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Optimizing Post-operative Analgesia for Early Rehabilitation after Orthopedic Knee Surgery: A Randomized Comparison of Adductor Canal, Infiltration between the Popliteal Artery and Capsule of the Posterior Knee and Genicular Nerve Blocks

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Learning Point of the Article:

In orthopedic patients having knee surgery, a motor-sparing genicular nerve block gave better pain control and less opioid use after the operation than an adductor canal block or an IPACK block, which suits early mobilization and rehabilitation.

Abstract

Introduction: Orthopedic knee surgery, including anterior cruciate ligament tear repair, patellar fracture fixation, and surgery for knee osteoarthritis, is often followed by moderate to severe pain that delays early mobilization, quadriceps activation, and physiotherapy. Motor-sparing, opioid-sparing analgesia is therefore preferred. Ultrasound-guided adductor canal block (ACB), infiltration between the popliteal artery and capsule of the posterior knee (IPACK) block, and genicular nerve block (GNB) are three such options, but direct comparisons in orthopedic knee surgery are limited.

Aims: To compare the post-operative analgesic efficacy of ultrasound-guided ACB, IPACK block, and GNB in patients undergoing knee surgeries under subarachnoid block.

Materials and Methods: This prospective, randomized, single-blind comparative study was conducted in the Department of Anaesthesiology, N.S.C.B. Medical College and Hospital, Jabalpur, over 18 months after institutional ethics committee approval (IEC/2023/7335–1). Ninety-nine ASA physical status I-II patients aged 18–60 years scheduled for elective knee surgery were randomized equally into three groups (n = 33 each). Group A received ultrasound-guided ACB, Group I received ultrasound-guided IPACK block, and Group G received ultrasound-guided GNB. Each block was performed with 20 mL of 0.375% ropivacaine, followed by standardized spinal anesthesia. Post-operative pain was assessed using a Visual Analog Scale (VAS) over 24 h. Time to rescue intravenous paracetamol, tramadol requirement, and block-related complications were recorded.

Results: Baseline demographic characteristics were comparable among groups. Group G had lower mean VAS scores at most post-operative time points, including 16, 20 and 24 h. The time to first rescue paracetamol was longest in Group G (5.87 ± 0.43 h), followed by Group A (5.62 ± 0.48 h) and Group I (5.42 ± 0.49 h). The second paracetamol dose was also delayed the longest in Group G (11.79 ± 0.83 h). Tramadol was required in 6.06% of patients in Group G, compared with 21.21% in Group A and 30.30% in Group I.

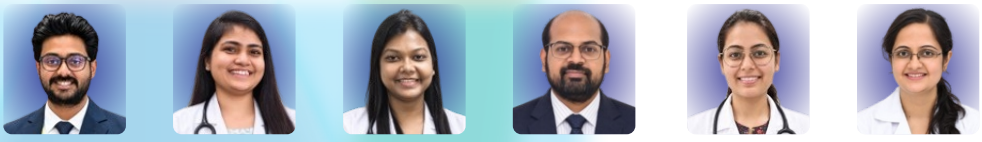
Conclusion: In patients undergoing orthopedic knee surgery, all three ultrasound-guided motor-sparing blocks provided clinically useful post-

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operative analgesia. GNB was associated with lower pain scores at most intervals, delayed rescue analgesic requirement, and reduced tramadol use compared with ACB and IPACK block, making it a promising option to support early rehabilitation. Larger adequately powered trials with procedure-specific subgroup analysis and functional outcomes, such as quadriceps strength and range of motion, are warranted.

Keywords: knee surgery, orthopedic surgery, post-operative analgesia, adductor canal block, Infiltration between the popliteal artery and capsule of the posterior knee block, genicular nerve block, early rehabilitation.

Introduction

Knee surgeries are among the most frequently performed orthopedic procedures and are often associated with moderate to severe post-operative pain. Effective analgesia is essential not only for patient comfort but also for early ambulation, participation in physiotherapy, prevention of pain-related complications, and overall functional recovery. Inadequate analgesia can delay rehabilitation, intensify the surgical stress response, increase opioid consumption, and reduce patient satisfaction [1].

Multimodal analgesia is now central to perioperative pain management for knee surgery [2,3]. Ultrasound-guided regional anesthesia has gained prominence because real-time visualization of anatomical landmarks, needle trajectory, and local anesthetic spread improves technical precision and may reduce procedure-related complications. Traditional femoral nerve block provides effective analgesia but may impair quadriceps strength, thereby increasing concern about delayed ambulation and fall risk. Consequently, motor-sparing regional techniques are increasingly preferred [4].

