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Ultrasound-Guided Pericapsular Nerve Group Block vs Suprainguinal Fascia Iliaca Block for Analgesia in Hip Fracture Surgery: A Prospective Comparative Observational Study

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Data Collection B
Statistical Analysis C
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Background: Hip fractures cause severe perioperative pain, increased opioid use, and delayed recovery. The ultrasound-guided pericapsular nerve group (PENG) and suprainguinal fascia iliaca (SIFI) blocks are regional techniques targeting hip innervation. This study aimed to compare the effects of ultrasound-guided PENG and SIFI blocks on perioperative analgesia and clinical outcomes in hip fracture surgery.

Material/Methods: This prospective observational study included patients undergoing hip fracture surgery under spinal anesthesia. Patients received either an ultrasound-guided PENG block or a suprainguinal fascia iliaca block as part of routine clinical practice. The primary outcome was perioperative pain intensity measured using the numerical rating scale (0-10), including baseline pre-block assessments, pain during spinal positioning, and postoperative pain scores. All other variables, including ease of spinal positioning, hemodynamic parameters, cumulative 24-hour postoperative tramadol consumption, time to first analgesic requirement, range of motion of the affected limb, patient satisfaction, and adverse events, were evaluated as secondary outcomes.

Results: A total of 67 patients were included (PENG, n = 34; SIFI, n = 33). The SIFI group had significantly lower pain scores in the neutral position ($P = 0.004$), during limb elevation ($P < 0.001$), and at 2 to 8 hours postoperatively ($P < 0.001$). The 24-hour consumption of tramadol was lower ($P = 0.011$), and active hip flexion at 8 hours was greater ($P = 0.001$) in the SIFI group. Other outcomes were similar.

Conclusions: Both the PENG and SIFI blocks provided effective perioperative analgesia. SIFI was associated with lower pain scores at selected intervals and reduced opioid consumption; however, these findings represent time-specific associations rather than definitive superiority.

Keywords: analgesia • anesthesiology • hip fractures • nerve block • ultrasonography

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Introduction

Hip fracture is a common condition in the older adult population and is frequently associated with prolonged hospitalization and high mortality rates [1,2]. The high prevalence of comorbidities and reduced cardiopulmonary reserve in geriatric patients create substantial challenges for perioperative anesthetic management [2,3]. Severe perioperative pain is common, and although oral or intravenous analgesics are typically used as first-line therapy, increased drug sensitivity and susceptibility to adverse effects in this population necessitate safer and more tolerable analgesic strategies [4-6]. Despite their effectiveness in pain control, the use of opioids is often restricted due to a range of established adverse effects, such as gastrointestinal symptoms, altered mental status, and respiratory suppression [4,5].

Regional anesthesia techniques reduce opioid consumption, lower pain scores, and facilitate postoperative mobilization; therefore, they are frequently preferred over systemic opioid-based regimens [7,8]. In the emergency department setting, a recent randomized controlled trial demonstrated that ultrasound-guided femoral nerve block provides superior analgesia, reduces rescue opioid requirements, and is associated with fewer adverse effects compared with intravenous opioid analgesia in patients with hip fracture, including those with cognitive impairment [9]. However, conventional regional approaches for hip analgesia, including femoral nerve block and fascia iliaca block, may not consistently provide adequate analgesia of the hip joint capsule and can be associated with quadriceps weakness, potentially delaying postoperative mobilization and functional recovery [8,10].

As a relatively novel regional anesthesia technique, the ultrasound-guided pericapsular nerve group (PENG) block targets the articular branches of the femoral, obturator, and accessory obturator nerves by depositing local anesthetic in the musculofascial plane between the psoas tendon and the pubic ramus [11,12]. Clinical studies suggest that the PENG block provides effective analgesia with minimal motor impairment in patients with hip-related pain; however, the extent and consistency of its clinical benefits remain under investigation [10,13].

The ultrasound-guided suprainguinal fascia iliaca (SIFI) block involves the injection of local anesthetic above the inguinal ligament, allowing more proximal spread and facilitating femoral and lateral femoral cutaneous nerve blockade [14,15]. However, variability in block success and clinical outcomes has been reported depending on technique and patient population [8,16].

Recent comparative studies, including a systematic review and meta-analysis and a randomized controlled trial, have evaluated PENG and SIFI blocks for hip fracture surgery, reporting variable findings regarding analgesic efficacy, opioid consumption, and functional outcomes [17,18]. However, much of the available evidence is derived from heterogeneous study populations, varying surgical settings, and differing analgesic protocols, which limits direct comparison between techniques. Despite evidence supporting effective analgesia with both techniques, findings regarding their comparative analgesic efficacy, opioid-sparing capacity, and effect on perioperative functional recovery remain inconsistent. Moreover, evidence specifically focusing on patients with hip fractures undergoing spinal anesthesia—particularly in terms of spinal positioning quality and early postoperative mobility—remains limited, representing a clinically relevant knowledge gap.

Therefore, in this study, we aimed to evaluate and compare the analgesic effectiveness and perioperative clinical outcomes of ultrasound-guided PENG and SIFI blocks administered before spinal anesthesia in patients undergoing hip fracture surgery.

Material and Methods

Ethical Considerations

Approval was obtained from the institutional ethics committee (December 9, 2022; approval number: 265), and the study protocol was prospectively registered at ClinicalTrials.gov (NCT06001996) as an observational cohort study prior to patient enrollment. The investigation was conducted in accordance with the principles of the 2013 Declaration of Helsinki. Participants and their family members were informed about the study procedures, and written informed consent was obtained prior to inclusion.

Study Design

This investigation was structured as a prospective, non-randomized, comparative observational study. Due to its observational design, neither randomization nor blinding was implemented. To reduce potential selection bias, consecutive patients meeting the inclusion criteria during the study period were recruited. The choice of regional block technique was based on routine clinical practice and the judgment of the attending anesthesiologist rather than on a predefined allocation protocol.

This approach was chosen to reflect routine clinical practice. In our institution, anesthetic technique selection is individualized based on patient characteristics and clinician judgment; therefore, randomization was not implemented, as it could have interfered with routine decision-making. Both techniques are commonly used in our practice, and an observational design was considered appropriate to evaluate their comparative performance under real-world conditions. However, we

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acknowledge that this may introduce selection bias and confounding by indication. Baseline characteristics were therefore systematically recorded and compared between groups.

Setting

The study was conducted between October 1, 2023, and December 31, 2023, at the Department of Anesthesiology and Reanimation, University of Health Sciences, Diyarbakır Gazi Yaşargil Training and Research Hospital, Diyarbakır, Turkey.

Participants

During the study period, patients scheduled for hip fracture surgery under spinal anesthesia were screened for eligibility.

The inclusion criteria were patients aged 18 to 90 years with an American Society of Anesthesiologists (ASA) physical status classification of I-III undergoing hip fracture surgery under spinal anesthesia.

