

Pericapsular nerve group (PENG) block vs. surgical articular infiltration for direct anterior total hip arthroplasty under general anaesthesia: a randomized pilot trial

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Background: The effectiveness of ultrasound-guided pericapsular nerve group (PENG) blocks for postoperative analgesia following direct anterior total hip arthroplasty under general anaesthesia remains uncertain. We conducted a prospective randomized trial to determine whether a PENG block would reduce postoperative intravenous morphine consumption compared with surgical local anaesthetic infiltration.

Methods: Consecutive patients were randomized to receive either an ultrasound-guided PENG block after induction of anaesthesia or surgical local anaesthetic infiltration after femoral neck resection. General anaesthesia and perioperative analgesic management were standardized according to institutional practice, and all procedures were performed by a single surgeon. The primary outcome was total intravenous morphine consumption during the post-anaesthesia care unit (PACU) stay. The secondary outcome measure was total oral morphine consumption from PACU discharge to postoperative day 1 (POD#1), expressed in oral morphine equivalents (OME).

Results: Of the 60 recruited patients, 56 were analysed using a modified intention-to-treat analysis. Median (interquartile range) PACU morphine consumption did not differ significantly between the control and PENG groups (0 [0–6] mg vs. 0 [0–3] mg; median difference 0 mg, 95% confidence interval (CI) –2 to 4.5; $P = 0.235$). Total OME consumption through POD#1 was lower in the PENG group compared to the control group (0 [0–10] mg vs. 7 [3–20] mg; $P = 0.040$).

Conclusions: In patients undergoing direct anterior total hip arthroplasty, PENG block, when implemented as part of a multimodal analgesic pathway, did not reduce PACU intravenous morphine consumption compared with surgical local infiltration.

Key words: hip surgery, pain management, postoperative outcomes, local anaesthetics, lidocaine, regional anaesthesia, enhanced recovery after surgery.

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INTRODUCTION

Total hip arthroplasty (THA) is an effective and life-changing procedure for those suffering from hip osteoarthritis. With an ageing population and increasing success rates of this surgery, the demand for THA is projected to rise significantly in the coming decades, making optimization of perioperative pain management increasingly important [1, 2].

The value of peripheral nerve blocks for decreasing postoperative pain scores and improving

overall patient outcomes is well established for patients having hip and knee arthroplasty [3, 4]. The pericapsular nerve group (PENG) block is an emerging nerve block that has been proposed to target the articular sensory branches of the anterior hip joint, which may offer a motor-sparing effect for hip arthroplasty [5–8]. This may help achieve both goals of postoperative analgesia and early mobilization facilitating timely discharge.

Although a meta-analysis on the effectiveness of PENG blocks when compared to placebo demonstrated better postoperative pain scores and a reduction of total opioid consumption 24 and 48 hours after surgery [9], other recent randomized trials found no significant improvement in pain scores between groups receiving a PENG block plus surgical infiltration compared with surgical infiltration alone [10, 11]. As such, the efficacy of the PENG block in THA surgery remains unclear.

We therefore conducted a single-centre prospective randomized controlled pilot trial to further investigate the efficacy of ultrasound-guided PENG block when compared to our current standard (surgical infiltration alone) in patients undergoing elective direct anterior THA under general anaesthesia. We hypothesized that patients who received a PENG block would require less morphine (mg) in the post-anaesthesia care unit (PACU) when compared to patients who received surgical infiltration.

METHODS

Study design

This prospective, parallel-group, pilot randomized controlled, single-blinded, superiority study was carried out at Medipole Hospital in Villeurbanne, Lyon, France. The study was approved by the French Institutional Review Board (Comité de Protection des Personnes Île-de-France VII) on 29 March 2022. The study was also registered on ClinicalTrials.gov (NCT05250492) on 10 February 2022, before first patient inclusion (principal investigator: Vincent Collange). Written informed consent was obtained from all patients. The study adheres to the Consolidated Standards of Reporting Trials (CONSORT) checklist provided in the supplementary material.

