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Regional nerve blocks are associated with greater early analgesia for femoral neck fractures in the emergency department

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Abstract

Femoral neck fractures are highly painful emergency department (ED) presentations, particularly among older adults, and early analgesia is essential for imaging, positioning, and surgical preparation. This prospective, comparative, non-randomized ED study compared intravenous (IV) paracetamol, IV tramadol, ultrasound-guided femoral nerve block (FNB), and ultrasound-guided pericapsular nerve group (PENG) block in adults with isolated femoral fractures, particularly femoral neck fractures. The primary outcome was maximum pain reduction during the 240-minute follow-up. Because baseline pain scores differed between groups, maximum pain reduction was compared using analysis of covariance adjusted for age, fracture type, and baseline pain score. Among 125 patients, 113 (90.4%) had femoral neck fractures. Among 125 patients, 113 (90.4%) had femoral neck fractures. Ultrasound-guided regional blocks were associated with faster and greater pain reduction than systemic analgesics across visual analog, numeric rating, and facial pain scales. The largest early reductions occurred within the first 15 min after the FNB and PENG block. Effect sizes for maximum pain reduction were large on both the visual analog and numeric rating scales. Rescue analgesia was rarely required after regional blocks, whereas adverse events occurred mainly in the opioid group. These findings suggest that ultrasound-guided regional blocks may provide effective early analgesia in similar ED fracture analgesia settings where trained clinicians are available.

Keywords Femoral fracture · Emergency department · Regional analgesia · Femoral nerve block · Pericapsular nerve group block · Ultrasound-guided nerve block

Introduction

Femoral neck fractures are common and highly painful emergency department (ED) presentations, particularly among older adults, and are associated with substantial morbidity and mortality[1]. In real-world ED settings, inadequate pain control may interfere with positioning, imaging, clinical examination, and surgical preparation, while also increasing physiological stress and the risk of complications such as delirium. Although early analgesia is

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recommended in elderly and frail trauma patients, analgesic practice for isolated FF remains variable across EDs[2].

Intravenous (IV) systemic analgesics, including opioids and paracetamol, are frequently used as initial analgesic options in the ED[3,4]. However, these agents have important limitations. Opioids may cause nausea, vomiting, hypotension, respiratory depression, and delirium, particularly in older patients with comorbidities, whereas paracetamol, despite its more favorable safety profile, may provide insufficient analgesia when used alone for severe fracture-related pain[5–7]. These limitations highlight the need for effective, rapid, and opioid-sparing analgesic strategies in this population.

Ultrasound-guided regional anesthesia has become an increasingly important component of acute pain management for femoral and hip fractures. Femoral nerve block (FNB) is an established regional technique associated with improved analgesia and reduced opioid requirements[7–9]. Nevertheless, conventional FNB may not consistently cover the obturator and accessory obturator nerve branches involved in hip joint innervation[10,11]. The pericapsular nerve group (PENG) block was developed to target the articular branches of the femoral, obturator, and accessory obturator nerves while potentially preserving quadriceps strength[11,12]. Although emerging evidence suggests that PENG block may provide effective analgesia in proximal FF, direct ED-based comparisons between PENG block, FNB, and systemic analgesics remain limited, and many previous studies have focused on perioperative or anesthesia-led settings rather than real-time ED trauma care[8–10,13–15].

Accordingly, real-world ED-based head-to-head comparisons of systemic analgesics and regional blocks using standardized pain scales are needed. Therefore, this prospective, comparative, non-randomized ED study aimed to compare the analgesic effectiveness of systemic analgesics, FNB, and PENG block in adults presenting with isolated femoral fractures, particularly femoral neck fractures.

Materials and methods

Study design and setting

This prospective, comparative, non-randomized study was conducted in the emergency department (ED) of a tertiary care hospital between July 19, 2023, and December 2, 2023. The study was approved by the institutional ethics committee (IRB approval number: AEŞH-EK1-2023-307) and was conducted in accordance with the Declaration of Helsinki and its later amendments. Written informed consent was obtained from all participants or their legally authorized representatives. The study was registered with ClinicalTrials.gov (NCT06531564); however, because the registry record became publicly available after patient enrollment was completed, the registration was retrospective. Because the treating emergency physician selected the analgesic strategy in accordance with routine clinical practice and the research team did not assign it, the study was designed and analyzed as a prospective, comparative, non-randomized observational ED study. The manuscript was prepared in accordance with the STROBE recommendations for observational studies.

Study population

Patients aged 18 years or older with isolated FF who agreed to participate in the study were included. Exclusion criteria were: refusal or inability to provide informed consent; pregnancy; referral from another facility; receipt of any analgesic prior to ED arrival; inability to communicate; history of allergy to study drugs; known or suspected diabetic neuropathy; bleeding diathesis; infection at the injection site; presence of ≥ 2 fracture types requiring concurrent treatment; or lack of follow-up availability. A STROBE-style flow diagram of patient selection and treatment allocation is provided in Fig. 1.