Exclusion criteria were infection at the injection site, coagulopathy, morbid obesity (body mass index [BMI] > 35 kg/m^2), drug allergy, chronic pain, long-term opioid use, psychiatric disease, or required emergency surgery. Patients who declined participation were also excluded.

Patients were allocated into 2 groups according to the block technique applied: the PENG block group (PENG group) and the SIFI block group (SIFI group).

Patients with insufficient postoperative follow-up were excluded from the final analysis.

Preoperative Assessment

All patients underwent preoperative evaluation by an anesthesiologist. Detailed explanations regarding the surgical procedure, anesthetic management, and analgesic block techniques were provided. Participants received standardized instruction regarding perioperative pain assessment using the numerical rating scale (NRS), defined from 0 (no pain) to 10 (worst imaginable pain). Informed written consent was obtained from every patient prior to inclusion. On the scheduled day of surgery, patients were transferred to the operating room after an 8-hour fasting period. Two peripheral intravenous cannulas (20-gauge) were inserted into the antecubital region approximately 30 minutes beforehand. Patients were then transferred to the preoperative preparation area, where standard monitoring was initiated, including pulse oximetry, noninvasive blood pressure measurement, and electrocardiography. Intravenous premedication with midazolam 1 mg and fentanyl 50 µg was administered.

Pain severity was measured using the NRS immediately before the block while the patient was in a neutral position (NRS1) and after 15° elevation of the affected extremity (NRS2). NRS1 and NRS2 were recorded immediately before block administration and therefore represent baseline pre-block pain measurements rather than post-block outcomes. Demographic and clinical data, including age, sex, comorbidities, type of surgical procedure, ASA physical status, and BMI, were documented for each patient.

Interventions

The nerve blocks were performed in the supine position using a sterile technique under ultrasound guidance on the fractured side by an anesthesiologist with at least 5 years of clinical experience. All peripheral nerve blocks were administered prior to spinal anesthesia. An ultrasonography device (GE LOGIQ e, GE Healthcare, Wauwatosa, WI, USA) equipped with a 4- to 13-MHz linear transducer and 100-mm short-bevel block needles (Stimuplex Ultra 360, B. Braun Medical, Melsungen, Germany) was used. The total dose and concentration of bupivacaine were standardized for all participants. In both groups, 15 mL of 0.375% bupivacaine solution was administered, prepared from bupivacaine HCl (Buvasin 0.5%, Istanbul, Turkey). During block performance, the ultrasound monitor was consistently positioned outside the patient's direct field of view.

In our clinic, 1 of 2 regional nerve block techniques is routinely used for patients with hip fractures.

PENG Group

The ultrasound probe was first positioned transversely over the anterior inferior iliac spine and subsequently rotated to align parallel with the pubic ramus, enabling visualization of the iliopsoas muscle-tendon complex in the short axis. Using an in-plane lateral-to-medial approach, the needle tip was advanced to the musculofascial plane between the psoas tendon and the pubic ramus. Under continuous ultrasound visualization and intermittent aspiration, the prepared local anesthetic solution was administered slowly (**Figure 1A**).

SIFI Group

The ultrasound probe was positioned in a parasagittal orientation to visualize the characteristic "bow-tie" sign medial to the anterior superior iliac spine. An in-plane caudal-to-cephalad approach was then used, and the needle tip was advanced beneath the fascia iliaca into the plane between the internal oblique and iliacus muscles. Following negative aspiration, the prepared local anesthetic solution was administered while the needle was advanced slowly in the cephalad direction within the fascia iliaca plane (**Figure 1B**).

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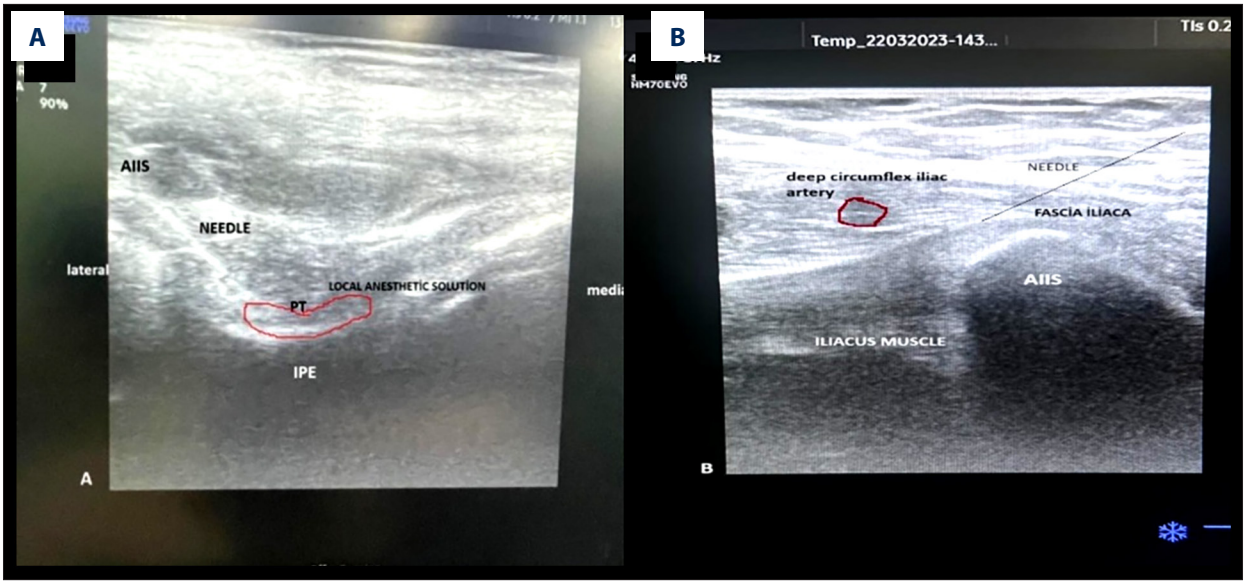

Figure 1. Ultrasound-guided block techniques used in the study. (**A**) Ultrasound-guided pericapsular nerve group (PENG) block. (**B**) Ultrasound-guided suprainguinal fascia iliaca (SIFI) block. Abbreviations: AIIS, anterior inferior iliac spine; IPE, iliopubic eminence; PT, psoas tendon.

Perioperative Management

Standard monitoring, which had been initiated in the preoperative area, was continued upon arrival in the operating room. For spinal anesthesia, patients were placed in the sitting position. During positioning, ease of spinal positioning (EOSP) scale scores, Modified Richmond Agitation-Sedation Scale (RASS) scores, and pain intensity during positioning (NRS3) were recorded. EOSP was evaluated with the 4-point (0-3) EOSP scale [43]: 0 = unable to position; 1 = abnormal posturing due to pain and required support for positioning; 2 = mild discomfort but did not require support for positioning; and 3 = optimal condition of positioning without pain. Patient agitation during positioning was assessed using the RASS as follows: 0 = awake and calm; +1 = restless; +2 = agitated; +3 = very agitated; and +4 = nervous.