The adductor canal block predominantly targets sensory components, including the saphenous nerve and nerve to vastus medialis, while attempting to preserve quadriceps motor function. It provides effective anteromedial knee analgesia but may be insufficient for posterior capsular pain [5,6]. The infiltration between the popliteal artery and capsule of the posterior knee (IPACK) block was developed to target sensory articular branches supplying the posterior capsule by depositing local anesthetic between the popliteal artery and posterior femoral cortex, with the goal of avoiding tibial and common peroneal motor blockade [7,8].

Genicular nerve block (GNB) targets articular sensory branches around the knee, typically the superomedial, superolateral and inferomedial genicular nerves. Because these nerves are primarily sensory, GNB may provide analgesia without clinically meaningful motor impairment. The complex innervation of the knee joint means that no single block is universally effective for all pain generators. Direct comparison of adductor canal block (ACB), IPACK block and GNB is therefore clinically relevant, particularly in settings where safe, opioid-sparing and motor-sparing analgesia is desirable [9,10].

This study was designed to compare the post-operative analgesic efficacy of ultrasound-guided ACB, IPACK block and GNB in patients undergoing knee surgeries under subarachnoid block.

Materials and Methods

Study design and setting

This prospective, randomized, single-blind comparative study was conducted in the Department of Anaesthesiology, Orthopaedics Operation Theatre, N.S.C.B. Medical College and Hospital, Jabalpur, Madhya Pradesh, over 18 months. The study compared three ultrasound-guided motor-sparing blocks – ACB, IPACK block, and GNB – for post-operative analgesia in elective knee surgeries performed under subarachnoid block.

Ethics and consent

Institutional Ethics Committee approval was obtained before commencement of the study (IEC/2023/7335–1). Written informed consent was obtained from all participants after explanation of the anesthetic procedure, study objectives, expected benefits and possible complications. All patients underwent pre-anesthetic evaluation and observed a minimum fasting period of 6 h before surgery.

Participants

Patients aged 18–60 years, of ASA physical status I or II and scheduled for elective knee surgery were eligible. Exclusion criteria were refusal to participate, age outside the specified range, ASA physical status higher than II, known hypersensitivity to study drugs, infection at the block or spinal anesthesia site, diabetes mellitus, hypertension, psychiatric illness, bleeding disorder, hepatic dysfunction, renal dysfunction, pregnancy and lactation.

Sample size and randomization

Sample size was calculated using the Power and Sample Size module for one-way analysis of variance (ANOVA) in R version 4.4.3 for Windows, with delta 0.3209, variance 0.103 in each group, alpha error 0.05, confidence interval 95%, power 80%, and three study groups. The calculated sample size was 33 patients per group; therefore, 99 patients were included. Patients were allocated on the day of surgery into three equal groups using the sealed-envelope technique.



Figure 1: Probe position for adductor canal block.

Interventions

Group A received ultrasound-guided ACB with 20 mL of 0.375% ropivacaine. Group I received ultrasound-guided IPACK block with 20 mL of 0.375% ropivacaine. Group G received ultrasound-guided GNB with a total of 20 mL of 0.375% ropivacaine distributed across the superomedial, superolateral and inferomedial genicular nerve targets.

Block techniques

On arrival in the operating theatre, the operative limb was verified and standard monitoring was applied, including pulse oximetry, non-invasive blood pressure and 3-lead electrocardiography. Baseline heart rate, systolic and diastolic blood pressure, mean arterial pressure and oxygen saturation were recorded. Intravenous access was secured, and Ringer lactate infusion was started at 10 mL/kg/h. All blocks were performed under aseptic precautions with the patient in the supine position unless posterior access was required.



Figure 3: Probe position for IPACK block.

For ACB, a high-frequency linear ultrasound transducer was placed over the anterior thigh at the midpoint between the inguinal crease and medial femoral condyle (Fig. 1). The femoral artery, sartorius muscle and adductor canal were identified. Under continuous ultrasound guidance and after negative aspiration, 20 mL of 0.375% ropivacaine was deposited in the adductor canal [11,12].

