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Original Article

Analgesic efficacy and safety of transversus abdominis plane block versus thoracic paravertebral block in laparoscopic total hysterectomy: propensity score matching and mFI-5 subgroup analysis

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Abstract: Objective: The analgesic efficacy and safety of transversus abdominis plane block (TAPB) and thoracic paravertebral block (TPVB) were compared following laparoscopic total hysterectomy (LTH), and whether their treatment effects differ by frailty level was also examined. Methods: From January 2019 to January 2024, an enrolled population of 368 consecutive patients who underwent laparoscopic total hysterectomy was analyzed. Out of 368 patients, 200 patients received TAPB and 168 patients received TPVB. We used propensity score matching to control for baseline confounders, analysed between-group differences in baseline confounders, and in the outcome measure, i.e. 30-day postoperative complication rate. The main outcomes were NRS pain scores and 24-hour sufentanil consumption at 6, 12, and 24 hours post-operatively. Ramsay sedation scores, time to first demand for patient-controlled analgesia (PCA), surgical factors, and adverse events were secondary outcomes. An mFI-5-stratified subgroup interaction analysis was done to evaluate effect robustness across different levels of frailty. Results: PSM yielded 161 matched pairs. Compared to TAPB, TPVB showed significantly lower NRS scores at all postoperative time points (all P<0.001), but higher 24-hour sufentanil consumption (21.50 vs 19.30 μg, P<0.001). Patients in the TPVB group experienced significantly higher incidence of nausea, vomiting, and dizziness. There was no difference in time to first PCA demand (P=0.325). The treatment effects were similar irrespective of frailty level. Conclusion: In laparoscopic total hysterectomy, TPVB proved to be more effective than TAPB in controlling postoperative pain, but it required more opioids and was associated with a higher incidence of nausea, vomiting, and dizziness. Safety for all degrees of frailty remained acceptable.

Keywords: Transversus abdominis plane block, thoracic paravertebral block, laparoscopic hysterectomy, postoperative analgesia, propensity score matching

Introduction

Laparoscopic total hysterectomy is now a standard minimally invasive procedure for benign gynecological conditions. Even though the cuts are smaller and patients recover faster now, the pain after surgery is still quite significant. Research indicates that 72% of patients experience moderate pain intensity (NRS>4) [1], while 6 months post-operatively 26.0% still have pelvic pain [2]. Another 32% meet criteria for persistent postsurgical pain at 12 weeks [3]. The pain hampers early mobilization, effective coughing, and oral intake, and causes more opioid use. Opioid application in gynecologic surgery leads to a rate of 23.8% for vomiting and 51.3% for nausea in postoperative nausea and vomiting [4]. Further, it increases the risk of any complication associated with opioid and jeopardizes ERAS. In frail patients, these problems become even more important. This is because these patients are more likely to experience

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postoperative complications, a decline in function, and a prolonged hospital stay. These patients also cannot tolerate opioid-related bad effects very well. Thus, this vulnerable cohort would benefit enormously from the optimization of local anaesthetic strategies. These local strategies are capable of providing effective pain relief. Moreover, these strategies would provide effective pain relief with less systemic exposure to opioids.

Regional anesthesia is a fundamental component of multimodal analgesia. This technique can enhance pain control and decrease the necessity for opioids, which is why it is widely used. TAPB specifically disables sensory afferents in the anterolateral abdominal wall (T6-L1) to provide dependable somatic pain control [5]. TPVB affects the ventral rami and sympathetic-afferent nerves at the same thoracic level. Theoretically, it covers the somatic pain pathways and part of the visceral pain pathways and can give more extensive analgesia [6]. Nonetheless, it is uncertain how superior they are in laparoscopic hysterectomy groups. Studies of high quality have not reached a consensus on effects and safety profiles of opioid sparing, leaving this choice to clinical practice.

Numerous studies inadequately control essential confounders, such as age, menopausal state, baseline frailty, and ASA classification, which diminishes the trustworthiness of group comparisons [7]. In practice, blocks often reflect patient characteristics and provider preferences, leading to greater selection bias. If a study is not properly designed and statistically corrected, baseline imbalances may distort study conclusions instead of effect. Patients with different levels of frailty, measurable by the mFI-5, may experience different benefits and risks from regional blocks, yet very few studies conduct any stratifying or interaction analyses to fill this evidence gap [8, 9].