Patients

All adult patients scheduled for elective direct anterior THA surgery under general anaesthesia were eligible for inclusion in this study. Exclusion criteria were contraindication to local anaesthesia, high levels of assistance required for activities of daily living (Iso Resource Group level 1 or 2), study refusal, pregnancy or breastfeeding, participation in another clinical study and inability to provide consent.

Randomization and masking

Patients were randomized using a centralized list and were divided into two equal groups of 30 patients. The list was generated with SAS software (version 9.4; SAS Institute, Cary, NC, USA) with a block size of 4. This list was held by study investigators who informed the patient's anaesthesiologist of group allocation the day before the procedure.

All preparations and application of the protocol were carried out by the anaesthesia team in charge of the patient on the day of the procedure. While anaesthesiologists performing the procedures were aware of group assignments, all of the patients, PACU nurses, and research assistants collecting postoperative data were blinded to group allocation.

Study intervention

All surgeries were performed using a minimally invasive anterior approach by a single surgeon to ensure a high degree of surgical standardization. The anterior hip capsule was exposed through a vertical incision, and the joint was replaced following standard procedures.

Intraoperative monitoring

Anaesthesia monitoring consisted of a 5-lead EKG, pulse oximetry, non-invasive blood pressure monitoring, temperature, and relevant gas concentrations. The depth of anaesthesia was monitored with SedLine (Masimo, Irvine, California, USA), pre-load dependence with the Pleth Variability Index (PVI; Masimo, Irvine, California, USA) and neuromuscular blockade with a monitoring device that provided quantitative train-of-four count and ratio (Idmed, Marseille, France).

General anaesthesia

At our institution, elective primary THA through the direct anterior approach is routinely performed under general anaesthesia according to institutional practice. This standardized approach was used for all study participants to minimize variability in perioperative management.

The general anaesthetic technique was standardized for all patients. Intravenous access and standard monitoring were established and the patient was pre-oxygenated via a facemask. Following induction with propofol 2 mg kg⁻¹, sufentanil 10 µg and rocuronium 0.6 mg kg⁻¹, the patient was intubated. Immediately after induction of general anaesthesia, all patients received intravenous lidocaine (100 mg) and ketamine (15 mg) as part of a standardized multimodal anaesthetic protocol. The lidocaine was administered exclusively by the intravenous route as a systemic analgesic adjunct and was not incorporated into either the PENG block or the surgical local infiltration solution. Maintenance of anaesthesia was achieved with sevoflurane (2%) and sufentanil boluses (5 µg) as required. Prior to skin closure, all patients without contraindications received a combination of intravenous non-opioid analgesics (ketoprofen 50–100 mg, nefopam 20 mg and paracetamol 1 g).

Surgical infiltration

Participants received local infiltration during the procedure, after resection of the femoral neck. The infiltration consisted of 100 mL of a mixture of ropivacaine 2 mg mL⁻¹, 150 µg of clonidine and 0.5 mg of epinephrine.

PENG block

The PENG fascial plane block was completed following intubation and before surgical preparation and draping. Following skin preparation with chlorhexidine and using an aseptic non-touch technique, a curvilinear probe was aligned in a plane between the anterior superior iliac spine (ASIS) and pubic symphysis, visualizing the ASIS, iliopubic eminence, iliopsoas tendon and femoral vessels. Using an in-plane technique and from a lateral to medial direction, a 22-gauge, 80 mm Pajunk needle was advanced to a position between the iliopsoas tendon and the ilium. Following negative aspiration, 20 mL of local anaesthetic (2.5 mg mL⁻¹ levobupivacaine with 1 mg dexamethasone and 75 µg of clonidine) was then injected, observing for spread of fluid and displacement of the iliopsoas tendon away from the ilium. Of note, patients who received the PENG block did not receive the surgical infiltration.

