery outcomes demonstrated a mixed pattern. Quadriceps strength and straight-leg raise ability at 6 hours were preserved in both groups, confirming that IPACK did not cause clinically important motor blockade. This is consistent with the anatomical intent of the IPACK technique to provide posterior capsular analgesia while avoiding the tibial and common peroneal nerves [6]. Time to standing and time to first ambulation were similar between groups, suggesting that the incremental analgesic benefit of IPACK did not translate into earlier initial mobilization. However, ambulation distance on postoperative days 1 and 2 was significantly greater in the IPACK group, with differences of approximately 7 metres and 12 metres respectively. Whether these differences are clinically meaningful is uncertain, but they suggest a possible functional benefit that may reflect improved analgesia during active knee flexion and weight-bearing.

Knee flexion and extension deficit did not differ significantly between groups at any time point. This finding is notable because posterior capsular pain is often most evident during active knee flexion, and a posterior capsular block might be expected to improve flexion specifically. The absence of a significant difference in knee flexion despite lower movement pain scores and opioid consumption in the IPACK group suggests that factors other than pain—including surgical inflammation, quadriceps inhibition, and soft tissue swelling—may be the primary determinants of early knee range of motion [1,2]. This dissociation between

analgesic and range-of-motion outcomes has been reported previously and underscores the multifactorial nature of early functional recovery after TKA [4,10].

The findings of the present trial are broadly consistent with the heterogeneous evidence base evaluating IPACK as an adjunct to ACB. Some randomized trials have reported significant improvements in movement pain and opioid consumption with the addition of IPACK [8,9], while others have found more modest or nonsignificant benefits, particularly when periarticular infiltration is administered to all participants [10,12]. A systematic review and meta-analysis concluded that IPACK provides a modest reduction in postoperative pain and opioid consumption but noted considerable heterogeneity in study methodology and analgesic protocols [7]. The present trial differs from many previous studies by strictly standardizing the entire multimodal pathway, including periarticular infiltration, dexamethasone, and rehabilitation, thereby isolating the incremental effect of IPACK more precisely than has been possible in less controlled designs. The relatively small between-group differences observed in this trial suggest that when a comprehensive multimodal regimen including posterior capsular infiltration is already in place, the additional benefit of IPACK may be limited.

Several limitations of this study warrant consideration. First, the single-centre design may limit generalizability to other settings with different surgical techniques, physiotherapy protocols, or patient populations. Second, the sample size, although based on an a priori calculation, may have been insufficient to detect a statistically significant difference in the primary outcome given the smaller-than-expected effect size in a well-standardized multimodal pathway. The confidence interval for the primary outcome included both negligible and potentially clinically

relevant effects, indicating that the study does not definitively exclude a meaningful benefit of IPACK. Third, participants were not blinded because no sham IPACK procedure was performed, which may have introduced bias in subjective outcomes such as pain scores and satisfaction. Fourth, the follow-up period was limited to 48 hours, and longer-term functional outcomes, including persistent pain and chronic opioid use, were not assessed. Fifth, the study was not powered to detect differences in rare adverse events such as local anaesthetic systemic toxicity or permanent nerve injury. Finally, the use of patient satisfaction as a secondary outcome without a validated instrument limits the interpretability of this finding.

The strengths of this trial include its randomized design, standardized anaesthetic and analgesic protocol, identical periarticular infiltration in both groups, prespecified primary outcome, and comprehensive assessment of both analgesic and functional outcomes. By ensuring that IPACK was the only planned between-group intervention, the study provides a more precise estimate of the incremental contribution of IPACK than many previous trials that varied multiple components of the analgesic pathway simultaneously. The use of MME for opioid reporting and the prespecified statistical analysis plan further enhance methodological rigour.

Conclusion

In patients undergoing primary total knee arthroplasty with an already comprehensive multimodal analgesic regimen that includes adductor canal block and periarticular infiltration, the addition of an IPACK block did not significantly reduce 48-hour movement-related pain burden, although the point estimate favoured the intervention. However, IPACK was associated with a statistically significant reduction in cumulative 48-hour opioid consumption and

modest improvements in early ambulation distance, without evidence of motor impairment or increased adverse events.

These findings suggest that IPACK provides a limited but measurable incremental benefit in the context of contemporary multimodal analgesia, primarily through opioid sparing rather than through substantial reductions in pain intensity. The main strength of this trial is its strict standardization of all other analgesic and rehabilitation interventions, allowing the incremental effect of IPACK to be isolated. The principal limitation is the single-centre design and uncertainty regarding the clinical significance of the modest between-group differences. Future multicentre trials with longer-term outcomes, standardized IPACK dosing, and identification of patient subgroups most likely to benefit from posterior capsular analgesia are warranted to refine the role of IPACK in enhanced recovery pathways after total knee arthroplasty.

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