For GNB, a high-frequency linear transducer was used to identify the superomedial, superolateral, and inferomedial genicular nerve regions using vascular and periosteal landmarks (Fig. 2). The superomedial and superolateral genicular nerves were targeted near the corresponding femoral epicondylar regions, and the inferomedial genicular nerve was targeted near the anteromedial tibial region. After negative aspiration, 7 mL, 7 mL and 6 mL of 0.375% ropivacaine were deposited at the

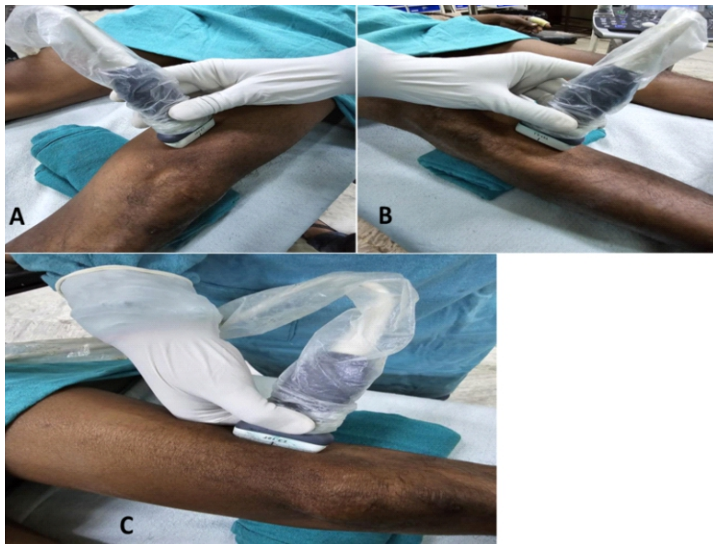


Figure 2: Genicular block probe position (a-Supero-medial, b-Supero-lateral, c-Infero-medial).

superomedial, superolateral and inferomedial targets, respectively, for a total volume of 20 mL [13,14,15].

For the IPACK block, the posterior distal femoral surface and popliteal artery were identified using a low-frequency curvilinear transducer to optimize depth penetration (Fig. 3). An echogenic needle was advanced in-plane into the tissue plane between the popliteal artery and posterior femoral cortex. After negative aspiration, 20 mL of 0.375% ropivacaine was injected incrementally to achieve satisfactory spread in the target plane [16,17].

Spinal anesthesia and post-operative assessment

Thirty minutes after block placement, all patients received a subarachnoid block with 3 mL of 0.5% hyperbaric bupivacaine through a 23 G Quincke spinal needle, after which surgery commenced. After regression of spinal anesthesia, the operative

Table 1: Age, sex and surgery distribution of patients

Block	Male patients	Female patients	21–30 years age	31–40 years age	41–50 years age	51–60 years age	ACL tear repair	Close fracture patella	Osteoarthritis knee
Adductor canal block	20	13	7	8	6	12	7	12	14
IPACK block	19	14	7	11	5	10	11	9	13
Genicular nerve block	18	15	7	11	4	11	10	11	12

IPACK: Infiltration between the popliteal artery and capsule of the posterior knee, ACL: Anterior cruciate ligament

limb was assessed for analgesic coverage and motor power during mobilization. Post-operative pain was assessed using a 10-cm Visual Analog Scale (VAS) at pre-defined intervals over 24 h. Intravenous paracetamol 1 g was administered as first-line rescue analgesia when VAS exceeded 4. Intravenous tramadol 50 mg was used when analgesia remained inadequate despite paracetamol [18,19]. Block-related complications, including block failure, vascular puncture, local anesthetic systemic toxicity and hypersensitivity reactions, were documented [20,21].

Outcomes

The primary outcome was post-operative VAS score over the first 24 h. Secondary outcomes were time to first and second rescue intravenous paracetamol dose, tramadol requirement and block-related complications.

Statistical analysis

Data were entered, validated, and analyzed using the IBM Statistical Package for the Social Sciences version 27.0 for Windows. Quantitative variables are presented as mean ± standard deviation and categorical variables as frequency and percentage. Baseline demographic variables were compared descriptively. Continuous outcomes were compared using one-way ANOVA or appropriate pairwise tests according to distribution, while categorical variables were analyzed using the Chi-square test or Fisher exact test when required. VAS scores were analyzed at each time point and interpreted with attention to the repeated-measure nature of the data. A $P < 0.05$ was considered statistically significant.