In view of these problems, this study was planned to compare analgesic efficacy and safety of TAPB versus TPVB in patients undergoing laparoscopic total hysterectomy. Our primary outcome measures were pain scores at different timepoints post operatively and total 24-hour opioid consumption. Moreover, we studied the effects of these scores on postoperative adverse events. We hypothesized that TPVB would lead to lower postoperative pain intensity and lesser opioid use than TAPB with minimal anesthesia-related adverse events. Our additional hypothesis was that frailty levels (mFI-5 strata) will not alter these effects.

This study innovates by using propensity score matching (PSM) to control the baseline differences for both groups, thus minimising the selection bias. Moreover, the modified frailty index-5 (mFI-5) was introduced for subgroup analysis to assess analgesic efficacy and safety across frailty levels, which is a rare feature in the existing literature. Compared to many studies just measuring pain scores or opioid use, our study takes a holistic approach to evaluation. It assesses not only pain scores and opioid use, but also side effects such as nausea, vomiting, or dizziness. A multifactorial model gives a better understanding of treatment effects. Additionally, the study places importance on creating a balance between postoperative pain management strategies and clinical data that allows for the right conclusion. Through these innovations, our study improves the clinical decision-making process and offers more precise recommendations for optimizing anesthesia techniques in laparoscopic total hysterectomy.

Materials and methods

Sample size calculation

This retrospective study drew sample size from consecutive cases available, without prospective sample size estimation. To evaluate statistical power, we conducted post hoc power analysis based on primary outcomes. Referencing Desai et al [10] on ultrasound-guided TAPB for laparoscopic gynecologic surgery, which reported 2-hour postoperative NRS scores of 5±2.5 and considered a 2-point reduction (40%) clinically meaningful, calculations using effect size 0.80, two-sided α=0.05, and 90% power suggested 33 patients per group. With two-sided α=0.05 and 80% power, given variance levels in our cohort, current sample size (TAPB 200, TPVB 168; 161 per group post-PSM) could detect small to medium effect differences in 6/12/24-hour NRS scores and 24-hour sufentanil consumption.

Sample source and ethics

We retrospectively included 368 consecutive patients who underwent laparoscopic total hys-

terectomy under general anesthesia at West China Second University Hospital and The People's Hospital of Rugao from January 2019 to January 2024. Patients were grouped by postoperative analgesic block method: TAPB group (n=200) received ultrasound-guided bilateral TAPB after anesthesia induction, while TPVB group (n=168) received ultrasound-guided bilateral paravertebral blocks at T4-T6 levels after induction. The study followed the Declaration of Helsinki [11]. This study has been approved by The People's Hospital of Rugao Ethics Committee. Since this involved retrospective, de-identified data analysis, the ethics committee waived written informed consent.

Inclusion and exclusion criteria

Inclusion criteria: age ≥18 years; scheduled for laparoscopic total hysterectomy; received TAPB or TPVB as regional analgesia; complete perioperative key data available. Exclusion criteria: conversion to laparotomy; concurrent other major regional blocks affecting comparison (such as epidural or rectus sheath blocks); history of local anesthetic allergy; decompensated cardiac, hepatic, or renal insufficiency; perioperative reoperation or life-threatening events; missing key outcomes or substantially incomplete records.

Anesthesia protocol

Preoperative preparation: Before surgery, patients did not eat for 8 hours and drink for 4 hours. We placed routine monitoring on the ECG, NIBP, SpO_2, $EtCO_2$, and temperature after intubation in the operation theatre. If necessary, other invasive monitoring such as arterial line or BIS monitoring were added. Patients were induced with sufentanil (0.3 μg/kg), etomidate (0.3 mg/kg), and cisatracurium (0.2 mg/kg) for general anesthesia. After the successful endotracheal intubation, the mechanical ventilation was started, and the maintenance of anesthesia was performed with propofol (4-8 mg·kg-1·h-1) and remifentanil (0.05-2 μg·kg-1·min-1). Extra muscle relaxants and fluids were given as required.