Postoperative care

In the PACU, pain was assessed once every 15 minutes at rest using a numeric rating scale (NRS), where 0 indicates no pain and 10 indicates the worst pain imaginable. Patients with an NRS pain score > 3/10 received intravenous morphine titration using 2-mg boluses administered every 5 minutes until adequate analgesia (NRS ≤ 3/10), according to our standardized institutional PACU nurse-driven protocol and previously published postoperative morphine titration protocols [12]. Patient-controlled analgesia was not routinely used because our enhanced recovery pathway favours supervised PACU morphine titration followed by oral multimodal analgesia on the surgical ward. Patients were discharged from the PACU once they met discharge criteria and had pain scores ≤ 3/10. The analgesic regimen on the surgical ward and on discharge included scheduled doses of paracetamol 1 g orally four times a day, ibuprofen 400 mg orally three times a day and nefopam 20 mg once daily; if the NRS was > 3, patients received either oral morphine (5 or 10 mg) or tramadol (50 or 100 mg).

Nursing personnel assessing pain at rest and on mobilization every 6 hours in the ward were blinded to group allocation. All patient data were collected in the PACU and on postoperative days 1, 7 and 45 (POD#1, POD#7 and POD#45) by a research assistant also blinded to group allocations.

Outcome measures

The primary outcome was total intravenous morphine consumption (mg) during the PACU stay. The trial was initially registered on 10 February 2022, with a broad primary outcome – total opioid consumption over 45 days – which served as a placeholder during the early planning phase. Prior to data analysis and manuscript preparation, and following a methodological review with our statistician, we revised the primary outcome in December 2024 to focus on PACU morphine consumption. This endpoint was chosen for being more specific, objectively measurable, and clinically relevant, aligning with our intraoperative analgesic strategy and allowing for a more standardized and comparable assessment across studies. Importantly, this change was made before any data analysis was performed by an independent statistician (T.G.) located in the United States. The revised endpoint was supported by the original sample size assumptions based on pre-study institutional data; however, the unexpectedly low observed PACU morphine use and resulting floor effect may have reduced the study's ability to detect smaller between-group differences.

The secondary outcome measure was total morphine consumption from PACU discharge to POD#1, expressed in oral morphine equivalents (OME).

Key exploratory outcome measures were postoperative maximum pain scores at rest and during mobilization on POD#1, POD#7 and POD#45. Other exploratory outcome measures were use of different analgesics (paracetamol, nefopam, ibuprofen and oral morphine at POD#1), time to first walk (expressed in hours after the end of the surgery) and hospital length of stay. Patient-reported questionnaires (Oxford Hip Score [OHS], Hip Disability and Osteoarthritis Outcome Score [HOOS] and EuroQol 5-dimension 5-level questionnaire [EQ-5D-5L]) were all measured preoperatively and at POD#45. EQ-5D-5L was also measured on POD#1 and POD#7.

Sample size calculation

The sample size calculation was based on pre-study local institutional data, independent of the present trial dataset, showing a mean PACU intravenous morphine consumption of 7 ± 3.9 mg among patients undergoing THA with surgical infiltration. Although the registered primary outcome was revised before any statistical analysis, the revised endpoint was supported by this pre-existing sample size calculation and was not informed by the observed outcomes of the randomized trial. To detect a clinically meaningful reduction of at least 3 mg (from 7 mg to 4 mg) in PACU intravenous morphine consumption in the PENG group, representing a 42.9% reduction, 28 patients per group were