For spinal anesthesia, 2 mL of 0.5% hyperbaric bupivacaine combined with 20 μg of fentanyl was administered intrathecally. Mean arterial pressure and peak heart rate were recorded at baseline, during spinal block placement, 5 minutes after spinal block, during surgery, and at skin closure. The doses of spinal anesthetic agents, as well as the durations of surgery and anesthesia, were documented.

Every surgical procedure was performed by a single surgical team using a posterior surgical approach with patients positioned in the lateral decubitus position. No periarticular local anesthetic infiltration was administered during surgery.

After surgery, patients were admitted to the postanesthesia care unit. Patients were transferred to the ward once the Aldrete score reached 9 or higher. Patients who required postoperative intensive care were admitted to the intensive care unit (ICU).

Postoperatively, all patients received intravenous paracetamol 1 g (Perfalgan, Bristol-Myers Squibb, Itxassou, France) every 8 hours. Postoperative pain severity was measured with the NRS (0 = no pain, 10 = worst imaginable pain). Postoperative NRS assessments were performed with the patient at rest rather than during active movement or physiotherapy. Pain scores were routinely recorded before rescue analgesic administration when NRS scores exceeded 4. If rescue tramadol was administered, reassessment was performed 30 minutes later; however, for study reporting, the highest pain score recorded within each predefined postoperative interval was retained as the representative value for that interval. Therefore, NRS4, NRS5, and NRS6 represent peak resting pain scores within the postoperative 0-2 hour, 2-8 hour, and 8-24 hour periods, respectively. When the NRS score exceeded 4, intravenous tramadol 100 mg (Tramadol HCl, Tramosel 100 mg/2 mL, Istanbul, Türkiye) was administered as rescue analgesia. Pain intensity was reassessed 30 minutes after tramadol administration. Adequate analgesic response was defined as a reduction of the NRS score to 4 or lower or a decrease of at least 2 points from the pre-rescue value. If adequate analgesia was not achieved or if pain recurred with NRS higher than 4, tramadol administration could be repeated at a minimum interval of 6 hours. The maximum allowable tramadol dose was limited to 400 mg within the first postoperative 24 hours. No additional opioid or regional analgesic rescue intervention was used during

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this period. Time to first analgesic requirement was calculated from the time of block administration to the first postoperative rescue analgesic administration. Time to first analgesic requirement and the cumulative tramadol requirement within the initial 24-hour period were recorded.

Postoperative pain assessments were performed hourly during the first 24 hours after surgery by investigators not involved in block administration or intraoperative anesthesia management, and these assessments were anchored to the end of surgery. For reporting purposes, the highest (peak) pain scores recorded within each predefined postoperative interval were documented as NRS4 (0-2 hours), NRS5 (2-8 hours), and NRS6 (8-24 hours), rather than instantaneous point measurements. These intervals were defined as 0-2, 2-8, and 8-24 hours after the end of surgery. Range of motion (ROM) was evaluated as the degree of active flexion of the operated hip joint using a standard goniometer by a trained clinical assessor at postoperative hours 4 and 8. A questionnaire was administered to patients 24 hours postoperatively to assess satisfaction with analgesic management, and patient satisfaction scores were recorded as 1 = very unsatisfied; 2 = quite unsatisfied; 3 = moderately satisfied; 4 = quite satisfied, and 5 = very satisfied. ICU and ward lengths of stay, postoperative complications, and adverse effects were recorded.

In cases of severe nausea or vomiting, patients received 10 mg of metoclopramide. All patients were prescribed daily thromboembolism prophylaxis with a direct factor Xa inhibitor for 4 weeks postoperatively. Rehabilitation exercises targeting the quadriceps were started on the day of surgery, and early postoperative mobilization was encouraged.

Outcomes

The primary outcome was perioperative pain intensity. Pain intensity was assessed using the NRS, ranging from 0 (no pain) to 10 (worst imaginable pain), at predefined time points including baseline pre-block assessment in the neutral position (NRS1), baseline pre-block assessment during 15° elevation of the affected extremity (NRS2), during spinal positioning (NRS3), and within postoperative intervals 0-2 hours (NRS4), 2-8 hours (NRS5), and 8-24 hours (NRS6).

All other variables, including EOSP, hemodynamic parameters, cumulative 24-hour postoperative tramadol consumption, time to first analgesic requirement, ROM of the affected limb, patient satisfaction, and adverse events, were evaluated as secondary outcomes. The EOSP scale was scored from 0 (unable to position) to 3 (optimal positioning without pain). Patient agitation during positioning was assessed using the RASS. Perioperative hemodynamic parameters, including mean arterial pressure and heart rate, were recorded at baseline, during spinal anesthesia, 5 minutes after spinal block, intraoperatively, and at skin closure. Postoperative analgesic use was quantified by cumulative tramadol consumption within the first 24 hours, and the interval to initial analgesic requirement was defined as the time from block administration to the first request for rescue analgesia. Mobility of the affected limb was evaluated by measuring active hip flexion ROM in degrees of the operated hip joint at 4 and 8 hours after surgery, using a standard goniometer. Measurements were performed by a trained clinical assessor and recorded as the maximum degree of active flexion tolerated by the patient. Patient-reported satisfaction was assessed at 24 hours using a 5-point Likert scale (1 = very unsatisfied to 5 = very satisfied). Adverse events, including nausea, vomiting, and other complications, were prospectively recorded during the perioperative period.

Data Sources and Measurements

Perioperative anesthesia management, surgical technique, intraoperative monitoring, and postoperative analgesic protocols were standardized for all patients to reduce potential confounding effects. Pain scores and perioperative variables were recorded prospectively at predefined time points using standardized protocols. Study data were collected from medical records and through face-to-face assessments conducted in both the operating room and the ICU. Outcome assessments were performed using standardized protocols by investigators who were not involved in block administration or intraoperative anesthesia management, to ensure consistency of data collection. However, formal assessor blinding to the type of regional block was not feasible because postoperative follow-up and perioperative documentation were integrated into routine clinical workflow. As a result, assessors were aware of the block technique applied, which may have introduced measurement bias, particularly for subjective outcomes such as pain scores and patient satisfaction.

Bias

Potential sources of bias were considered during the study design and analysis. Selection bias was minimized by consecutive patient inclusion, and standardized perioperative protocols were applied to reduce variability between groups. However, due to the non-randomized design, confounding by indication cannot be completely excluded. In particular, baseline clinical characteristics may have influenced both the treatment allocation and study outcomes. Among these, BMI was considered a potentially important confounder, as weight-related differences can affect the pharmacodynamic response to commonly used analgesic and anesthetic agents. To address this issue, BMI was incorporated as a covariate in adjusted statistical models. Nevertheless, residual confounding due to unmeasured or inadequately controlled variables cannot be entirely ruled out.

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In addition, formal assessor blinding was not feasible, due to the observational design and routine perioperative workflow. Although outcome assessments were conducted by investigators not involved in block performance, assessors were aware of group allocation, which may have introduced observer bias, particularly for patient-reported outcomes.