Regional block procedures: After induction, the regional blocks were performed under ultrasound guidance as follows: Bilateral TAPB was done by identifying the plane between the transversus abdominis and internal oblique muscles at the level of the subcostal margin (generally between T 10 and L 1) in real-time ultrasound. The needle was inserted in the mid-axillary line under the guidance of ultrasound to inject local anesthetic into the transversus abdominis plane. A total of 30 mL ropivacaine (0.375%) was injected with a divided dose (15 mL on each side), given slowly to avoid inadvertent intravascular injection. In the transverse plane, the transversus abdominis and internal oblique muscles were distinctly visualized while the needle tip was placed between the two muscle layers. Using a posterior approach, bilateral TPVB was performed in T4-T6 levels targeting the paravertebral space. The needle was inserted at the level of the spinous process using real-time ultrasound to visualize the paravertebral space and position the local anesthetic next to the thoracic nerve roots. Ultrasound-guided verification of spread was confirmed after which a total of 20 mL (10 mL per side) of ropivacaine (0.375%) was injected at each level. The aim of this technique was to obtain adequate nerve block without exceeding the safe dose. By locating the transverse processes of thoracic vertebrae, the paravertebral space was identified. The needle was inserted on the skin at about 45-degree angle towards the paravertebral space and local anaesthetic spread was confirmed under real time ultrasound. In both groups, total dosing of ropivacaine was closely regulated to prevent toxicity and monitoring of spread during injection was done. Flexible injections were used to guarantee the traditional anesthetic was evenly distributed across the required nerves.

Postoperative pain management: Postoperative pain management recorded with PCA sufentanil mainly used. The PCA system was programmed with the following parameters Demand Dose 0.05 mg per demand. Rewording of Lockout Interval: 10 minutes to avoid overdose. No background infusion was utilized to restrict opioid consumption the only doses delivered were the demand doses with subsequent requests made for additional doses. As per their protocols, either a bolus dose of sufentanil administered by IV or any other rescue analgesics was given if NRS pain scores exceeded 4 or otherwise pain was inadequately controlled. Specifically, as part of the postoperative instructions, 5-HT3 receptor antagonists (for instance, ondansetron) and glucocorticoids were

given based on stratification for the prevention of postoperative nausea and vomiting (PONV). This helped us prevent opioid consumption by locking them out for a certain time period, which helped the patients have better access to pain relief and enhanced recovery with early mobilization after surgery.

Postoperative care and monitoring: Prior to the procedure, prophylactic antibiotics were given half an hour before the procedure, as a routine care. Ultrasound guidance was used throughout the duration of regional block procedures for the correct placement of local anaesthetic and checking of spread and toxicity. All complications were resolved in line with SOPs. Vasopressors and fluid volume optimization were given for hypotension issues. The 20% lipid emulsion protocol was used immediately against local anesthetic toxicity. Specific monitoring was done for pnuemothorax, epidural spread and hypotension due to sympathetic block in TPVB group. The ERAS goal overall was to ensure optimal analgesia, minimize opioid requirement, reduce adverse events, and facilitate early mobilization and recovery.

Clinical data collection

Two researchers independently extracted hospital electronic medical record data, anesthesia information system data, nursing record data, and follow-up documentation data. Cross verification was done. We gathered baseline characteristics such as age, BMI, ASA classification [12], disease type, smoking history, alcohol consumption, years of education, menopausal status, mFI-5, and preoperative hemoglobin status. The 5-factor modified frailty index (mFI-5) was used to measure frailty. One point is assigned for each of five comorbid or functional deficits (diabetes mellitus, chronic obstructive pulmonary disease, congestive heart failure, hypertension requiring treatment, and a partially or totally dependent functional status). Therefore, the total score lies between 0 and 5, with higher scores indicating increased frailty. In this study, mFI-5 ≥2 was defined as frail. Preoperative hemoglobin (Hb) value was defined as the last laboratory value assessed by the laboratory in less than seven days preceding surgery, and Hb<110 was considered anemia. Data recorded as perioperative were operative time, blood loss intraoperatively, volume of fluid infusion intraoperatively, block procedure time of analgesia in postoperative, and available PCA to prescribe. The postoperative outcomes incorporated NRS scores [13] and Ramsay scores [14] at 6 h, 12 h, and 24 h after surgery, 24 h sufentanil consumption, time to first PCA demand, and adverse events (nausea, vomiting, dizziness, abdominal distension and cognitive dysfunction).