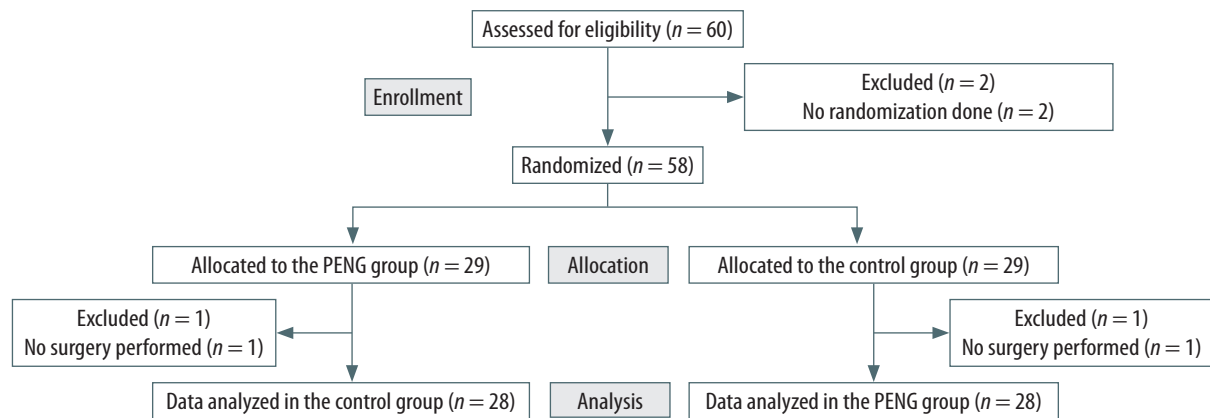


FIGURE 1. CONSORT (Consolidated Standards of Reporting Trials) flow diagram

required to achieve 80% power with a two-sided α level of 0.05. Considering potential dropout, we included 60 patients in total (2 groups of 30 patients each). Importantly, a minimum of 30% difference of OME consumption in the first 24 h after surgery between two different analgesic strategies is usually considered clinically relevant [13] and typically supported as clinically meaningful in publications and regulatory review [14–17].

Statistical analysis

A modified intention-to-treat analysis was performed. The modified intention-to-treat population included all randomized patients who underwent surgery and had available outcome data. Patients who were assessed for eligibility but not randomized, as well as randomized patients who did not undergo surgery and therefore had no postoperative outcome data, were excluded from the analysis. This was defined *a priori* as patients who were either not randomized or did not receive the surgery. In other words, we analysed only randomized patients who underwent hip surgery. Patient variables were expressed as mean (standard deviation [SD]), median (interquartile range [IQR]) or frequency (percentage). Baseline characteristics were compared using standardized mean differences (SMD) [18]. For outcome variables, groups were compared using either the *t*-test or Mann-Whitney *U* test depending on the distribution of the data, which was assessed using the Shapiro-Wilk test. Categorical variables were analysed using a χ^2 test. As the primary outcome was not normally distributed, it was expressed as median (IQR) and compared with a Mann-Whitney *U* test. In order to compute median differences and 95% confidence intervals (CIs) for skewed measures, we estimated the limits from the bootstrap method using the 'confintr' package in R and for binary outcomes utilized Newcombe's method [19]. In our study, PACU morphine consumption and OME at POD#1 were highly skewed. Therefore, bootstrapping

was used to provide more accurate and robust estimates of median differences and 95% CIs, without relying on assumptions of normality that may not hold. This approach is particularly appropriate for skewed clinical outcomes and relatively small sample sizes, as it enhances the reliability of statistical inference under these conditions. For the primary and secondary outcomes, a *P*-value < 0.05 was considered statistically significant. For all exploratory outcomes, we did not apply corrections for multiple comparisons and the *P*-values are shown for designing future trials on this topic. No interim analysis was conducted on the data. Statistical analysis was performed using SAS Studio version 5.2 with R used to estimate bootstrap confidence intervals for median differences.

RESULTS

Of the 60 patients recruited from 2 March 2022 to 9 September 2022, 4 were excluded because they did not receive the surgery and therefore did not have outcome data. A CONSORT flow diagram is shown in Figure 1.

Baseline characteristics of the patients are presented in Table 1. Distributions of patient characteristics between groups were similar at baseline because standardized mean differences ranged from 0.00 to 0.50 with an average of around 0.24, which is generally considered to be a small effect size.

Mean surgical duration (44 ± 8 min vs. 46 ± 10 min, $P = 0.388$) and intraoperative sufentanil consumption (17 ± 8 μ g vs. 15 ± 5 μ g, $P = 0.657$) did not significantly differ between the control and PENG groups, respectively.