Study Size

The required sample size was determined using G*Power software (version 3.1.9.4; Kiel University, Kiel, Germany), based on early perioperative pain intensity assessed using the NRS as the primary outcome. The expected standardized effect size (Cohen's $d \approx 0.72$) was derived from previously published randomized controlled trial data on postoperative pain outcomes in patients undergoing hip surgery [19], based on the difference in mean NRS values and the pooled standard deviation between treatment groups. Assuming a 2-sided α level of 0.05, a statistical power of 80%, and equal group allocation (1: 1), the minimum required sample size was calculated as 32 patients in each group.

Statistical Analysis

Statistical analyses were performed using SPSS software (version 16.0; IBM Corp, Armonk, NY, USA). Continuous variables are presented as mean ± standard deviation (SD) when normally distributed and as median (interquartile range, [IQR]) when non-normally distributed. Categorical variables are expressed as frequencies and percentage.

The normality of continuous variables was assessed using the Shapiro-Wilk test together with visual inspection of Q-Q plots and histograms. Variables demonstrating non-normal distribution, including 24-hour tramadol consumption, ROM at 4 and 8 hours after surgery, and ICU length of stay, were reported as median (IQR) and compared using the Mann-Whitney U test. Length of hospital stay showed a normal distribution and was therefore presented as mean ± SD and compared using the independent samples *t* test. Between-group comparisons for continuous variables were performed using either the independent samples *t* test or the Mann-Whitney U test, as appropriate. Categorical variables were compared using the chi-square test or Fisher's exact test when expected cell counts were less than 5.

Perioperative repeated measurements of NRS pain scores and hemodynamic variables were analyzed using linear mixed-effects models to account for within-subject correlations over time. Time was treated as a categorical factor, and fixed effects for group, time, and group × time interaction were included, together with a random intercept for participants. All predefined NRS assessment points (NRS1 to NRS6) were included in the longitudinal model as repeated categorical time levels. Baseline pre-block pain measurements (NRS1 and NRS2) were retained within the model as predefined perioperative assessment points rather than being treated as separate covariates, as they were considered part of the overall perioperative pain trajectory.

Because the allocation of block technique was not randomized and was based on routine clinical practice, potential confounding factors were considered in the statistical analysis. BMI was identified as a clinically relevant covariate, as weight-related differences may influence the pharmacodynamic response to analgesic and anesthetic agents. Accordingly, BMI was included as the primary adjustment covariate in adjusted models. Other baseline variables, including ASA physical status, type of surgical procedure, and major comorbidity burden, were also evaluated as potential confounders. However, these variables showed no clinically meaningful between-group imbalance, and inclusion of multiple covariates in a relatively small sample may increase the risk of model instability and overfitting. Therefore, BMI was selected as the primary adjustment variable based on statistical imbalance and clinical relevance. This adjustment was performed to control for the potential confounding effect of weight-related variability on pain scores, positioning conditions, and perioperative outcomes.

Because postoperative NRS assessment intervals were anchored to the end of surgery rather than the time of block administration, operative duration was also considered a clinically relevant variable that could influence the elapsed time between block performance and postoperative pain evaluation. Therefore, operative duration was reported descriptively and additionally included in adjusted models together with BMI where appropriate.

Hemodynamic variables, including mean arterial pressure and heart rate, were analyzed using separate linear mixed-effects models with fixed effects for group, time, and group × time interaction, while BMI and operative duration were included as covariates, and a random intercept for participants was included to account for repeated measurements. Overall (omnibus) significance of fixed effects was evaluated using Type III tests derived from the mixed-effects models. Adjusted pairwise comparisons were performed when appropriate.

Holm-Bonferroni–adjusted post hoc pairwise comparisons were conducted for prespecified clinically relevant time intervals to support interpretation of time-specific between-group differences identified within the longitudinal models. Mixed-effects model estimates are presented with standard errors and 95% confidence intervals where applicable. Time-specific comparisons were interpreted descriptively and in relation to the

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overall mixed-effects model findings. All statistical tests were 2-sided, and $P < 0.05$ was considered statistically significant.

All study outcomes were prospectively defined before data collection. Pain scores and repeated perioperative measurements were analyzed using linear mixed-effects models to appropriately account for repeated observations within participants over time. Single-time-point continuous variables, including tramadol consumption, time to first analgesic requirement, and range of motion, were analyzed using independent samples *t* tests or Mann-Whitney U tests as appropriate. Categorical variables, including adverse events and positioning scores, were analyzed using chi-square or Fisher's exact tests. This approach ensured a structured, transparent, and reproducible statistical evaluation of all study outcomes.

Missing data and losses to follow-up were assessed before statistical analysis. Patients excluded from the final analysis due to insufficient postoperative follow-up were primarily those who were discharged early, transferred to another unit or institution, or had incomplete postoperative pain assessments within the predefined time intervals. The frequency and reasons for missing follow-up were evaluated and compared between groups, and no clinically meaningful imbalance was observed. Because the proportion of missing data was low and limited to outcome measurements rather than baseline variables, a complete-case analysis approach was adopted. No imputation methods were applied. Given the low rate of missingness and its presumed non-differential distribution between groups, sensitivity analyses were not performed; however, the potential impact of missing data on study findings is acknowledged as a limitation. Accordingly, no missing data were present in the final analysis dataset.

Results

During the study period, 85 patients were assessed for eligibility. Twelve patients were excluded prior to enrollment because of refusal to participate (n = 3), coagulopathy (n = 2), BMI > 35 kg/m^2 (n = 2), chronic pain (n = 1), psychiatric disease (n = 2), and emergency surgery (n = 2). No patients were excluded because of infection at the injection site, drug allergy, or long-term opioid use.

A total of 73 patients were included in the study. During postoperative follow-up, 6 patients were excluded from the final analysis because of incomplete outcome assessment within the predefined postoperative intervals (4 in the PENG group and 2 in the SIFI group). These patients were primarily discharged early, transferred to another unit or institution, or had incomplete postoperative pain assessments. No clinically meaningful between-group imbalance was observed regarding the frequency

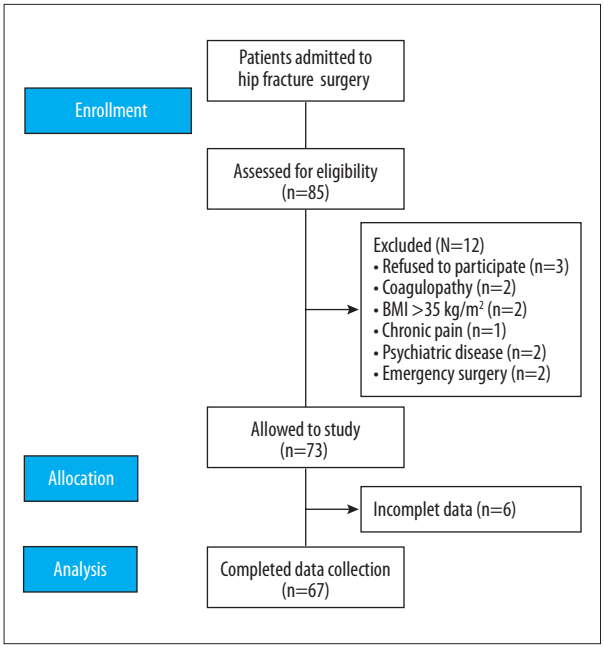

Figure 2. Flow diagram of patient enrollment, exclusion, and final analysis.

or reasons for missing follow-up. Consequently, 67 patients were included in the final analysis, consisting of 34 patients in the PENG group and 33 patients in the SIFI group (**Figure 2**).