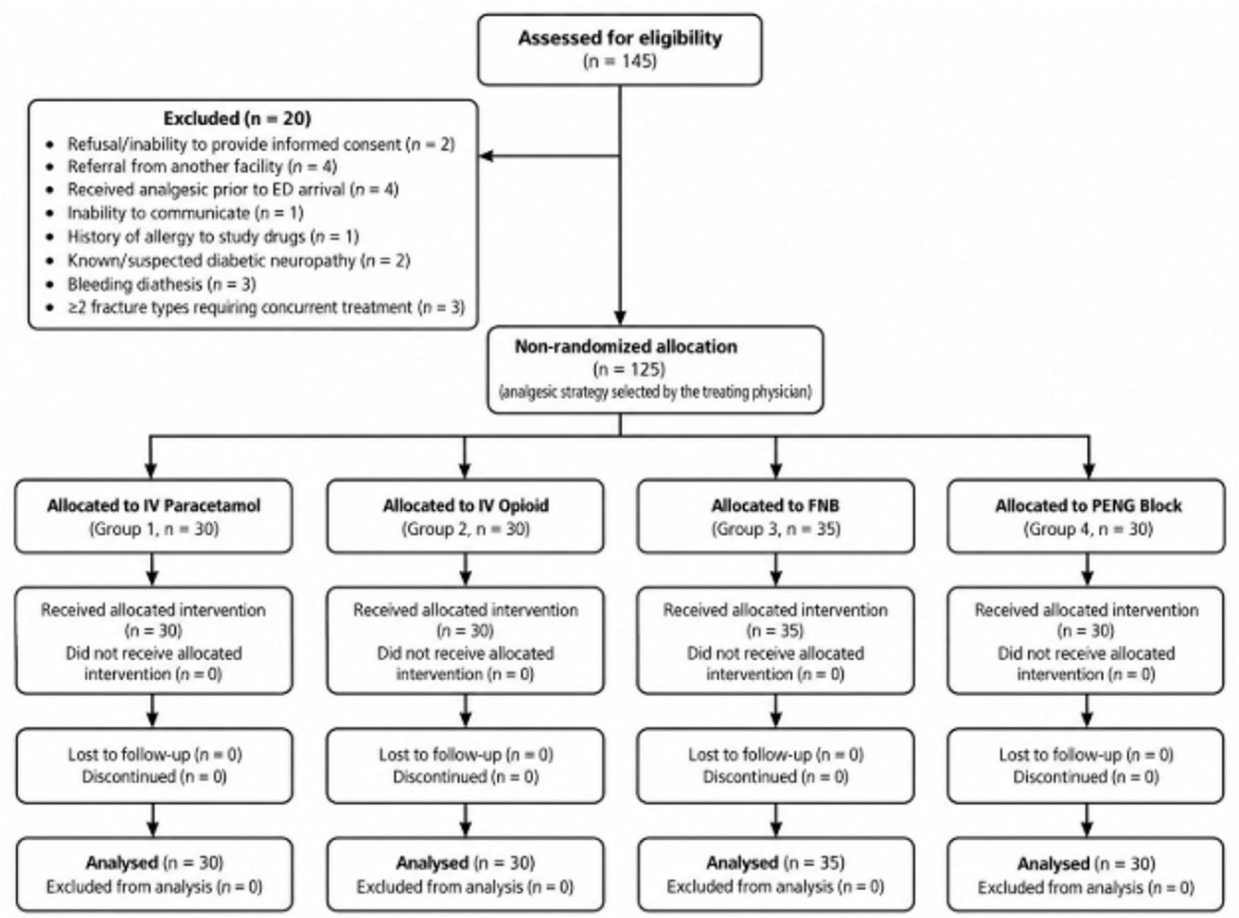


Fig. 1 STROBE-style flow diagram of patient selection and treatment allocation. The diagram shows the number of patients assessed for eligibility, excluded with reasons, and included in each treatment group. *FNB* femoral nerve block, *PENG* pericapsular nerve group block, *IV* intravenous.

Sample size calculation

An a priori sample size calculation was performed using G*Power. Because no prior head-to-head four-arm emergency department study comparing IV opioid, IV paracetamol, FNB, and PENG block was available at the time of study planning, the expected effect size was derived from previous ED hip fracture regional anesthesia literature. A clinically meaningful between-group difference of 1.5 points on a 0–10 pain scale with an estimated standard deviation of 2.4 was used, corresponding to a moderate effect size of approximately Cohen's f = 0.32. Using a fixed-effects one-way ANOVA framework with an omnibus F-test comparing four independent groups, an alpha level of 0.05, 80% power, and Cohen's f = 0.32, the minimum required sample size was calculated as 111 patients. This was rounded up to 112 patients to allow an equal planned allocation of approximately 28 patients per group. To account for potential incomplete follow-up or missing pain measurements, we aimed to include at least this number of patients. The final analytic cohort included 125 patients: 30 in the IV opioid group, 30 in the IV paracetamol group, 35 in the FNB group, and 30 in the PENG block group.

Patient assessment and treatment groups

Upon presentation, patients were evaluated according to the Advanced Trauma Life Support guidelines[13]. FF were classified according to the AO Foundation/Orthopedic Trauma Association (AO/OTA) fracture classification,

which was used to anatomically classify the fracture[14]. Based on the analgesia method used, patients were divided into four groups: IV paracetamol (Group 1), IV opioid (Group 2), FNB (Group 3), and PENG block (Group 4).

The treating emergency physician selected the analgesic strategy in accordance with routine clinical practice, patient characteristics, contraindications, and the physician's judgment. Patients in the IV paracetamol group received 1 g of paracetamol administered intravenously over 15 min. Patients in the IV opioid group received 100 mg tramadol diluted in 0.9% isotonic saline and infused intravenously over 15 min.

Ultrasound-guided regional techniques

Ultrasound-guided FNB and PENG blocks were performed as previously described[16,17]. An emergency physician with at least four years of emergency medicine experience and formal training in point-of-care ultrasound and ultrasound-guided regional anesthesia performed all regional procedures. Before the study, the operator completed additional training in ultrasound-guided regional techniques in the radiology department of the same institution.

Standard monitoring was applied in accordance with the American Society of Anesthesiologists' recommendations[18]. IV access was established before the procedure, and resuscitation equipment, an oxygen supply, and emergency medications, including 20% lipid emulsion for potential systemic toxicity from local anesthetics, were readily available. After standard antiseptic preparation and sterile draping, FNB or PENG block was performed using a GE Healthcare Logiq P9 ultrasound system. After identification of the relevant anatomical landmarks, a 22-gauge block needle (Stimuplex®, B. Braun, Germany) was advanced using an in-plane technique. Following negative aspiration, 20 mL of 0.25% bupivacaine was injected incrementally under ultrasound visualization. The team performed a neurovascular examination before and after the procedure.

Pain assessment

Pain intensity was assessed using validated pain assessment tools commonly used in ED analgesia studies. The Visual Analog Scale (VAS) and Numeric Rating Scale (NRS) were used as the main self-reported pain measures. The Faces Pain Scale (FPS) was used as an additional standardized measure in patients who had difficulty with numerical pain scoring or preferred a visual scale. In patients with known or suspected cognitive impairment, pain was assessed using the Pain Assessment in Advanced Dementia Scale (PAINAD)[15,19–23].

Pain scores were recorded at baseline and at 15, 30, 60, 120, 180, and 240 min after analgesic administration or regional block. Rescue analgesia requirements, adverse events, vital signs, patient disposition, 7-day mortality, and 30-day mortality were also recorded.

Outcome measures

The primary outcome was maximum pain reduction during the 240-minute follow-up period. Maximum pain reduction was defined as the difference between the baseline pain score and the lowest pain score recorded during follow-up.

Secondary outcomes included serial changes in pain scores at predefined time points, early pain reduction between consecutive measurements, need for rescue analgesia, adverse events, changes in vital signs, patient satisfaction, ED disposition, 7-day mortality, and 30-day mortality. Patient satisfaction with the analgesic approach was assessed using a 5-point scale, with higher scores indicating greater satisfaction.