Laboratory testing

Laboratory parameters included complete blood count (Hb, WBC, PLT), biochemistry (creatinine, ALT, AST, glucose, electrolytes), and when applicable, inflammatory markers (CRP). Complete blood counts were measured by Sysmex XN-1000 automated hematology analyzer (Sysmex Corporation, Kobe, Japan); biochemical values by Roche Cobas c702 automated chemistry analyzer (Roche Diagnostics GmbH, Mannheim, Germany); immunological values including CRP by Abbott Architect i2000SR chemiluminescence analyzer (Abbott Diagnostics, Abbott Park, IL, USA). All tests followed manufacturer instructions and our laboratory's standard operating procedures for daily quality control and calibration.

Outcome measures

Primary outcomes: NRS scores at 6, 12, and 24 hours postoperatively; cumulative 24-hour sufentanil consumption. Secondary outcomes: time to first PCA demand; Ramsay scores (preoperative, 6, 12, 24 hours postoperatively); surgical duration, intraoperative blood loss, intraoperative fluid volume, block procedure time (for postoperative analgesia); adverse events (nausea, vomiting, dizziness, abdominal distension, cognitive dysfunction).

Statistical analysis

Statistical analysis used R 4.5.1 (R Foundation for Statistical Computing). Normally distributed continuous variables were presented as mean ± standard deviation and compared using independent samples t-tests; non-normally distributed variables were presented as median (interquartile range) and compared using Mann-Whitney U tests. Categorical variables were presented as frequencies (percentages) and compared using chi-square or Fisher's exact tests. PSM used block method as dependent variable, with covariates including age, BMI, ASA classification, disease type, smoking history,

alcohol consumption, menopausal status, education years, mFI-5, and preoperative Hb<110 g/L. Propensity scores were estimated by logistic regression, with 1:1 nearest neighbor matching using caliper width of 0.2 × standard deviation of logit, evaluated by standardized mean difference (|SMD|<0.1). Post-matching comparisons primarily used paired methods (paired t-test, paired rank-sum test, McNemar's test, or conditional logistic regression), with sensitivity analysis via generalized linear models (GLM) with robust variance. Primary endpoints were pre-specified as NRS scores (6, 12, 24 hours postoperatively) and 24-hour sufentanil consumption; others were secondary or exploratory endpoints. No formal correction was made for multiple endpoints, with conservative interpretation; Benjamini-Hochberg method was applied as sensitivity analysis when controlling false discovery rate was needed. When the missing data proportion was <5%, complete case analysis was used; when it exceeded multiple imputation (m=20) then pooled inference was done. All tests were two-tailed with significance level P<0.05.

Results

Comparison of baseline characteristics between TAPB and TPVB

This study made an analysis of the baseline characteristics of TAPB and TPVB patients. The groups differed significantly in age (P=0.013), menopausal status (P=0.032), and mFI-5 (P=0.004). Specifically, TPVB group had a higher proportion of patients ≥45 years (61.9%) compared to the TAPB group (49.0%, P=0.013); TPVB group had more postmenopausal patients (51.2%) versus the TAPB group (40.0%, P=0.032); the TPVB group showed a higher proportion with mFI-5≥2 (63.1%) compared with the TAPB group (48.0%, P=0.004). For BMI, ASA classification, disease type, smoking history, alcohol consumption, education years, and preoperative Hb<110 g/L, no significant differences existed between groups (P>0.05) (**Table 1**).