The mean age of the study population was 79 ± 11 years. The mean surgical duration was 59 ± 15 minutes, and the total duration including anesthetic procedures was 78 ± 16 minutes. Surgical duration was recorded for all patients and was considered in the adjusted analysis because postoperative pain assessment intervals were defined according to the end of surgery rather than the exact time of block administration. Inclusion of operative duration in adjusted models did not alter the direction or statistical significance of the primary findings.

When the PENG and SIFI groups were compared with respect to demographic and clinical characteristics, no significant differences were observed, except for BMI, which was significantly lower in the SIFI group than in the PENG group ($P = 0.04$) (**Table 1**). ASA class distribution, type of surgical procedure, and major comorbidity profiles were comparable between groups. Because BMI showed both statistical imbalance and clinical relevance for perioperative analgesic response, it was retained as the primary adjustment covariate in the final mixed-effects models, whereas the remaining baseline variables were not included, to avoid unnecessary model instability and overfitting in a relatively small sample.

Perioperative pain scores, the primary outcome of the study, are presented in **Table 2**. NRS1 and NRS2 represented baseline pre-block pain measurements obtained before block

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Table 1. Comparison of demographic and intraoperative characteristics between the pericapsular nerve group (PENG) and suprainguinal fascia iliaca (SIFI) groups.

Features	All patients (N = 67) (Mean ± SD)	PENG group (n = 34) (Mean ± SD)	SIFI group (n = 33) (Mean ± SD)	*P*
Age	79 ± 11	79 ± 12	79 ± 11	0.97
BMI (kg/m^2)	26 ± 4	27 ± 4	25 ± 4	**0.04**
Surgery duration (min)	59 ± 15	60 ± 18	58 ± 13	0.87
Anesthesia duration (min)	78 ± 16	81 ± 19	75 ± 13	0.24
Spinal anesthesia dose (mg)	11 ± 2	11 ± 2	11 ± 2	0.29
	n (%)	n (%)	n (%)	
Sex				
Male	27 (40%)	14 (41%)	13 (39%)	0.88
Female	40 (60%)	20 (59%)	20 (61%)	
Comorbidity				
1	36 (54%)	20 (59%)	16 (48%)	0.64
2	21 (31%)	10 (29%)	11 (33%)	
3	10 (15%)	4 (12%)	6 (18%)	
ASA physical status				
I	1 (1%)	0	1 (3%)	0.28
II	26 (39%)	11 (32%)	15 (45%)	
III	40 (60%)	23 (68%)	17 (52%)	
Surgical procedure				
Hip prosthesis	29 (43%)	12 (35%)	17 (51%)	0.18
PFN	38 (57%)	22 (65%)	16 (48%)	

Abbreviations: SD, standard deviation; BMI, body mass index; ASA, American Society of Anesthesiologists physical status classification; PFN, proximal femoral nail.

Table 2. Comparison of perioperative pain scores between the pericapsular nerve group (PENG) and suprainguinal fascia iliaca (SIFI) groups assessed by the numerical rating scale (NRS).

	PENG Group (n = 34) Median (IQR)	SIFI Group (n = 33) Median (IQR)	*P*
NRS1	7 (6-8)	6 (5.5-7)	**0.004**
NRS2	10 (9-10)	9 (8-9)	**<0.001**
NRS3	4 (3-5)	4 (4-5)	0.15
NRS4	0 (0-0)	0 (0-0)	0.3
NRS5	4 (2-5)	2 (1-2.5)	**<0.001**
NRS6	3 (2-4)	4 (3-4.5)	0.12

Abbreviations: IQR, interquartile range; NRS, numerical rating scale; NRS1, neutral position; NRS2, 15° elevation of the affected extremity; NRS3, spinal positioning; NRS4, 0-2 hours after surgery; NRS5, 2-8 hours after surgery; NRS6, 8-24 hours after surgery.

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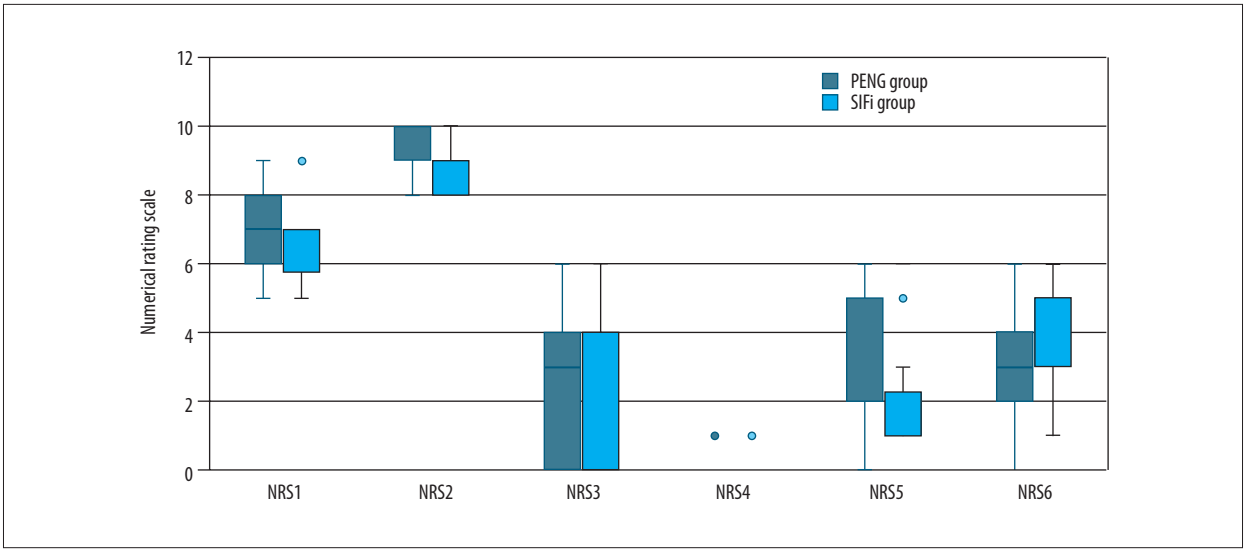