Bias control

Because this was a non-randomized, real-world ED study, the research team did not control treatment allocation. The treating emergency physician determined the analgesic strategy in accordance with routine clinical practice.

To reduce selection bias, the physicians who selected the analgesic strategy were not involved in data analysis or outcome interpretation.

Pain assessments and follow-up data collection were performed by an investigator who was not involved in treatment selection or intervention administration. Baseline demographic characteristics, fracture type, initial pain scores, and vital signs were recorded to identify potential between-group imbalances. Because baseline pain scores differed between treatment groups, maximum pain reduction was analyzed using analysis of covariance adjusted for age and baseline pain score.

Statistical analyses

Statistical analyses were performed using IBM SPSS Statistics version 28.0 (IBM Corp., Armonk, NY, USA). The distribution of continuous variables was evaluated using the Shapiro–Wilk test and graphical methods. Continuous variables were expressed as mean ± standard deviation or median (interquartile range), as appropriate. Intergroup comparisons among the four treatment groups were performed using one-way ANOVA or Welch ANOVA for normally distributed variables and the Kruskal–Wallis test for non-normally distributed variables. Post hoc pairwise comparisons were conducted using Bonferroni or Dunnett T3 tests when appropriate. Categorical variables were compared using the Pearson chi-square or Fisher–Freeman–Halton test. Changes in pain scores over time were analyzed using repeated-measures ANOVA, with treatment group as the between-subject factor and time as the within-subject factor. When the sphericity assumption was violated, the Greenhouse–Geisser correction was applied. Effect sizes were reported as eta-squared (η^2) or partial eta-squared for continuous outcomes and ANOVA-based models, Cramér's V for categorical comparisons, and epsilon-squared (ε^2) for ordinal variables analyzed using the Kruskal–Wallis test. Because baseline pain scores differed between groups, analysis of covariance (ANCOVA) was used to compare maximum pain reduction scores, with treatment group and fracture type as fixed factors and age and the corresponding baseline pain score as covariates. As a sensitivity analysis, post-treatment VAS, NRS, and FPS scores measured at 15, 30, 60, 120, 180, and 240 min were analyzed separately using linear mixed-effects models. Each model included treatment group, time as a categorical factor, the treatment group × time interaction, the corresponding baseline pain score, and age as fixed effects. Within-patient correlation across repeated measurements was modeled using an unstructured covariance matrix. Models were estimated using restricted maximum likelihood, with denominator degrees of freedom estimated using the Satterthwaite approximation. Analyses included all available post-treatment observations from the 116 patients eligible for self-reported pain assessment. The nine patients assessed using PAINAD were excluded from these models by design, and their structurally inapplicable self-reported pain scores were not imputed. Correlation analyses were performed using Spearman's rank correlation coefficient. Because multiple correlation analyses were performed, p-values from full-sample correlation analyses were adjusted using the Benjamini–Hochberg false discovery rate (FDR) procedure. FDR-adjusted q-values < 0.05 were considered statistically significant. Group-specific correlation analyses were considered exploratory because of the small number of patients in each treatment group and were interpreted descriptively. Missing data were summarized as n (%). Missingness was evaluated using Little's MCAR test. Multiple imputation was performed using fully conditional specification with a linear regression model, generating five imputed datasets. For each self-reported pain scale, the imputation model included treatment group and the corresponding baseline and serial pain measurements. Baseline pain scores were complete and were included as predictors but were not imputed. The nine patients assessed using PAINAD were ineligible for VAS, NRS, and FPS assessment by design; therefore, their structurally inapplicable self-reported pain scores were not imputed. A p-value < 0.05 was considered statistically significant.

Results

Study population and baseline characteristics

The study included 125 patients with isolated femoral fractures, of whom 113 (90.4%) had femoral neck fractures. Of these, 30 patients received IV opioid therapy, 30 received IV paracetamol, 35 underwent FNB, and 30 underwent PENG block. The median age was 78 years, and 60.8% of the patients were male. Low-energy falls were the most common injury mechanism.

Baseline demographic characteristics, body mass index (BMI), injury mechanism, and fracture classification were broadly comparable among the four treatment groups. However, baseline pain scores differed significantly between groups. The IV paracetamol group had lower initial VAS, NRS, and FPS scores than the IV opioid, FNB, and PENG block groups. Baseline hemodynamic parameters also differed between groups, with lower systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial pressure (MAP), and pulse values in the IV paracetamol group. Table 1 presents baseline and clinical characteristics.

Rescue analgesia requirements differed significantly between treatment groups. Nearly all patients in the FNB and PENG block groups required no additional analgesia, whereas rescue analgesia was more frequently required in the IV opioid and IV paracetamol groups. Adverse events were observed mainly in the IV opioid group, most commonly nausea/vomiting and desaturation, whereas no procedure-related complications were observed in the FNB or PENG block groups. Patient satisfaction scores also differed significantly across treatment groups, with higher scores observed in the IV opioid and IV paracetamol groups than in the FNB and PENG block groups.

Changes in pain levels over time

Among the 116 patients eligible for self-reported VAS, NRS, and FPS assessment, baseline measurements were complete. Across the six post-treatment assessments, 52 of 696 possible observations per scale were missing, corresponding to an overall missing rate of 7.5% for each scale. Visit-specific missingness ranged from 0.9% to 24.1%. Eighty-four patients (72.4%) had complete data at all six follow-up assessments, whereas 32 patients (27.6%) had at least one missing follow-up measurement. Little's MCAR test was not statistically significant ($\chi^2 = 44.61$, df = 32, $p = 0.068$), providing no evidence against the assumption that the observed missing data were missing completely at random. Analyses before and after multiple imputation showed no meaningful differences in the direction or statistical significance of the main findings.

Pain scores decreased over time across all treatment groups, but the magnitude and trajectory of pain reduction varied by analgesic strategy. Repeated-measures analysis showed significant time effects for VAS, NRS, and FPS scores, indicating an overall reduction in pain during the 240-minute follow-up period. Significant group effects were also observed across all three scales, and the time × group interactions were significant for VAS, NRS, and FPS scores, indicating that pain-reduction trajectories differed between treatment groups. The interaction effect sizes were moderate to large, particularly for NRS (partial $\eta^2 = 0.375$), VAS (partial $\eta^2 = 0.332$), and FPS (partial $\eta^2 = 0.292$). PAINAD scores did not change significantly over time ($\chi^2 = 5.57$, $p = 0.423$). Table 2 shows detailed repeated-measures results.

The most pronounced early reductions in pain scores were observed in the FNB and PENG block groups, particularly within the first 15 min. In contrast, the IV paracetamol group showed the smallest reduction in pain scores throughout the follow-up period.