Results

A total of 99 patients were enrolled, with 33 patients in each group. Overall, 57 patients (57.58%) were male, and 42 patients (42.42%) were female. Sex distribution was comparable across groups (Table 1). The maximum number of patients belonged to the 51–60 years age group (33.33%), followed by 31–40 years (30.30%), 21–30 years (21.21%), and 41–50 years (15.15%).

Baseline VAS scores before block placement were high and comparable among groups (Table 2). Group G showed lower mean VAS scores than the other two groups' at most post-operative intervals. At 16, 20 and 24 h, Group G continued to demonstrate lower pain scores, particularly compared with Group I. The time to first and second rescue paracetamol doses was longest in Group G (Table 3). Tramadol requirement was

Table 2: Post-operative VAS scores and pairwise *P*-values

Time point	ACB mean±SD	IPACK mean±SD	GNB mean±SD	*P*: ACB versus IPACK	*P*: ACB versus GNB	*P*: IPACK versus GNB
Before block	9.61±0.50	9.79±0.42	9.76±0.44	0.111	0.192	0.773
10 min	6.55±0.51	6.67±0.48	6.36±0.49	0.321	0.142	0.013
30 min	3.36±0.65	3.79±0.65	3.33±0.48	0.01	0.83	0.002
2 h	0.39±0.50	0.48±0.51	0.15±0.36	0.465	0.027	0.003
4 h	0.64±0.78	0.85±0.67	0.52±0.67	0.241	0.501	0.047
6 h	2.61±0.83	3.00±0.71	2.52±0.71	0.042	0.634	0.007
8 h	1.97±0.73	2.09±0.63	1.48±0.76	0.472	0.01	0.001
12 h	4.18±0.39	4.24±0.44	4.12±0.33	0.554	0.5	0.208
16 h	2.45±0.51	2.71±0.42	2.12±0.33	0.027	0.002	<0.0001
20 h	3.09±0.29	3.28±0.36	2.95±0.24	0.021	0.037	<0.0001
24 h	1.42±0.50	1.78±0.50	1.12±0.50	0.005	0.018	<0.0001

VAS: Visual Analog Scale, ACB: Adductor canal block, IPACK: Infiltration between popliteal artery and capsule of posterior knee, GNB: Genicular nerve block, SD: Standard deviation. Pairwise *P* values are presented as reported in the dataset and should be interpreted in the context of multiple time-point comparisons

Table 3: Time to rescue intravenous paracetamol

Variable	ACB mean±SD (h)	IPACK mean±SD (h)	GNB mean±SD (h)	*P*: ACB versus IPACK	*P*: ACB versus GNB	*P*: IPACK versus GNB
First dose of IV paracetamol 1 g	5.62±0.48	5.42±0.49	5.87±0.43	0.104	0.029	0.0002
Second dose of IV paracetamol 1 g	11.29±0.94	10.74±0.87	11.79±0.83	0.017	0.025	<0.0001
Tramadol 50 mg requirement out of 33 patients	7	10	2			

***The group-wise counts indicate that 19 patients required tramadol. This corrects an internal inconsistency in the source draft, where the total was written as 10 despite group counts of 7, 10, and 2. ACB: Adductor canal block, IPACK: Infiltration between popliteal artery and capsule of posterior knee, GNB: Genicular nerve block, SD: Standard deviation**

lowest in Group G (6.06%), compared with Group A (21.21%) and Group I (30.30%). No major block-related complication was documented in the available dataset.

Discussion

This prospective randomized comparative study found that all three ultrasound-guided regional techniques provided useful post-operative analgesia after knee surgery. However, GNB was associated with lower VAS scores at most post-operative time points, longer time to rescue paracetamol, and the lowest tramadol requirement. These findings support the analgesic value of directly targeting articular sensory branches of the knee joint [22,23].

The demographic distribution was balanced across groups, reducing the likelihood that age or sex differences substantially influenced analgesic outcomes. Baseline VAS scores were also comparable, supporting the internal validity of post-operative comparisons. The early reduction in pain after all three blocks confirms that ultrasound-guided regional techniques can form an effective component of multimodal analgesia for knee procedures.

The relative advantage of GNB may be explained by its direct targeting of the superomedial, superolateral, and inferomedial genicular sensory branches, which contribute substantially to articular nociception. In contrast, ACB predominantly covers anteromedial sensory pathways and may not consistently address posterior knee pain. The IPACK block targets posterior capsular sensory branches, but its effect may vary according to spread of local anesthetic, anatomical variability, and whether the dominant post-operative pain generator is anterior, posterior, periosteal, or capsular.