Figure 3. Comparison of perioperative pain scores across different time points between the pericapsular nerve group (PENG) and suprainguinal fascia iliaca (SIFI) groups. Abbreviations: NRS, numerical rating scale; NRS1, neutral position; NRS2, 15° elevation of the affected extremity; NRS3, spinal positioning; NRS4, 0-2 hours after surgery; NRS5, 2-8 hours after surgery; NRS6, 8-24 hours after surgery.

administration, whereas NRS3 to NRS6 reflected pain during spinal positioning and postoperative follow-up. The *P* values in **Table 2** represent unadjusted time-point comparisons and were used descriptively. The main statistical inference was based on the mixed-effects model presented in **Table 3**. NRS scores at time points 1, 2, and 5 were significantly lower in the SIFI group than in the PENG group ($P = 0.004$, $P < 0.001$, and $P < 0.001$, respectively), whereas no significant between-group differences were observed at the remaining time points (**Figure 3**). However, NRS1 and NRS2 represented baseline pre-block pain assessments obtained before administration of the regional block and therefore reflect pre-existing between-group differences rather than treatment-related analgesic effects. Accordingly, interpretation of comparative analgesic efficacy should primarily focus on post-intervention assessments.

Longitudinal analysis using a linear mixed-effects model demonstrated a significant overall effect of time on perioperative NRS scores ($P < 0.001$) as well as a significant time × group interaction ($P < 0.001$), indicating that the temporal evolution of pain differed between the PENG and SIFI groups. The mixed-effects model included all predefined perioperative pain assessments (NRS1 to NRS6), including baseline pre-block measurements (NRS1 and NRS2), which were analyzed as repeated time points within the overall perioperative pain trajectory rather than as separate adjustment covariates. In contrast, the overall group effect was not statistically significant after accounting for repeated measurements and covariate adjustment ($\beta = -0.065$, SE = 0.296, 95% CI -0.645 to 0.515; $P = 0.827$), indicating that mean perioperative pain scores across all time points were similar between groups. BMI was retained in adjusted models based on both baseline imbalance and clinical relevance; however, it was not independently associated with NRS scores ($\beta = 0.001$, SE = 0.003, 95% CI -0.004 to 0.007; $P = 0.646$). Reflecting the significant time × group interaction, adjusted pairwise comparisons demonstrated that the most pronounced between-group difference occurred during the postoperative 2-8 hour interval (NRS5). Significantly lower NRS5 scores were observed in the SIFI group compared with the PENG group (adjusted mean difference = -1.59; 95% CI, -2.13 to -1.05). Holm-Bonferroni–adjusted pairwise comparisons confirmed that this difference at NRS5 remained statistically significant after adjustment (adjusted $P < 0.001$). Furthermore, operative and anesthesia durations were comparable between groups, suggesting that major differences in block-to-assessment timing were unlikely. Together, these findings indicate that between-group differences in pain were time-dependent associations rather than reflecting a constant overall treatment effect (**Table 3**).

Secondary outcomes included intraoperative hemodynamic parameters, postoperative analgesic consumption, mobilization outcomes, hospital stay, ICU stay, patient satisfaction, and adverse events.

Regarding intraoperative hemodynamic parameters, unadjusted comparisons showed that mean arterial pressure values were significantly lower in the PENG group than in the SIFI group at 5 minutes after spinal block, during surgery, and at skin closure ($P = 0.037$, $P = 0.017$, and $P = 0.031$, respectively). Heart rate values were significantly higher in the PENG group at all measured time points except baseline ($P = 0.009$, $P = 0.004$,

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Table 3. Comparison of perioperative numerical rating scale (NRS) scores between the pericapsular nerve group (PENG) and suprainguinal fascia iliaca (SIFI) groups using a linear mixed-effects model.

Effect	Estimate (β)	SE	95% CI	*P*
Group	-0.065	0.296	-0.645 to 0.515	0.827
BMI	0.001	0.003	-0.004 to 0.007	0.646
Time (overall)	—	—	—	**<0.001**
Time × group (overall)	—	—	—	**<0.001**

Abbreviations: BMI, body mass index; SE, standard error.All predefined perioperative pain assessments (NRS1–NRS6), including baseline pre-block measurements (NRS1 and NRS2), were included in the mixed-effects model as repeated categorical time levels. Time and time × group *P* values represent overall (omnibus) Type III tests derived from the mixed-effects model. Holm-Bonferroni–adjusted post hoc comparisons were used to support interpretation of prespecified clinically relevant intervals.

Table 4. Comparison of intraoperative hemodynamic parameters between the pericapsular nerve group (PENG) and suprainguinal fascia iliaca (SIFI) groups.

	PENG Group (n = 34) (Mean ± SD)	SIFI Group (n = 33) (Mean ± SD)	*P*
MAP baseline	111 ± 18	115 ± 13	0.24
MAP when performing spinal block	108 ± 13	112 ± 12	0.15
MAP 5 minutes after spinal block	91 ± 16	98 ± 9	**0.037**
MAP during surgery	91 ± 14	99 ± 6	**0.017**
MAP in skin closure	92 ± 13	98 ± 8	**0.031**
HR baseline	87 ± 14	83 ± 8	0.16
HR when performing spinal block	89 ± 12	82 ± 8	**0.009**
HR 5 minutes after spinal block	77 ± 12	69 ± 6	**0.004**
HR during surgery	77 ± 13	68 ± 5	**0.005**
HR in skin closure	76 ± 13	67 ± 5	**0.006**

Abbreviations: SD, standard deviation; MAP, mean arterial pressure; HR, heart rate. Table 4 presents unadjusted between-group comparisons at individual perioperative time points. In addition, repeated hemodynamic measurements were analyzed using separate linear mixed-effects models including fixed effects for group, time, and group × time interaction, with body mass index and operative duration as covariates and a random intercept for subjects. For both MAP and HR, significant overall time effects were observed ($P < 0.001$), whereas neither the overall group effect nor the group × time interaction remained statistically significant after adjustment (all $P > 0.05$), indicating no consistent longitudinal between-group differences.

$P = 0.005$, and $P = 0.006$). These descriptive between-group comparisons are presented in **Table 4**. Because these comparisons were based on isolated time-point analyses, longitudinal mixed-effects modeling was additionally performed to evaluate overall hemodynamic trajectories. The hemodynamic findings presented in **Table 4** should therefore be interpreted as descriptive unadjusted time-point comparisons rather than definitive longitudinal between-group effects.

To account for repeated measurements over time and potential confounding related to BMI and operative duration, separate linear mixed-effects models were performed for mean arterial pressure and heart rate. These models included fixed effects for group, time, and group × time interaction, with a random intercept for participants. Both mean arterial pressure and heart rate demonstrated significant overall effects of time, reflecting expected perioperative physiological variation. However, after adjustment, neither the overall group effect nor the group × time interaction remained statistically significant, indicating no consistent longitudinal between-group differences in hemodynamic profiles. Accordingly, the primary interpretation was based on the repeated-measures mixed-effects

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Table 5. Comparison of ease of spinal positioning (EOSP) and sedation levels between the pericapsular nerve group (PENG) and suprainguinal fascia iliaca (SIFI) groups.