Maximum pain reduction

Maximum pain reduction differed significantly among the four treatment groups across all self-reported pain scales. After adjustment for age, fracture type, and the corresponding baseline pain score, adjusted maximum VAS reduction was greater in the FNB and PENG block groups than in the IV opioid and IV paracetamol groups.

Table 1 Baseline and clinical characteristics of the study population.

Category	IV opioid ($n=30$)	IV paracetamol ($n=30$)	FNB ($n=35$)	PENG ($n=30$)	p	Post-hoc	Effect size
Demographic characteristics							
Age (mean ± SD)	70.2 ± 18.4	71.9 ± 13.8	75.5 ± 15.8	74.9 ± 15.4	0.503	-	η^2= 0.02
Male n(%)	18 (60%)	20 (66.7%)	19 (54.3%)	19 (63.3%)	0.766	-	Cramér's V = 0.096
Female n(%)	12 (40%)	10 (33.3%)	16 (45.7%)	11 (36.7%)			
Dementia n(%)	3 (10%)	2 (6.6%)	1 (2.9%)	3 (10%)	0.623	-	Cramér's V = 0.117
BMI	24.5 ± 3.9	25.1 ± 6.2	23.2 ± 4.8	23.5 ± 5.5	0.468	-	η^2= 0.021
Trauma mechanism, n (%)							
Fall	28 (93.3%)	28 (93.3%)	31 (88.6%)	29 (96.7%)	0.857	-	Cramér's V = 0.125
MVC	2 (6.7%)	1 (3.3%)	2 (5.7%)	0			
Assault	0	0	1 (3.3%)	1 (3.3%)			
Other	0	1 (3.3%)	1 (3.3%)	0			
Fracture classification, n (%)							
Neck fracture	27 (90%)	26 (86.7%)	33 (94.3%)	27 (90%)	0.981	-	Cramér's V = 0.109
Shaft fracture	2 (6.7%)	2 (6.7%)	2 (5.7%)	2 (6.7%)			
Distal fracture	1 (3.3%)	1 (3.3%)	0	1 (3.3%)			
Head fracture	0	1 (3.3%)	0	0			
Initial pain scores (mean ± SD)							
VAS	8.4 ± 0.8	5.7 ± 0.6	8.8 ± 1.0	8.7 ± 0.9	< 0.001	b < a,c, d	η^2 = 0.691
NRS	8.4 ± 0.8	5.7 ± 0.6	8.6 ± 1.6	8.7 ± 0.9	< 0.001	b < a,c, d	η^2 = 0.555
Faces	7.4 ± 1.1	6.4 ± 0.9	7.8 ± 0.9	7.4 ± 0.9	< 0.001	b < a,c, d	η^2 = 0.210
PAINAD	4.67 ± 0.57	4 ± 1.41	6.00 ($n=1$)	5.67 ± 1.15	0.256	-	-
Initial vital signs							
SBP	136.1 ± 19.8	128.1 ± 17.2	145.7 ± 22.6	155.2 ± 28.9	< 0.001	b < c,d; a < d	η^2 =0.169
DBP	76.4 ± 10.7	73.8 ± 6.8	79.3 ± 11.4	82.9 ± 12.0	0.007	b < d	η^2 =0.096
MAP	96.1 ± 10.5	91.6 ± 7.5	100.3 ± 13.4	105.0 ± 15.8	< 0.001	b < c,d	η^2 =0.142
Pulse	91.2 ± 14.0	80.4 ± 14.0	87.3 ± 14.0	92.1 ± 18.7	0.01	b < a,d	η^2 =0.084
Hospital length of Stay (mean ± SD)							
LOS (days)	6.4 ± 2.4	6.5 ± 2.7	7.3 ± 2.3	6.8 ± 1.7	0.486	-	η^2 = 0.02
Rescue analgesia							
None	7	2	35	30	< 0.001	-	Cramér's V = 0.553
Paracetamol	23	22	0	0			
Opioid	0	3	0	0			
PCM+Tramadol	0	1	0	0			
Tramadol+Fentanyl	0	1	0	0			
Triple combo	0	1	0	0			
Complications							
None	16 (53.3%)	28 (93.3%)	35 (100%)	30 (100%)	< 0.001	-	Cramér's V = 0.349
Desaturation	3 (10%)	1 (3.3%)	0	0			
Nausea/Vomiting	9 (30%)	0	0	0			
Hypotension	1 (3.3%)	0	0	0			
Other	1 (3.3%)	1 (3.3%)	0	0			

Table 1 (continued)

Category	IV opioid ($n=30$)	IV paracetamol ($n=30$)	FNB ($n=35$)	PENG ($n=30$)	p	Post-hoc	Effect size
Patient satisfaction (median, IQR)							
Satisfaction	5 (0)	5 (0)	3 (1)	3 (0)	<0.001	a, b > c,d	ε^2 (Kruskal–Wallis) = 0.575

Values are presented as mean ± standard deviation (SD), median (interquartile range [IQR]), or number (percentage) as appropriate. Comparisons of continuous variables were performed using one-way ANOVA or Kruskal–Wallis test, depending on distribution. Welch's ANOVA was used when the assumption of homogeneity of variance was not satisfied. Post hoc pairwise comparisons were performed using Bonferroni or Dunnett's T3 tests when appropriate. Categorical variables were compared using the Pearson chi-square test or Fisher–Freeman–Halton test. Effect sizes are reported as eta-squared (η^2) for continuous variables, Cramér's V for categorical variables, and epsilon-squared (ε^2) for ordinal variables analyzed using the Kruskal–Wallis test. PAINAD scores were analyzed only in patients with dementia. The PAINAD subgroup included 9 patients: 3 in the IV opioid group, 2 in the IV paracetamol group, 1 in the FNB group, and 3 in the PENG block group. Because only one patient in the FNB group had PAINAD data, this value is presented as an individual value rather than mean ± SD. a = IV opioid group, b = IV paracetamol group, c = femoral nerve block group, d = PENG block group.

Table 2 Summary of repeated-measures analysis for all pain scales.