Comparison of surgical duration, intraoperative blood loss, fluid volume, and block procedure time between TAPB and TPVB

This study analyzed surgical duration, intraoperative blood loss, fluid volume, and postoperative analgesic block procedure time between TAPB and TPVB groups. Results showed no significant differences in surgical duration (P=0.876), intraoperative blood loss (P=0.266), or fluid volume (P=0.447). However, postoperative analgesic block procedure time differed significantly (P<0.001), with TPVB requiring longer duration (**Table 2**).

Comparison of 24-hour sufentanil consumption and time to first PCA demand between TAPB and TPVB

This study analyzed 24-hour sufentanil consumption and time to first PCA demand between TAPB and TPVB groups. Results showed significant difference in 24-hour sufentanil consumption (P<0.001), with the TPVB group consuming significantly more than the TAPB group (**Table 3**). However, time to first PCA demand showed no significant difference (P=0.910) (**Table 3**).

Comparison of postoperative scores between TAPB and TPVB

This study analyzed NRS and Ramsay scores at preoperative and various postoperative timepoints between TAPB and TPVB groups. NRS scores at 6, 12, and 24 hours postoperatively differed significantly (P<0.001), with TPVB showing markedly lower pain scores than TAPB (**Table 4**). Preoperative NRS scores showed no significant difference (P=0.484) (**Table 4**). Ramsay scores at 6 and 12 hours postoperatively also differed significantly (P<0.001), with TPVB showing lower scores, while 24-hour scores showed no significant difference (P=0.467) (**Table 4**).

Comparison of postoperative adverse events between TAPB and TPVB

The TPVB group showed a higher incidence of nausea and vomiting than the TAPB group (nausea: P=0.010; vomiting: P=0.020). Dizziness, abdominal distension, and cognitive dysfunction showed no statistical differences between groups (dizziness: P=0.061; abdominal distension: P=0.680; cognitive dysfunction: P=0.118) (**Table 5**).

Comparison of covariate balance before and after PSM between TAPB and TPVB

Figure 1 displays changes in covariate balance after propensity score matching (PSM) between

Table 1. Comparison of baseline characteristics between TAPB and TPVB in patients undergoing laparoscopic total hysterectomy

Factor	Total	TAPB (n=200)	TPVB (n=168)	Test Statistic	*P*-value	OR (95% CI)
Age				6.141	0.013	
≥45	202 (54.9%)	98 (49.0%)	104 (61.9%)			1.691 (1.115-2.566)
<45	166 (45.1%)	102 (51.0%)	64 (38.1%)			
BMI				0.32	0.572	
≥23	211 (57.3%)	112 (56.0%)	99 (58.9%)			1.127 (0.744-1.708)
<23	157 (42.7%)	88 (44.0%)	69 (41.1%)			
ASA Classification				0.143	0.705	
I	191 (51.9%)	102 (51.0%)	89 (53.0%)			1.082 (0.718-1.632)
II	177 (48.1%)	98 (49.0%)	79 (47.0%)			
Disease Type				0.66	0.719	
Uterine Fibroids	196 (53.3%)	110 (55.0%)	86 (51.2%)			Reference
Adenomyosis	71 (19.3%)	36 (18.0%)	35 (20.8%)			0.804 (0.467-1.386)
Other	101 (27.4%)	54 (27.0%)	47 (28.0%)			0.898 (0.555-1.455)
Smoking History				0.273	0.601	
Yes	52 (14.1%)	30 (15.0%)	22 (13.1%)			0.854 (0.472-1.545)
No	316 (85.9%)	170 (85.0%)	146 (86.9%)			
Alcohol Consumption				1.577	0.209	
Yes	36 (9.8%)	16 (8.0%)	20 (11.9%)			1.554 (0.778-3.105)
No	332 (90.2%)	184 (92.0%)	148 (88.1%)			
Menopausal Status				4.618	0.032	
Yes	166 (45.1%)	80 (40.0%)	86 (51.2%)			1.573 (1.040-2.380)
No	202 (54.9%)	120 (60.0%)	82 (48.8%)			
Education Years				0.925	0.336	
≥12 years	229 (62.2%)	120 (60.0%)	109 (64.9%)			1.232 (0.805-1.883)
<12 years	139 (37.8%)	80 (40.0%)	59 (35.1%)			
mFI-5				8.402	0.004	
≥2	202 (54.9%)	96 (48.0%)	106 (63.1%)			1.852 (1.219-2.815)
<2	166 (45.1%)	104 (52.0%)	62 (36.9%)			
Preoperative Hb<110 g/L				0.273	0.601	
Yes	52 (14.1%)	30 (15.0%)	22 (13.1%)			0.854 (0.472-1.545)
No	316 (85.9%)	170 (85.0%)	146 (86.9%)			