Primary outcome

PACU morphine requirements (median [IQR]) did not significantly differ between the control group: 0 (0–6) mg and the PENG group: 0 (0–3) mg, with a median difference of 0 mg, 95% CI: –2 to 4.5, $P = 0.235$ (Table 2, Figure 2).

TABLE 1. Baseline characteristics

Variables	Control (<i>n</i> = 28)	PENG (<i>n</i> = 28)	SMD
Age (year)	65.5 (10.1)	69.9 (12.8)	0.38
Number of patients aged ≥ 70 years old (%)	9 (32.1)	14 (50.0)	0.37
Female sex, <i>n</i> (%)	17 (60.7)	12 (42.9)	0.36
Weight (kg)	79.0 (18.7)	83.2 (22.1)	0.21
Height (cm)	168.5 (9.3)	168.6 (11.2)	0.02
Body mass index (kg m ⁻²)	27.6 (4.7)	28.9 (5.6)	0.25
Number of patients with a BMI > 30, <i>n</i> (%)	9 (32.1)	10 (35.7)	0.08
ASA physical status, <i>n</i> (%)			
ASA physical status I	5 (17.9)	4 (14.3)	0.50
ASA physical status II	18 (64.3)	13 (46.4)	
ASA physical status III	5 (17.9)	11 (39.3)	
Comorbidities, <i>n</i> (%)			
Arterial hypertension	12 (42.9)	17 (60.7)	0.36
Diabetes (any type)	3 (10.7)	3 (10.7)	0
Smoker	8 (28.6)	3 (10.7)	0.46
Anxiety and/or depression	6 (21.4)	6 (21.4)	0
Chronic pain syndrome	1 (3.7)	2 (7.1)	0.15

Values presented as mean (SD) or frequencies (%).

ASA – American Society of Anesthesiologists, BMI – body mass index, PENG – pericapsular nerve group, SD – standard deviation, SMD – standardized mean difference

Secondary outcome

OME use (median [IQR]) at POD#1 was significantly lower in the PENG group: 0 (0–10) mg when compared to the control group: 7 (3–20) mg with a median difference of 7 mg, 95% CI: 0 to 15, $P = 0.040$ (Table 2, Figure 3).

Exploratory outcomes

Apart from non-steroidal anti-inflammatory drug (NSAID) use (79% vs. 46%; $P = 0.013$), the other exploratory outcomes were similar between groups (Table 2). Additionally, patient-reported outcome measures for ongoing hip disability, functional recovery and quality of life did not show any significant differences between groups (Table 3).

DISCUSSION

Contrary to our hypothesis, we found no statistically significant difference in postoperative intravenous morphine use during the PACU stay between patients receiving a PENG block and those receiving only surgical local anaesthetic infiltration. Importantly, opioid requirements were remarkably low in both groups, with a median PACU morphine consumption of 0 mg, indicating that both multimodal analgesic strategies provided excellent early postoperative analgesia. Although total OME consumption through POD#1 was significantly lower in the PENG group, the absolute difference was small and its clinical relevance remains uncertain.

Furthermore, because this was a secondary outcome and no adjustment for multiple comparisons was performed, this finding should be interpreted cautiously. Our results should not be interpreted as evidence against the use of the PENG block. Rather, they suggest that when contemporary multimodal analgesia, including paracetamol, NSAIDs, nefopam, ketamine, and standardized perioperative care, is already implemented, a PENG block used instead of local infiltration may offer little additional opioid-sparing benefit.

Importantly, the PENG group received levobupivacaine combined with dexamethasone and clonidine, a formulation expected to provide a longer duration of analgesia than the ropivacaine-based infiltration used in the control group. In addition, the PENG block was performed before skin incision, whereas surgical infiltration was administered intraoperatively. Both the pharmacological differences and the timing of intervention would be expected to favour the PENG strategy. Despite these potential advantages, no significant reduction was observed in the primary outcome. Accordingly, the present study should be interpreted as a pragmatic comparison of two multimodal analgesic pathways rather than as an explanatory trial evaluating the isolated efficacy of the PENG block. Future trials should standardize local anaesthetic formulations and adjuvants between groups to isolate the independent effect of the block technique.