Pain scale	Effect	F / χ^2	p-value	Partial η^2
VAS	Time	F = 3.559	<0.001	0.599
	Group	F = 10.387	<0.001	0.280
	Time × Group	F = 10.676	<0.001	0.332
NRS	Time	F = 126.276	<0.001	0.612
	Group	F = 10.795	<0.001	0.288
	Time × Group	F = 16.027	<0.001	0.375
Facial pain scale	Time	F = 154.753	<0.001	0.659
	Group	F = 10.912	<0.001	0.290
	Time × Group	F = 11.000	<0.001	0.292
PAINAD	Time (Friedman)	$\chi^2 = 5.57$	0.423	—

Changes in pain scores over time were analyzed using a repeated-measures analysis of variance (ANOVA), with treatment group as the between-subjects factor and time as the within-subjects factor. When the assumption of sphericity was violated, the Greenhouse–Geisser correction was applied. Because PAINAD scores did not meet the assumption of normality, the Friedman test was used to evaluate changes over time. Effect sizes are presented as partial eta squared (η^2). A p-value < 0.05 was considered statistically significant.

VAS visual analog scale, *NRS* numeric rating scale, *PAINAD* pain assessment in advanced dementia.

The adjusted estimated marginal means ± SE were 4.01 ± 0.70 for IV opioid, 3.01 ± 0.79 for IV paracetamol, 6.22 ± 0.71 for FNB, and 6.05 ± 0.71 for PENG block ($p < 0.001$; partial $\eta^2 = 0.206$). A similar pattern was observed for NRS, with adjusted reductions of 3.95 ± 0.70, 2.85 ± 0.73, 6.14 ± 0.69, and 6.01 ± 0.70, respectively ($p < 0.001$; partial $\eta^2 = 0.248$).

For FPS, adjusted reductions were 2.98 ± 0.45, 2.31 ± 0.43, 3.51 ± 0.45, and 4.27 ± 0.45, respectively ($p < 0.001$; partial $\eta^2 = 0.217$). Post hoc comparisons showed that FNB and PENG block were associated with greater adjusted maximum VAS and NRS reductions than both systemic analgesic groups. For FPS, PENG block was associated with greater adjusted reduction than both systemic analgesic groups, whereas FNB was significantly greater than IV paracetamol. Table 3 presents detailed ANCOVA results.

Sensitivity analysis of post-treatment pain trajectories

In the sensitivity analysis modeling post-treatment pain scores directly, adjusted pain trajectories differed significantly among treatment groups for VAS and NRS. In the linear mixed-effects models, the treatment group × time interaction was significant for both VAS and NRS (both $p < 0.001$), indicating that adjusted post-treatment pain trajectories differed by treatment strategy. For FPS, the overall treatment-group and time effects were significant, whereas the treatment group × time interaction did not reach statistical significance ($p = 0.08$). These findings

Table 3 Adjusted comparison of maximum reductions in VAS, NRS, and Facial Pain Scale scores between treatment groups using ANCOVA.

Pain Scale	IV Opioid	IV Paracetamol	Femoral Nerve Block	PENG Block	*p*-value	Post-hoc	Partial η^2
Maximum VAS reduction	4.01 ± 0.70	3.01 ± 0.79	6.22 ± 0.71	6.05 ± 0.71	< 0.001	a, b < c,d	0.206
Maximum NRS reduction	3.95 ± 0.70	2.85 ± 0.73	6.14 ± 0.69	6.01 ± 0.70	< 0.001	a, b < c,d	0.248
Maximum FPS reduction	2.98 ± 0.45	2.31 ± 0.43	3.51 ± 0.45	4.27 ± 0.45	< 0.001	b < c; a, b < d	0.217

Values are presented as adjusted estimated marginal means ± standard error (SE). Group comparisons were performed using analysis of covariance (ANCOVA), with treatment group and fracture type as fixed factors and age and the corresponding baseline pain score as covariates. Pairwise comparisons were conducted using Bonferroni-adjusted post-hoc tests. Effect sizes are reported as partial eta squared (partial η^2). a = IV opioid group; b = IV paracetamol group; c = femoral nerve block group; d = PENG block group. Post hoc comparisons indicated statistically significant pairwise differences between groups. A p-value < 0.05 was considered statistically significant.

VAS visual analog scale, *NRS* numeric rating scale, *FPS* facial pain scale, *FNB* femoral nerve block, *PENG* pericapsular nerve group block.

Table 4 Between-group comparison of changes in consecutive pain measurements (mean ± SD).

Pain score difference	IV opioid (a)	IV paracetamol (b)	Femoral nerve block (c)	PENG block (d)	*p*-value	Post-hoc	η^2
VAS1–VAS2	0.56 ± 1.20	0.14 ± 0.52	4.58 ± 2.37	4.85 ± 2.41	< 0.001	a, b < c,d	0.593
VAS2–VAS3	2.93 ± 1.94	0.93 ± 1.30	1.97 ± 1.86	1.60 ± 1.89	< 0.001	b < a	0.143
VAS3–VAS4	1.37 ± 1.66	0.25 ± 1.04	1.00 ± 1.65	0.62 ± 1.76	0.020	b < a	0.067
VAS4–VAS5	0.15 ± 0.77	–0.88 ± 1.14	0.09 ± 0.37	–0.48 ± 1.55	< 0.001	b < a,c	0.152
VAS5–VAS6	–1.08 ± 2.14	–0.40 ± 0.81	–0.77 ± 1.42	–0.70 ± 1.42	0.392	—	0.026
VAS6–VAS7	–0.75 ± 1.40	–0.12 ± 0.33	–2.21 ± 2.27	–0.71 ± 1.38	< 0.001	c < b	0.223
NRS1–NRS2	0.55 ± 1.21	0.14 ± 0.52	4.30 ± 2.80	4.84 ± 2.41	< 0.001	a, b < c,d	0.534
NRS2–NRS3	2.92 ± 1.93	0.92 ± 1.30	1.96 ± 1.86	1.60 ± 1.89	< 0.001	b < a	0.143
NRS3–NRS4	1.37 ± 1.66	0.25 ± 1.04	1.00 ± 1.65	0.61 ± 1.76	0.020	b < a	0.067
NRS4–NRS5	0.14 ± 0.76	–0.88 ± 1.14	0.08 ± 0.37	–0.48 ± 1.55	< 0.001	b < a,c	0.152
NRS5–NRS6	–1.08 ± 2.14	–0.40 ± 0.81	–0.76 ± 1.42	–0.69 ± 1.42	0.392	—	0.026
NRS6–NRS7	–0.75 ± 1.40	–0.12 ± 0.33	–2.21 ± 2.27	–0.71 ± 1.38	< 0.001	c < b	0.223
FPS1–FPS2	1.11 ± 1.78	0.42 ± 1.13	3.21 ± 1.40	3.23 ± 1.79	< 0.001	a, b < c,d	0.405
FPS2–FPS3	1.40 ± 1.82	0.57 ± 1.19	0.42 ± 0.83	1.12 ± 1.30	0.020	—	0.089
FPS3–FPS4	0.22 ± 0.84	0.00 ± 0.54	0.05 ± 0.34	0.15 ± 0.54	0.592	—	0.021
FPS4–FPS5	0.00 ± 0.00	–0.07 ± 0.39	0.00 ± 0.00	0.00 ± 0.00	0.350	—	0.030
FPS5–FPS6	–0.08 ± 0.40	–0.08 ± 0.40	0.00 ± 0.00	–0.08 ± 0.41	0.780	—	0.011
FPS6–FPS7	–0.10 ± 0.44	0.00 ± 0.00	–0.34 ± 0.77	–0.19 ± 0.60	0.163	—	0.059