Note: TAPB: Transversus abdominis plane block, TPVB: thoracic paravertebral block, mFI-5: modified frailty index-5, BMI: body mass index, ASA: American Society of Anesthesiologists classification, Hb: hemoglobin.

Table 2. Comparison of surgical duration, intraoperative blood loss, fluid volume, and postoperative analgesic block procedure time between TAPB and TPVB

Factor	Total	TAPB (n=200)	TPVB (n=168)	Test Statistic	*P*-value
Surgical Duration (min)	97.00 (80.00, 114.25)	96.50 (81.00, 113.00)	97.00 (79.75, 115.00)	-0.156	0.876
Intraoperative Blood Loss (mL)	64.64±9.75	64.12±10.32	65.26±9.01	1.115	0.266
Intraoperative Fluid Volume (mL)	1197.99±155.71	1192.32±147.61	1204.74±165.02	0.762	0.447
Postoperative Analgesic Block Procedure Time (min)	27.00 (20.00, 34.00)	21.00 (17.00, 25.00)	35.00 (31.00, 39.00)	-15.275	<0.001

Note: TAPB: Transversus abdominis plane block, TPVB: thoracic paravertebral block.

the TAPB and TPVB groups. **Figure 1A** shows standardized mean differences of covariates before and after matching. Before matching, TAPB and TPVB groups showed substantial differences in multiple covariates (such as age and menopausal status), with large standardized mean differences. After matching, all covariate standardized mean differences

Table 3. Comparison of 24-hour sufentanil consumption and time to first PCA demand between TAPB and TPVB

Factor	Total	TAPB (n=200)	TPVB (n=168)	Test Statistic	*P*-value
24-Hour Sufentanil Consumption (μg)	20.45 (18.30, 22.60)	19.30 (17.70, 21.10)	21.45 (19.80, 23.42)	6.611	<0.001
Time to First PCA Demand (h)	8.00 (7.00, 9.00)	8.00 (7.00, 9.00)	8.00 (7.00, 9.00)	<0.001	0.91

Note: TAPB: Transversus abdominis plane block, TPVB: thoracic paravertebral block.

Table 4. Comparison of postoperative scores between TAPB and TPVB

Factor	Total	TAPB (n=200)	TPVB (n=168)	Test Statistic	*P*-value
Preoperative NRS	1.00 (1.00, 2.00)	1.00 (1.00, 2.00)	1.00 (1.00, 2.00)	0.701	0.484
6 h Postoperative NRS	3.00 (3.00, 4.00)	4.00 (3.00, 4.00)	3.00 (2.00, 3.00)	-8.616	0.001
12 h Postoperative NRS	3.00 (2.00, 4.00)	3.00 (2.00, 4.00)	2.00 (2.00, 3.00)	-7.078	0.001
24 h Postoperative NRS	3.00 (2.00, 3.00)	3.00 (2.00, 3.00)	2.00 (2.00, 3.00)	-5.572	0.001
Preoperative Ramsay	2.00 (2.00, 2.00)	2.00 (2.00, 2.00)	2.00 (2.00, 2.00)	0.978	0.328
6 h Postoperative Ramsay	3.00 (2.00, 3.00)	3.00 (3.00, 3.00)	3.00 (2.00, 3.00)	-4.063	<0.001
12 h Postoperative Ramsay	3.00 (2.00, 3.00)	3.00 (3.00, 3.00)	3.00 (2.00, 3.00)	-3.554	<0.001
24 h Postoperative Ramsay	2.00 (2.00, 3.00)	2.00 (2.00, 3.00)	2.00 (2.00, 3.00)	0.727	0.467

Note: Pain was assessed using the Numerical Rating Scale (NRS, 0-10; 0= no pain, 10= worst imaginable pain), and sedation was assessed using the Ramsay sedation scale (1-6; higher scores indicate deeper sedation).