The present results are consistent with contemporary literature suggesting that GNB can reduce post-operative pain and opioid requirement after knee arthroplasty, particularly when used as part of motor-sparing multimodal analgesia. Trials comparing IPACK-based strategies have reported variable analgesic benefit, which may reflect differences in technique, local anesthetic volume and concentration, concomitant blocks and outcome timing. The present study adds clinically relevant comparative data by evaluating ACB, IPACK block and GNB as separate ultrasound-guided interventions using the same local anesthetic volume and concentration.

The opioid-sparing finding is clinically important. Tramadol was required by only 6.06% of patients in the GNB group, compared with 21.21% in the ACB group and 30.30% in the IPACK group. Reduced opioid exposure may decrease nausea, vomiting, sedation, urinary retention, and delayed mobilization, although these outcomes were not formally analyzed in the available dataset [24,25].

No major block-related complication was documented. This supports the feasibility and apparent safety of ultrasound-guided motor-sparing blocks when performed by trained anesthesiologists using standard monitoring, incremental injection and aspiration precautions. Nevertheless, all local anesthetic techniques require vigilance for vascular puncture, local anesthetic systemic toxicity, nerve injury and block failure.

Strengths and limitations

Strengths of the study include prospective design, random allocation, equal group size, ultrasound-guided technique in all groups, standardized ropivacaine volume and concentration, and pre-defined rescue analgesic criteria.

This study has limitations. First, the relatively small sample size of 99 patients, with 33 participants in each group, may have

limited the statistical power to detect smaller between-group differences and uncommon adverse events, thereby restricting the generalizability of the results. Second, the single-center setting may limit the applicability of the findings to other institutions and clinical populations. The single-blind design may have introduced potential observer or assessment bias. Furthermore, the inclusion of different knee surgical procedures, including anterior cruciate ligament (ACL) repair, patellar fracture fixation, and surgery for knee osteoarthritis, may have introduced clinical heterogeneity, as post-operative pain and analgesic requirements can vary according to the procedure performed. The follow-up period was limited to the first 24 post-operative h, precluding assessment of longer-term analgesic efficacy, functional recovery and rehabilitation outcomes. Objective measures of quadriceps strength, range of motion, ambulation and rehabilitation progress, as well as patient satisfaction, quality of recovery and health-related quality of life, were not adequately evaluated. In addition, incomplete reporting of perioperative variables, including tourniquet use, surgical duration and intraoperative analgesic supplementation, may have limited the assessment of potential confounding factors. Although post-operative pain scores were assessed at multiple time points, a comprehensive repeated-measures statistical analysis was not reported, and the available analysis may not have fully accounted for within-patient correlations or multiple comparisons. Finally, the limited sample size and short observation period constrain the ability to establish the safety profile of the blocks or detect rare block-related complications. Future multicenter, adequately powered, double-blind randomized controlled trials incorporating procedure-specific subgroup analyses, comprehensive statistical methods, longer follow-up and patient-cent red functional outcomes are warranted to validate these findings.

Conclusion

In patients undergoing orthopedic knee surgery (ACL tear repair, closed patella fracture fixation and knee osteoarthritis procedures), ultrasound-guided adductor canal, IPACK and GNBs all gave effective post-operative analgesia without motor blockade. GNB gave lower pain scores at most intervals over 24 h, delayed the first rescue analgesic request and had the lowest tramadol use. By controlling pain while sparing quadriceps strength, it appears to be a promising opioid-sparing option to support early mobilization and rehabilitation after knee surgery. Larger, adequately powered trials with procedure-specific subgroups and functional outcomes are needed before definitive recommendations can be made for individual orthopedic procedures.

Clinical Message

Post-operative pain after knee surgery can hold back early mobilization, physiotherapy and rehabilitation, which are central to orthopedic recovery. In this study, all three motor-sparing blocks gave useful analgesia, and no major complications were recorded. GNB gave the best result, with lower pain scores at most time points through 24 h, a later first rescue analgesic request and lesser tramadol use. Because it spares the quadriceps, it is a reasonable opioid-sparing option for knee surgery, where early quadriceps activation and ambulation matter.

Declaration of patient consent: The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient has given the consent for his/ her images and other clinical information to be reported in the journal. The patient understands that his/ her names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

Conflict of interest: Nil **Source of support:** None

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