PENG pericapsular nerve group block, *VAS* visual analog scale, *NRS* numeric rating scale, *FPS* facial pain scale.

were broadly consistent with the primary ANCOVA analysis, supporting greater early analgesia in the regional-block groups, although evidence for differential temporal trajectories was less consistent for FPS. Full model results are provided in Table S1.

Sequential pain reduction

Between consecutive time points, the largest early reductions in pain scores occurred during the first 15 min after analgesic administration or regional block. From baseline to 15 min, VAS scores decreased by 4.58 ± 2.37 in the FNB group and 4.85 ± 2.41 in the PENG block group, compared with 0.56 ± 1.20 in the IV opioid group and 0.14 ± 0.52 in the IV paracetamol group ($p < 0.001$). A similar pattern was observed for NRS scores, with reductions of 4.30 ± 2.80 in the FNB group and 4.84 ± 2.41 in the PENG block group, compared with 0.55 ± 1.21 and 0.14 ± 0.52 in the IV opioid and IV paracetamol groups, respectively ($p < 0.001$). FPS reductions from baseline to 15 min were also greater in the FNB and PENG block groups (3.21 ± 1.40 and 3.23 ± 1.79, respectively) than in the IV opioid and IV paracetamol groups (1.11 ± 1.78 and 0.42 ± 1.13, respectively; $p < 0.001$).

After the initial interval, between-group differences became less consistent and generally smaller. Table 4 summarizes sequential changes in pain scores.

Correlation analyses

Correlation analyses were interpreted after Benjamini–Hochberg FDR correction. After adjustment for multiple testing, the weak correlations between maximum VAS reduction and baseline SBP, baseline DBP, and BMI no longer met the corrected significance threshold. Similarly, the weak correlations between maximum FPS reduction and baseline DBP and MAP were no longer significant after FDR correction. Maximum NRS reduction remained weakly and negatively correlated with BMI, although this association was close to the adjusted threshold ($r = -0.235$, $q = 0.049$). Maximum FPS reduction also remained weakly and negatively correlated with BMI ($r = -0.260$, $q = 0.024$).

Baseline VAS and NRS scores remained positively correlated with baseline SBP, DBP, and MAP after FDR correction, and negatively correlated with BMI. Early pain reduction from baseline to 15 min remained correlated with ΔSBP for VAS, NRS, and FPS. Greater maximum pain reduction remained negatively correlated with patient satisfaction scores for VAS, NRS, and FPS. Higher patient satisfaction scores indicated greater satisfaction. Group-specific correlations were considered exploratory and interpreted descriptively because of the limited subgroup sample sizes. Table 5 presents detailed correlation coefficients and FDR-adjusted q-values.

Discussion

The present prospective study suggests that ultrasound-guided regional nerve blocks were associated with greater and faster pain reduction than systemic analgesics in patients presenting to the ED with FF. Consistent with previous studies on hip and femoral fracture analgesia, both FNB and PENG blocks were associated with larger reductions in VAS, NRS, and FPS scores than IV paracetamol or IV opioid therapy[8,24–26]. The difference was most pronounced early in treatment, particularly between baseline and 15 min, suggesting that regional blocks may provide rapid analgesic benefit in the acute ED setting. This early effect is clinically important because adequate pain control may facilitate patient positioning, imaging, clinical assessment, and preparation for definitive orthopedic management[9,26]. Across all pain scales, IV paracetamol showed the smallest analgesic effect. Although IV opioid therapy was associated with greater pain reduction than paracetamol, its effect remained lower than that observed with regional blocks, supporting previous concerns regarding the limited efficacy and adverse-effect profile of systemic opioids in elderly trauma patients[9,27].

The magnitude of pain reduction observed in the regional block groups also appears clinically meaningful, not only statistically significant. Commonly cited minimal clinically important difference (MCID) thresholds for acute pain measured using VAS or NRS are approximately 1.3–2.0 points[28,29]. In the present study, the adjusted maximum reductions in VAS and NRS scores in both the FNB and PENG block groups were substantially greater than this range, and the adjusted between-group differences compared with systemic analgesic groups also exceeded or approached commonly accepted MCID thresholds. Therefore, the observed analgesic benefit of regional blocks is likely to be clinically relevant in the acute ED setting. Nevertheless, MCID thresholds may vary by baseline pain intensity, patient population, fracture type, and clinical context[28,29]; therefore, these findings should be interpreted alongside the non-randomized design and baseline differences between groups.

No statistically significant difference in maximum analgesic response was observed between FNB and PENG blocks, indicating that both regional techniques provided comparable pain reduction in this cohort. This finding is clinically relevant because FNB is an established technique for femoral fracture analgesia, whereas the PENG block has been proposed as a more targeted approach to the articular branches of the femoral, obturator, and accessory obturator nerves, with the potential advantage of providing hip joint analgesia while minimizing quadriceps weakness[11,12]. However, the present study did not directly assess motor strength, mobilization, or fall risk. Therefore, although our findings support the analgesic effectiveness of the PENG block, its potential motor-sparing advantage should be interpreted cautiously and evaluated in future studies with functional outcomes.

Table 5 Combined correlation analyses of pain scores, vital parameters, and patient satisfaction.