Table 5. Comparison of postoperative adverse events between TAPB and TPVB

Factor	Total	TAPB (n=200)	TPVB (n=168)	Test Statistic	*P*-value
Nausea				6.658	0.01
Yes	31 (8.4%)	10 (5.0%)	21 (12.5%)		
No	337 (91.6%)	190 (95.0%)	147 (87.5%)		
Vomiting				5.385	0.02
Yes	18 (4.9%)	5 (2.5%)	13 (7.7%)		
No	350 (95.1%)	195 (97.5%)	155 (92.3%)		
Dizziness				3.519	0.061
Yes	27 (7.3%)	10 (5.0%)	17 (10.1%)		
No	341 (92.7%)	190 (95.0%)	151 (89.9%)		
Abdominal Distension				0.17	0.68
Yes	9 (2.4%)	6 (3.0%)	3 (1.8%)		
No	359 (97.6%)	194 (97.0%)	165 (98.2%)		
Cognitive Dysfunction				2.448	0.118
Yes	31 (8.4%)	21 (10.5%)	10 (6.0%)		
No	337 (91.6%)	179 (89.5%)	158 (94.0%)		

Note: OR: Odds ratio, CI: confidence interval.

decreased to the preset acceptable range (absolute SMD<0.1), indicating PSM significantly reduced baseline differences between groups. **Figure 1B** shows propensity score density distributions before and after matching: pre-matching distributions differed between groups, while post-matching distributions became consistent.

Comparison of baseline characteristics between TAPB and TPVB after PSM

This study compared baseline characteristics between TAPB and TPVB groups after propensity score matching (PSM). Results showed no statistical differences between groups for age (P=1.000), BMI (P=0.500), ASA classification

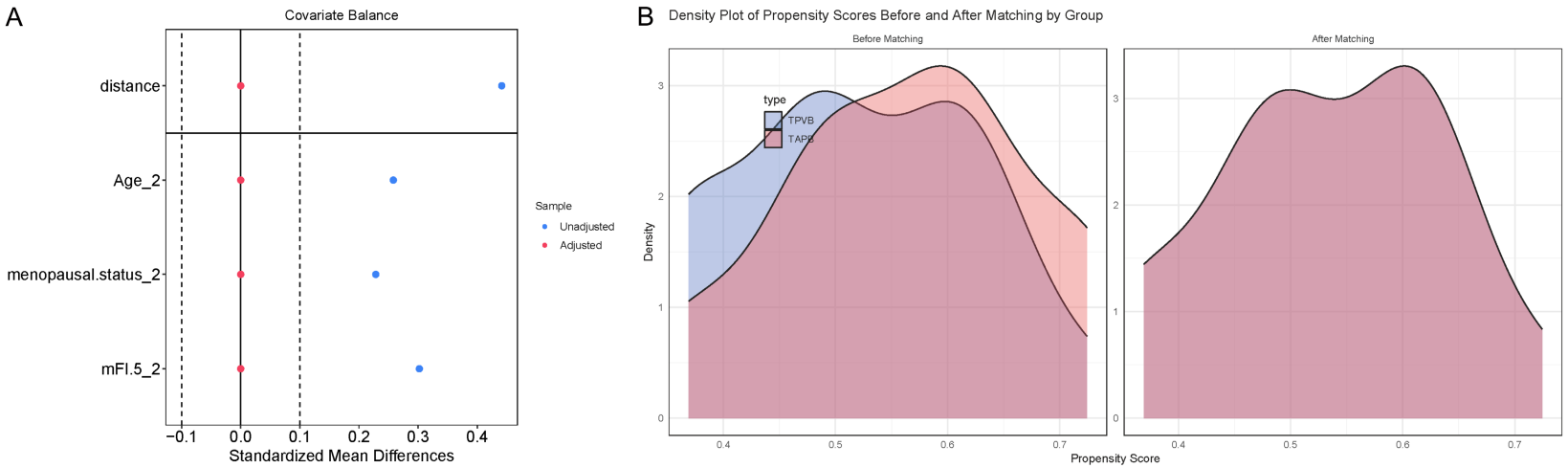

Figure 1. Covariate balance before and after propensity score matching between TAPB and TPVB. A: Standardized mean difference plot showing covariate balance (such as age, menopausal status) before and after matching. B: Propensity score density plot and Q-Q plot displaying propensity score distribution changes between the two groups before and after matching. Note: TAPB: Transversus abdominis plane block, TPVB: thoracic paravertebral block.