TABLE 2. Outcome data

Variables	Control (n = 28)	PENG (n = 28)	P-value
Primary outcome			
Intravenous morphine received in the PACU (mg)	0 (0–6)	0 (0–3)	0.235
Secondary outcomes			
Total oral morphine equivalent received at POD#1 (mg)	7 (3–20)	0 (0–10)	0.040
Exploratory outcomes			
In PACU			
Maximal rest pain score	3 [0–6]	2 [0–5]	0.509
Number of patients who required morphine, n (%)	14 (50)	10 (37)	0.333
At POD#1 (from PACU exit to POD#1)			
Rest pain score at POD#1	1 [0–4]	2 [1–5]	0.201
Mobilisation pain score at POD#1	5 [3–7]	3 [2–5]	0.064
Use of acetaminophen	27 (96)	28 (100)	0.999
Acetaminophen dose (g)	2.2 ± 1.1	2.3 ± 1.0	0.704
Use of nefopam	9 (32)	5 (18)	0.217
Nefopam dose (mg)	20 [20–20]	20 [20–20]	0.325
Use of NSAID, n (%)	22 (79)	13 (46)	0.013
Dose of NSAID (mg)	200 [100–200]	200 [200–400]	0.079
Patients receiving oral morphine (%)	5 (18%)	3 (11%)	0.445
Oral morphine dose (????)	3 (3–4)	4 (3–5)	0.393
Tramadol yes no (%)	9 (32.1)	6 (21.4)	0.365
Tramadol dose (????)	100 (100–200)	100 (100–100)	0.607
Any oral morphine or tramadol, n (%)	14 (50)	7 (25)	0.053
At POD#7			
Rest pain score at POD#7	0 [0–2]	0 [0–3]	0.439
Mobility pain score at POD#7	2 [0–4]	2 [0–3]	0.693
At POD#45			
Rest pain score at POD#45	0 [0–0]	0 [0–0]	0.357
Mobility pain score at POD#45	1 [0–4]	1 [0–3]	0.771
Time to first walk (hours) since end of surgery	19 ± 9	15 ± 8	0.165
Length of stay in the hospital	2 [2–2]	2 [2–2]	0.650

Data are expressed as number and (%), or median and [quartiles].

For continuous outcomes, since they were skewed, presented with median (Q1–Q3) and P-value from Mann-Whitney U test and median difference (95% CI) estimated from bootstrap method using the 'ci_median_diff' function in R (package='confintr').

CI – confidence interval, NSAID – non-steroidal anti-inflammatory drug, PACU – post-anaesthesia care unit, PENG – pericapsular nerve group, POD#1, POD#7, POD#45 – postoperative days 1, 7 and 45, Q1, Q3 – first and third quartiles

Our findings complement the existing literature evaluating PENG block for THA. A recent 2024 meta-analysis demonstrated reduced postoperative opioid consumption at 24 and 48 hours in patients receiving PENG blocks when compared to placebo [9], although the certainty of evidence was low because of substantial heterogeneity among studies. More recently, a randomized trial comparing PENG block with high-volume surgical infiltration similarly reported no significant reduction in postoperative morphine consumption [10]. Taken together, these findings suggest that the incremental benefit of PENG block becomes less apparent when effective

multimodal analgesic pathways and surgical local infiltration are routinely employed.

Neither time to first mobilization nor hospital length of stay differed between groups. This finding supports previous reports suggesting that the PENG block is motor-sparing while providing effective analgesia [5–8]. Furthermore, PENG block did not prolong operative time, indicating that the technique can be integrated into routine clinical practice without adversely affecting operating room efficiency.