Section	Variable / comparison	SBP1	DBP1	MAP1	Pulse1	Height	Weight	BMI
A. Maximum pain-score reductions vs. baseline vital/clinical parameters	Max VAS reduction	0.191, q=0.153 ns	0.187, q=0.163 ns	0.177	0.116	0.105	−0.037	−0.223, q=0.064 ns
	Max NRS reduction	0.159	0.180	0.150	0.138	0.101	−0.040	−0.235, q=0.049
	Max FPS reduction	0.146	0.226, q=0.062 ns	0.185, q=0.165 ns	0.149	0.106	−0.056	−0.260, q=0.024
B. Group-specific correlations — exploratory	VAS–SBP1 (Opioid)	−0.247	—	—	—	—	—	—
	VAS–SBP1 (Paracetamol)	−0.052	—	—	—	—	—	—
	VAS–SBP1 (FNB)	−0.155	—	—	—	—	—	—
	VAS–SBP1 (PENG)	−0.059	—	—	—	—	—	−0.524
	NRS–SBP1 (Opioid)	−0.247	—	—	—	—	—	—
	NRS–SBP1 (Paracetamol)	−0.052	—	—	—	—	—	—
	NRS–SBP1 (FNB)	−0.273	—	—	—	—	—	−0.071
	NRS–SBP1 (PENG)	−0.059	—	—	—	—	—	−0.524
	FPS–SBP1 (Opioid)	−0.369	—	—	—	—	—	−0.291
	FPS–SBP1 (Paracetamol)	0.032	—	—	—	—	—	0.032
	FPS–SBP1 (FNB)	0.054	—	—	—	—	—	−0.073
	FPS–SBP1 (PENG)	−0.006	—	—	—	—	—	−0.261
C. Baseline pain scores vs. vital/clinical parameters	Baseline VAS1	0.307, q=0.008	0.293, q=0.010	0.327, q=0.004	0.130	0.070	−0.090	−0.284, q=0.012
	Baseline NRS1	0.269, q=0.019	0.283, q=0.012	0.296, q=0.010	0.153	0.065	−0.094	−0.295, q=0.010
	Baseline FPS1	0.110	0.145	0.119	0.053	0.048	−0.103	−0.255, q=0.028
	Baseline PAINAD1	0.128	−0.119	0.164	0.329	−0.037	0.310	0.511
	VAS1–SBP1 (Opioid)	0.043	—	—	—	—	—	−0.332
	VAS1–SBP1 (Paracetamol)	−0.191	—	—	—	—	—	0.218
	VAS1–SBP1 (FNB)	0.127	—	—	—	—	—	−0.062
	VAS1–SBP1 (PENG)	0.038	—	—	—	—	—	−0.413
D. Pain-score changes vs. vital-sign changes	VAS1–VAS2 vs. ΔSBP	0.412, q<0.001	−0.087	0.117	0.110	—	—	—
	VAS2–VAS3 vs. ΔSBP	0.047	−0.104	−0.019	0.061	—	—	—
	VAS3–VAS4 vs. ΔSBP	−0.062	0.004	−0.040	−0.074	—	—	—
	VAS4–VAS5 vs. ΔSBP	−0.043	−0.107	−0.112	0.107	—	—	—
	VAS5–VAS6 vs. ΔSBP	0.018	−0.051	−0.029	−0.118	—	—	—
	VAS6–VAS7 vs. ΔSBP	0.162	0.112	0.146	0.209	—	—	—
	NRS1–NRS2 vs. ΔSBP	0.367, q<0.001	−0.055	0.102	0.121	—	—	—
	FPS1–FPS2	0.306, q=0.009	−0.057	0.073	0.049	—	—	—
	FPS2–FPS3	−0.088	−0.256, q=0.029	−0.174	−0.071	—	—	—
E. Correlation with patient satisfaction	Max VAS change – satisfaction	—	—	—	—	—	—	−0.508, q<0.001
	Max NRS change – satisfaction	—	—	—	—	—	—	−0.485, q<0.001
	Max FPS change – satisfaction	—	—	—	—	—	—	−0.425, q<0.001
	Baseline VAS1 – satisfaction	—	—	—	—	—	—	−0.431, q<0.001
	Baseline NRS1 – satisfaction	—	—	—	—	—	—	−0.403, q<0.001
	Baseline FPS1 – satisfaction	—	—	—	—	—	—	−0.288, q=0.011
	Baseline PAINAD1 – satisfaction	—	—	—	—	—	—	−0.300

Values represent Spearman correlation coefficients (r). Full-sample correlation analyses were adjusted for multiple testing using the Benjamini–Hochberg false discovery rate (FDR) procedure, and FDR-adjusted q-values are reported where applicable. $q < 0.05$ was considered statistically significant after FDR correction. Associations marked as "ns" did not remain statistically significant after FDR correction. Group-specific correlations were considered exploratory and interpreted descriptively because of limited subgroup sample sizes. The symbol — indicates that the variable was not applicable or not analyzed for that comparison. Δ indicates change between consecutive measurements. *SBP* systolic blood pressure, *DBP* diastolic blood pressure, *MAP* mean arterial pressure, *BMI* body mass index, *VAS* visual analog scale, *NRS* numeric rating scale, *FPS* facial pain scale, *PAINAD* pain assessment in advanced dementia.

These comparative findings should be interpreted in light of the baseline imbalance between treatment groups. Because the analgesic strategy was selected based on real-world ED decision-making rather than random allocation, the observed differences likely reflect, at least in part, confounding by indication[30,31]. In the ED, IV paracetamol may have been selected more often for patients with lower initial pain scores or more stable clinical findings, whereas opioid therapy or regional blocks may have been preferred for patients with higher initial pain scores, pain-related difficulty with positioning or imaging, or vital signs suggestive of a pain- or stress-related sympathetic response, such as elevated BP or tachycardia, or in accordance with injury context[27,30,31]. Physicians may also have considered the anticipated insufficiency of systemic analgesics for severe fracture-related pain, the desire to avoid opioid-related adverse effects in older or comorbid patients, the absence of contraindications to regional anesthesia, and the availability of an experienced clinician able to perform ultrasound-guided nerve blocks[32–34]. In the present study, this interpretation is indirectly supported by the markedly lower baseline VAS and NRS scores in the IV paracetamol group, as well as lower baseline SBP, MAP, and pulse values. Therefore, the baseline differences should be regarded not merely as a statistical imbalance, but as a clinically meaningful feature of treatment selection in this non-randomized ED cohort.

The exploratory correlation analyses suggested possible relationships among baseline pain intensity, BP, BMI, early pain reduction, and patient satisfaction. However, after FDR correction, several weak correlations no longer remained statistically significant. Therefore, these findings should be interpreted as hypothesis-generating rather than confirmatory[35]. Higher baseline pain scores were associated with higher SBP and DBP, and early pain reduction was correlated with changes in SBP. Although these findings suggest that effective early analgesia may attenuate pain-related sympathetic activation, vital signs in the ED are influenced by multiple factors, including anxiety, trauma-related stress, comorbidities, medications, and hydration status. The absence of correlations during later measurement intervals may reflect physiological stabilization following initial analgesic control. Accordingly, these associations should be interpreted cautiously and considered exploratory.