	PENG group n (%)	SIFI group n (%)	*P*
EOSP			
Cannot be positioned	0	0	0.11
Painful and positioned with support	2 (6%)	1 (3%)	
Slightly uncomfortable but does not need support	20 (59%)	13 (39%)	
Painless and self-positioning	12 (35%)	19 (58%)	
Modified RASS score in spinal positioning			
Awake and calm	25 (73%)	22 (67%)	0.55
Restless	8 (23%)	8 (24%)	
Uneasy-Agitated	1 (3%)	3 (9%)	
Very Agitated	0	0	
Combative	0	0	

Abbreviation: RASS, Richmond Agitation-Sedation Scale.

Table 6. Comparison of postoperative analgesic consumption and time to first analgesic requirement between the pericapsular nerve group (PENG) and suprainguinal fascia iliaca (SIFI) groups.

	PENG group (n = 34) Median (IQR)	SIFI group (n = 33) Median (IQR)	*P*
24-hour tramadol consumption (mg)	100 (0-100)	100 (0-100)	**0.011**
Time to first analgesic requirement (hours)	9 (6.75-12.25)	10 (8-12.5)	0.14

Abbreviation: IQR, interquartile range. Continuous variables were analyzed using the Mann-Whitney U test.

models, which supported comparable overall hemodynamic stability between the PENG and SIFI groups despite isolated significant unadjusted comparisons at specific time points.

No significant differences were observed between groups regarding EOSP, including EOSP and RASS scores during spinal positioning ($P = 0.11$ and $P = 0.55$, respectively), indicating comparable procedural comfort and sedation quality between the groups (**Table 5**).

Among secondary analgesic outcomes, postoperative analgesic consumption differed between groups, with significantly lower 24-hour tramadol consumption in the SIFI group than in the PENG group (median [IQR]: 100 [0-100] vs 100 [0-100] mg; $P = 0.011$) (**Table 6**). Although median values were numerically similar, differences in distribution between groups resulted in statistical significance on Mann-Whitney U testing, indicating lower overall postoperative opioid requirement in the SIFI group.

When the groups were compared in terms of postoperative mobilization, length of hospital stay, ICU stay, patient satisfaction, and adverse events, active hip flexion ROM in the SIFI group was higher at both 4 and and 8 hours postoperatively. However, the between-group difference reached statistical significance only at 8 hours postoperatively (median [IQR]: 35 [32.5-42.5] vs 30 [15-36.25]; $P = 0.001$). No significant differences were observed between groups regarding length of hospital stay, ICU length of stay, patient satisfaction scores, or the occurrence of adverse effects (**Table 7**).

Discussion

In the present study, we compared ultrasound-guided PENG and SIFI blocks in patients undergoing surgery for hip fractures and evaluated their perioperative analgesic and hemodynamic effects. Both techniques provided effective analgesia and facilitated spinal positioning; however, within the context of this prospective non-randomized observational design, the SIFI block was associated with lower pain scores at selected early perioperative time points, reduced postoperative opioid consumption, and improved early joint mobility, suggesting a time-dependent analgesic association rather than definitive superiority. Although both techniques significantly reduced

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Table 7. Comparison of postoperative recovery outcomes, patient satisfaction, and adverse effects between the pericapsular nerve group (PENG) and suprainguinal fascia iliaca (SIFI) groups.

	PENG group (n = 34) Median (IQR)	SIFI group (n = 33) Median (IQR)	*P*
Active hip flexion ROM at 4 hours postoperatively (°)	2.5 (0-15)	10 (5-15)	0.06
Active hip flexion ROM at 8 hours postoperatively (°)	30 (15-36.25)	35 (32.5-42.5)	**0.001**
Length of stay in intensive care unit (hours)	20.5 (18-36)	22 (15.5-33)	0.57
Length of hospital stay (hours) (mean ± SD)	53 ± 36	65 ± 18	0.08
	n (%)	**n (%)**	
Patient satisfaction score			0.24
Very dissatisfied	0	0	
Quite dissatisfied	0	0	
Moderate	5 (15%)	1 (3%)	
Quite satisfied	18 (53%)	19 (58%)	
Very satisfied	11 (32%)	13 (39%)	
Adverse effects			0.15
No	32 (94%)	33 (100%)	
Yes	2 (6%)	0	

Abbreviations: ROM, range of motion; IQR, interquartile range; SD, standard deviation. Continuous variables with normal distribution were analyzed using the independent samples *t* test; non-normally distributed variables were analyzed using the Mann-Whitney U test. Categorical variables were analyzed using the chi-square test or Fisher's exact test, as appropriate.

pain scores, NRS scores at time points 1, 2, and 5 were lower in the SIFI group, whereas no significant differences were observed at the remaining time points. Consistent with this pattern, linear mixed-effects analysis demonstrated a significant time × group interaction but no significant constant overall between-group effect after adjustment for repeated measures and baseline BMI, indicating that analgesic differences were time-dependent rather than globally superior. Hemodynamic parameters showed expected temporal variation but remained comparable between techniques, supporting similar perioperative physiological stability.

Postoperative outcomes further supported this pattern, with significantly lower tramadol consumption and greater joint ROM at 8 hours in the SIFI group, although no differences were observed in hospital stay, patient satisfaction, or adverse effects. However, these postoperative findings should be interpreted cautiously because postoperative assessment windows were defined broadly and were not strictly standardized according to the exact time elapsed from block administration. Since operative duration can vary substantially between patients, the interval between block performance and postoperative pain assessment could differ, which may directly influence measured analgesic efficacy. Although operative duration was reported and considered in the adjusted analysis, the study design did not allow complete elimination of this timing-related variability. Therefore, these findings should be considered time-specific associations rather than evidence of consistent postoperative superiority. Both techniques similarly improved EOSP and modified RASS scores during spinal positioning, confirming their clinical utility for facilitating neuraxial anesthesia in older adult hip fracture patients.

One possible explanation for the observed early analgesic differences is the anatomical spread pattern of the 2 techniques. The SIFI approach enables more proximal and cephalad distribution of local anesthetic within the fascia iliaca compartment, which may facilitate more consistent blockade of the femoral and lateral femoral cutaneous nerves, and in some cases extension toward the lumbar plexus [14]. This broader neural coverage may enhance early perioperative analgesia by more effectively attenuating nociceptive input from the anterior thigh and periarticular structures. In contrast, the PENG block primarily targets the articular branches of the femoral, obturator, and accessory obturator nerves, and several cadaveric and imaging studies have suggested that the spread of local anesthetic may be variable and sometimes limited, potentially affecting block consistency [12,20]. These anatomical and

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pharmacodynamic differences may explain the time-specific associations observed with the SIFI technique in our study, although causal interpretation remains limited by the non-randomized design and potential confounding by indication, since block allocation was based on routine clinical practice and clinician preference rather than randomization.