Importantly, each patient received only one regional/local anaesthetic technique (either PENG

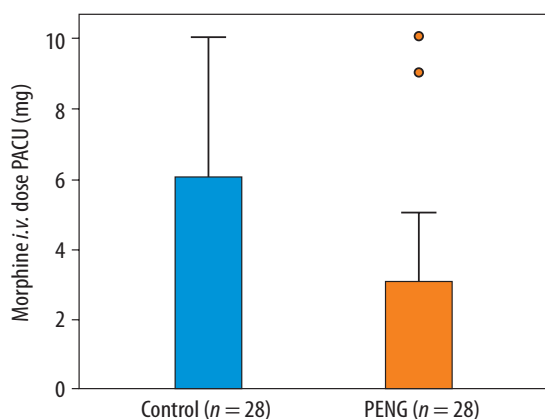


FIGURE 2. Intravenous morphine consumption during the post-anaesthesia care unit (PACU) stay. Boxplots representing the distribution of intravenous morphine consumption in the PACU in the control and pericapsular nerve (PENG) groups. The solid line represents the median value, the box edges represent the first and third quartiles, the whiskers represent the min-max values, the rest representing the more extreme value (outliers)

block or surgical infiltration), while intravenous lidocaine was administered separately as part of the standardized systemic multimodal analgesic regimen. Consequently, the overall local anaesthetic exposure remained within routinely accepted clinical dosing limits, and no cases of local anaesthetic systemic toxicity were observed.

A strength of this study is that all THA procedures were performed via an anterior approach and by the same surgeon, ensuring standardization of the surgical technique. The anterior hip capsule is innervated by the articular sensory branches of the femoral, obturator and accessory obturator nerves. These nerves are all targeted by a PENG block. A limitation of many other studies on this topic is that a posterolateral surgical approach was chosen. The posterior hip joint receives innervation from branches of the sciatic nerve, superior gluteal nerve and nerve to quadratus femoris, which would not be targeted by a PENG block and may have contributed to their negative findings [20]. The study was conducted in a private hospital which helped to standardize the patient experience.

We acknowledge that the study has some limitations. First, the primary outcome was revised before any statistical analyses were performed, although the revised endpoint and sample size calculation were both based on pre-existing institutional data. A separate follow-up study is planned to evaluate long-term opioid use at 45 days. While this change could introduce a risk of bias, we believe this concern is mitigated by the fact that the present study yielded a neutral result for the primary outcome, with no significant difference between groups. This minimizes the likelihood of selective outcome reporting influencing the study's conclusions. Second,

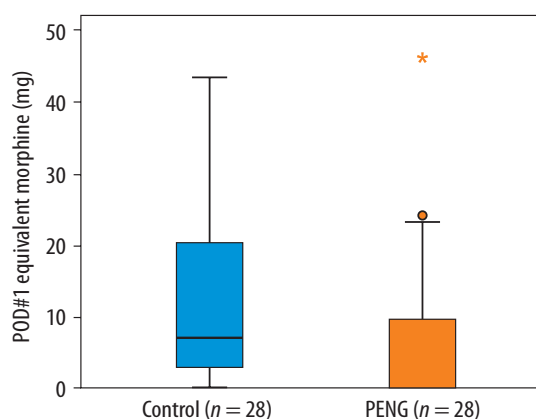


FIGURE 3. Oral morphine equivalents at postoperative day 1 (POD#1). Boxplots representing the distribution of oral morphine equivalents at POD#1 in the control and pericapsular nerve (PENG) groups. The solid line represents the median value, the box edges represent the first and third quartiles, the whiskers represent the min-max values, the rest representing the more extreme value (outliers)

TABLE 3. Patient-reported outcome measures for ongoing hip disability, functional recovery and quality of life between groups

Variables	Control (n = 28)	PENG (n = 28)	P-value
Preoperative			
EQ-5D-5L	54 ± 16	53 ± 20	0.944
HOOOS score	37 ± 15	32 ± 13	0.137
Oxford score	17 ± 8	15 ± 8	0.364
Postoperative day 1			
EQ-5D-5L	70 ± 17	66 ± 22	0.702
Postoperative day 7			
EQ-5D-5L	76 ± 14	70 ± 18	0.216
Postoperative day 45			
EQ-5D-5L	74 ± 21	78 ± 18	0.519
HOOOS score	74 ± 20	80 ± 17	0.318
Oxford score	33 ± 11	37 ± 9	0.124