BMI was negatively correlated with maximum pain reduction, particularly in the PENG block group. This finding may have technical relevance because increased adiposity can make ultrasound visualization and needle guidance more challenging and may influence local anesthetic distribution[36]. However, this was a subgroup-level correlation and should be interpreted with caution. Further studies are needed to determine whether BMI affects the technical success, onset time, or analgesic duration of the PENG block in patients with FF.

Patient satisfaction showed a pattern that differed from the pain reduction outcomes. Although regional blocks produced greater analgesic improvement, satisfaction scores were higher in the systemic analgesic groups. This discrepancy suggests that satisfaction in the acute ED setting may be influenced by factors beyond analgesic efficacy, including patient expectations, perceived invasiveness of regional procedures, procedural anxiety, preintervention communication, and the timing of satisfaction assessment. Therefore, satisfaction should be interpreted as a separate patient-reported outcome rather than a direct surrogate for analgesic effectiveness.

The choice of analgesic strategy is particularly important in older patients with FF, who frequently have multiple comorbidities and may be vulnerable to both undertreated pain and systemic analgesic-related adverse events[37,38]. In this context, our findings support incorporating ultrasound-guided regional blocks into ED analgesia pathways for isolated FF when trained clinicians and appropriate monitoring are available. Rather than replacing systemic analgesics in all patients, regional blocks may provide an effective opioid-sparing option and may be particularly valuable when rapid pain control is needed for positioning, imaging, and early orthopedic management.

By evaluating serial pain trajectories, adjusted maximum pain reduction, rescue analgesia, adverse events, and patient satisfaction, this study provides a pragmatic assessment of early analgesic effectiveness for isolated femoral fractures, particularly femoral neck fractures, in routine ED practice. Most previous evidence has focused on perioperative or anesthesia-led settings, whereas our study reflects real-time analgesic decision-making in the ED.

This study has several limitations that should be considered when interpreting the findings. First, although the study was prospectively designed, it was not randomized. Treatment allocation reflected real-world ED clinical

decision-making and was therefore susceptible to confounding by indication. Although ANCOVA was used to adjust for measured baseline imbalance, particularly baseline pain score, the specific reasons for analgesic selection were not prospectively recorded; therefore, residual confounding due to unmeasured indication-related factors cannot be excluded. In addition, the primary outcome of maximum pain reduction may be susceptible to floor/ceiling effects because patients with lower baseline pain scores have less possible room for improvement. Although baseline pain score was included as a covariate in the ANCOVA and a sensitivity analysis modeling post-treatment pain scores directly was performed, residual floor/ceiling bias cannot be fully excluded. Because most patients in the cohort had femoral neck fractures, the findings should be interpreted primarily in the context of femoral neck or proximal femoral fracture analgesia and should not be generalized to all femoral shaft or distal femoral fractures. This consideration is particularly relevant for the PENG block, which targets articular branches innervating the anterior hip capsule and may therefore be less suitable as a sole analgesic technique for femoral shaft fractures, where pain may arise predominantly from shaft periosteal and soft-tissue injury. Second, although an investigator not involved in treatment selection or intervention administration performed pain assessments, the outcome assessor could not be fully blinded to treatment allocation because the analgesic modalities were clinically apparent, including IV systemic analgesia and ultrasound-guided regional block procedures. Because pain intensity is a subjective outcome, the possibility of assessment bias cannot be excluded. Third, the PAINAD subgroup sample size was limited because this tool applied only to a small number of cognitively impaired patients. Therefore, analyses involving PAINAD scores were likely underpowered and should be interpreted cautiously. Fourth, although systemic analgesic doses were standardized, differences in timing, individual pharmacokinetics, patient characteristics, and clinician judgment may have influenced early pain trajectories. Similarly, a single experienced emergency physician with training in point-of-care ultrasound and ultrasound-guided regional anesthesia performed all ultrasound-guided regional blocks. Although this standardized the block technique, it may also have introduced an operator-related performance advantage for the regional-block groups, particularly in terms of technical success, onset of analgesia, and consistency of block administration. Therefore, the findings may not be generalizable to settings with multiple operators or to clinicians with varying levels of experience in ultrasound-guided regional anesthesia. Fifth, pain assessment intervals were fixed and may not have fully captured the onset dynamics of each analgesic modality, particularly the rapid, early effect of nerve blocks. More frequent measurements during the first minutes after intervention could provide additional information. Sixth, motor strength, mobilization, and fall risk were not assessed; therefore, the potential motor-sparing advantages of the PENG block could not be evaluated. In addition, SFICB was not included as a comparator, although it is an established regional technique that may provide broader sensory coverage by targeting the femoral, lateral femoral cutaneous, and obturator nerve territories. Therefore, no conclusions can be drawn regarding the comparative effectiveness of FNB or PENG block relative to suprainguinal fascia iliaca compartment block, and future ED-based studies should directly compare these techniques. Seventh, patient satisfaction was assessed as a secondary outcome and may have been influenced by factors unrelated to analgesic efficacy, including procedural anxiety, expectations, perceived invasiveness, and timing of assessment. Finally, although vital signs were recorded, potential confounders such as anxiety, concurrent medications, comorbidities, hydration status, and trauma-related stress were not systematically controlled, which may have influenced correlations between pain reduction and physiological parameters. The study was conducted at a single tertiary center, which may limit generalizability to institutions with different patient populations, staffing structures, or access to ultrasound-guided regional anesthesia. Despite these limitations, this prospective study provides clinically relevant ED-based data comparing systemic analgesics and ultrasound-guided regional blocks for early pain management in a femoral neck fracture–dominant ED cohort.

Conclusion

In this prospective, comparative, non-randomized ED study, ultrasound-guided FNB and PENG blocks were associated with faster and greater early pain reduction than systemic analgesics in adults with isolated femoral fractures in a femoral neck fracture–dominant ED cohort. These findings support the use of ultrasound-guided regional blocks as an effective opioid-sparing analgesic option when trained clinicians and appropriate monitoring are available. Further randomized controlled trials are needed to confirm these findings and to evaluate functional outcomes, patient satisfaction, and safety across different ED settings.

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Data availability The datasets used and/or analyzed during the present study are available from the corresponding author on reasonable request.

Declarations

Competing interests The authors declare no competing interests.

Ethical approval and consent to participate All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee at which the studies were conducted and approved by the Ankara Etlik City Hospital Ethics Committee (IRB approval number: AEŞH-EK1-2023-307) and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. All participants or their legally authorized representatives provided written informed consent.

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