Regional analgesia is widely recommended in this population because it reduces opioid exposure while maintaining effective pain control. The early postoperative period is critical for functional recovery in older adult patients with hip fracture, and opioid-sparing multimodal analgesic strategies—such as regional nerve blocks—may improve rehabilitation outcomes by providing effective analgesia while minimizing opioid-related adverse effects [21,22]. In line with this, a retrospective observational study demonstrated that ultrasound-guided femoral nerve block in older adult patients with hip fracture provided faster and more effective pain relief while significantly reducing opioid requirements in the emergency department [23]. These considerations support our findings and reinforce the clinical relevance of regional anesthesia techniques in improving early perioperative outcomes in this vulnerable population. By focusing on the articular innervation from the femoral, obturator, and accessory obturator nerves, the PENG block has demonstrated meaningful reductions in resting and dynamic pain scores in early clinical reports [11,24], findings consistent with the analgesic improvement observed in our cohort. The SIFI block, a fascia iliaca-based approach providing femoral and lateral femoral cutaneous nerve coverage, has shown mixed results in prior studies, ranging from no significant benefit over sham blockade [25] to significantly improved postoperative pain scores in randomized trials [26]. Our results support a clinically relevant analgesic effect for both techniques.

Recent comparative studies, including a systematic review and meta-analysis and a randomized controlled trial, have reported heterogeneous findings regarding the relative efficacy of PENG and SIFI blocks [17,18]. Randomized trials have demonstrated either comparable analgesic efficacy between techniques or context-dependent differences in opioid consumption and time to first analgesic request [27,28]. In contrast, our findings showed lower pain scores at selected perioperative time points and reduced postoperative opioid use in the SIFI group. Because the overall group effect was not significant after adjustment, and the main statistical signal was the time × group interaction, these findings should be interpreted as interval-specific associations rather than definitive comparative superiority. Similarly, Jadon et al [29] reported improved pain control and ease of positioning with one of the techniques, although methodological variations likely contribute to discrepancies across studies. Our time-dependent analysis may help explain these inconsistencies by demonstrating that analgesic differences may occur within specific perioperative intervals rather than as a sustained global effect.

Baseline BMI differed between groups, and although BMI was included in the mixed-effects model, adjustment for BMI alone may not fully account for all clinically relevant differences influencing both block selection and analgesic outcomes. Other factors such as frailty, pain severity, functional status, and clinician preference may also have contributed to residual confounding. In addition, perioperative analgesic and anesthetic agents are often influenced by body weight in clinical practice, and the use of fixed-dose regimens may introduce pharmacodynamic variability that could affect postoperative pain scores and opioid consumption. These factors should be considered when interpreting the observed associations.

Both techniques exhibited comparable hemodynamic profiles, and variations in mean arterial pressure and heart rate were most likely related to anesthetic depth, surgical stimulation, and physiological stress rather than block-specific mechanisms. This supports the hemodynamic safety of both regional approaches in older adult patients undergoing hip surgery.

This study has several strengths, including adjustment for baseline imbalance, use of a linear mixed-effects framework appropriate for repeated measurements, and comprehensive evaluation of analgesic and hemodynamic outcomes across clinically relevant perioperative intervals. Several limitations should be considered when interpreting these findings. First, the most important limitation of this study is its prospective non-randomized observational design. Because block allocation was determined by clinician judgment and routine clinical practice rather than randomization, confounding by indication cannot be excluded. Patients may have differed between groups in ways that influenced block selection and study outcomes. Although baseline characteristics were compared and BMI was included as a covariate, this adjustment alone is unlikely to account for all clinically relevant confounders, and residual confounding due to unmeasured factors remains possible. Baseline pain intensity also differed between groups before block administration, with lower pre-block NRS values observed in the SIFI group. Although longitudinal analyses accounted for repeated measurements and BMI adjustment, these initial differences may have influenced subsequent perioperative pain trajectories and should be considered when interpreting interval-specific associations. Although BMI was adjusted for in the mixed-effects analyses, additional residual confounding related to factors such as frailty status, comorbidity burden, surgical procedure type, and clinician-driven treatment selection cannot be fully excluded. Because the sample size was limited, inclusion of multiple simultaneous covariates could increase the risk of overfitting; therefore, adjustment was restricted to the most clinically relevant and statistically imbalanced variable,

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BMI. Accordingly, the findings should be interpreted as associative rather than causal and should not be considered evidence of definitive superiority of one technique over the other.

Second, postoperative pain outcomes were assessed within predefined intervals that were not standardized according to the exact timing of block administration. Variability in the elapsed time between block performance and outcome assessment may have influenced the observed differences, particularly the lower pain scores during the interval 2 to 8 hours after surgery and the reduced cumulative 24-hour tramadol consumption in the SIFI group. Although operative duration was recorded, reported, and considered in the adjusted analysis, residual bias related to individual differences in block-to-assessment intervals cannot be completely excluded. Accordingly, these findings should be interpreted as time-specific associations rather than evidence of consistent postoperative superiority.

Third, BMI differed between groups at baseline, and although statistical adjustment was performed, BMI may not fully capture body weight–related pharmacodynamic variability. In addition, perioperative medications were administered using fixed dosing protocols, which may have contributed to inter-individual differences in analgesic response. Furthermore, the use of a fixed local anesthetic volume for both block techniques, although methodologically consistent, may not reflect optimal individualized dosing strategies.

Finally, the single-center design, limited sample size, absence of blinding, and relatively short follow-up period may restrict generalizability, reduce statistical power to detect small overall differences between techniques, and introduce measurement bias in subjective outcomes, such as pain scores and patient satisfaction. Moreover, formal assessor blinding was not feasible, and postoperative outcome assessors were aware of the block technique applied. Although standardized assessment protocols were used and assessors were independent from block administration, awareness of group allocation may have influenced the evaluation of subjective outcomes, such as pain scores, satisfaction, and mobilization assessments, thereby introducing potential measurement bias. In addition, the study was not designed to evaluate long-term functional recovery or sustained analgesic effects beyond the early postoperative period. Further multicenter randomized controlled studies with longer follow-up are warranted to validate these findings.

Conclusions

PENG and SIFI blocks were associated with effective perioperative analgesia and facilitation of spinal positioning in patients undergoing hip fracture surgery, with comparable overall hemodynamic stability. In this prospective non-randomized observational study, the SIFI block was associated with lower pain scores at selected early perioperative time points, reduced postoperative opioid consumption, and greater early joint range of motion. However, as no consistent overall between-group effect on pain was observed after adjustment, and the differences were time-dependent, these findings should be interpreted as associative rather than indicative of definitive superiority. Further multicenter randomized controlled studies are warranted to confirm these findings.

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Declaration of Figures' Authenticity

All figures submitted have been created by the authors who confirm that the images are original with no duplication and have not been previously published in whole or in part.

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