EQ-5D-5L – EuroQol 5-dimension 5-level questionnaire, HOOOS – Hip Disability and Osteoarthritis Outcome Score, PENG – pericapsular nerve group

the study was not double-blinded, although the primary endpoint was objective and assessed using a standardized PACU opioid-titration protocol while patients and outcome assessors remained blinded. However, it was impractical to perform this strategy in our private practice clinic where turnover should be quick and efficient. Third, postoperative opioid consumption beyond POD#1 was not evaluated and remains the subject of an ongoing ancillary study. The ongoing use of prescription opioids after surgery is a risk factor for chronic opioid use [14]. Fourth, all secondary and exploratory outcomes should be considered hypothesis-generating for designing future trials on the topic. Fifth, differences in the timing of analgesic techniques (preopera-

tive PENG vs intraoperative infiltration) and non-standardized local anaesthetic formulations and doses across groups exist. These factors may have altered intraoperative anaesthetic requirements and the duration and density of analgesia, potentially influencing early pain and rescue-analgesia outcomes. Local anaesthetic formulations and doses were not standardized between arms: the PENG group received levobupivacaine with dexamethasone and clonidine, whereas the infiltration group received ropivacaine with epinephrine and clonidine. Levobupivacaine is slightly more potent and may have a longer sensory duration than ropivacaine, and perineural dexamethasone can prolong block duration, whereas epinephrine primarily acts via local vasoconstriction. These pharmacological differences may have produced unequal analgesic duration and intensity, potentially biasing the comparison in favour of the PENG group. Nevertheless, no significant difference was observed for the primary outcome, suggesting that this potential source of bias is unlikely to have altered the main study conclusion. The findings should therefore be interpreted as reflecting the comparative effectiveness of two multimodal analgesic regimens, rather than the independent analgesic effect of the PENG block. Future trials should standardize both the timing of analgesic interventions and local anaesthetic formulations to better isolate the independent contribution of the PENG technique. Sixth, postoperative NSAID administration was more frequent in the control group (79% vs. 46%), a difference that would be expected to reduce opioid requirements in the control arm and bias the comparison towards the null. Given the well-established opioid-sparing effects of NSAIDs, this imbalance would be expected to reduce postoperative opioid requirements in the control group, thereby biasing the comparison towards the null hypothesis and potentially underestimating any true treatment effect of the PENG strategy. Seventh, this pragmatic randomized trial intentionally included patients representative of routine clinical practice; therefore, common comorbidities such as diabetes, chronic pain syndrome, and anxiety/depression were not considered exclusion criteria. These characteristics were well balanced between groups through randomization. However, the present pilot study was not powered to evaluate whether these conditions modify the analgesic response to either strategy. Future larger trials could explore potential treatment-effect heterogeneity in these clinically relevant subgroups. Finally, postoperative opioid requirements were substantially lower than anticipated, resulting in a marked floor effect with a median PACU morphine consumption of 0 mg in both groups. Consequently, although no

significant difference was observed for the primary outcome, the study may have been underpowered to detect modest but clinically meaningful differences. These findings should therefore be considered pilot data that provide contemporary estimates of opioid requirements after anterior THA and may inform the design and sample size calculation of future adequately powered multicentre randomized trials.

CONCLUSIONS

Replacing surgical local infiltration with a PENG block in a contemporary multimodal analgesic regimen for anterior THA did not reduce postoperative intravenous morphine consumption during the PACU stay. Although total opioid consumption through POD#1 was lower in the PENG group, the absolute clinical benefit was modest and should be interpreted cautiously. Importantly, both analgesic strategies achieved excellent postoperative analgesia with very low opioid requirements. These findings suggest that the opioid-sparing benefit of a PENG block over surgical local infiltration may be limited when effective multimodal analgesia is routinely employed. Future adequately powered multicentre randomized trials are warranted to confirm these findings.

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