Table 6. Comparison of baseline characteristics between TAPB and TPVB after PSM

Factor	Total	TAPB (n=161)	TPVB (n=161)	Test Statistic	*P*-value	OR (95% CI)
Age				<0.001	1	
≥45	196 (60.9%)	98 (60.9%)	98 (60.9%)			1.000 (0.639-1.565)
<45	126 (39.1%)	63 (39.1%)	63 (39.1%)			
BMI				0.455	0.5	
≥23	182 (56.5%)	88 (54.7%)	94 (58.4%)			1.164 (0.749-1.809)
<23	140 (43.5%)	73 (45.3%)	67 (41.6%)			
ASA Classification				0.05	0.823	
I	168 (52.2%)	83 (51.6%)	85 (52.8%)			1.051 (0.679-1.628)
II	154 (47.8%)	78 (48.4%)	76 (47.2%)			
Disease Type				1.638	0.441	Reference
Uterine Fibroids	174 (54.0%)	90 (55.9%)	84 (52.2%)			0.693 (0.385-1.248)
Adenomyosis	61 (18.9%)	26 (16.1%)	35 (21.7%)			1.000 (0.597-1.674)
Other	87 (27.0%)	45 (28.0%)	42 (26.1%)			
Smoking History				0.101	0.75	
Yes	46 (14.3%)	24 (14.9%)	22 (13.7%)			0.903 (0.484-1.688)
No	276 (85.7%)	137 (85.1%)	139 (86.3%)			
Alcohol Consumption				1.749	0.186	
Yes	31 (9.6%)	12 (7.5%)	19 (11.8%)			1.661 (0.778-3.547)
No	291 (90.4%)	149 (92.5%)	142 (88.2%)			
Menopausal Status				<0.001	1	
Yes	160 (49.7%)	80 (49.7%)	80 (49.7%)			1.000 (0.646-1.548)
No	162 (50.3%)	81 (50.3%)	81 (50.3%)			
Education Years				1.304	0.254	
≥12 years	196 (60.9%)	93 (57.8%)	103 (64.0%)			1.298 (0.829-2.034)
<12 years	126 (39.1%)	68 (42.2%)	58 (36.0%)			
mFI-5				2.848	0.091	
≥2	183 (56.8%)	84 (52.2%)	99 (61.5%)			1.464 (0.940-2.280)
<2	139 (43.2%)	77 (47.8%)	62 (38.5%)			
Preoperative Hb<110 g/L				<0.001	1	
Yes	196 (60.9%)	98 (60.9%)	98 (60.9%)			1.000 (0.639-1.565)
No	126 (39.1%)	63 (39.1%)	63 (39.1%)			

Note: TAPB: Transversus abdominis plane block, TPVB: thoracic paravertebral block, mFI-5: modified frailty index-5, BMI: body mass index, ASA: American Society of Anesthesiologists classification, Hb: hemoglobin.

(P=0.823), disease type (P=0.441), smoking history (P=0.750), alcohol consumption (P=0.186), menopausal status (P=1.000), education years (P=0.254), mFI-5 (P=0.091), or preoperative Hb<110 g/L (P=1.000) (all P>0.05). Age, menopausal status, and preoperative Hb stratification distributions were completely identical between groups (these variables P=1.000); mFI-5 proportion was slightly higher in TPVB group but not statistically significant (P=0.091). Baseline characteristics achieved good balance between groups after PSM (**Table 6**).

Comparison of surgical duration, intraoperative blood loss, fluid volume, and block procedure time between TAPB and TPVB after PSM

After PSM, comparison of surgical duration, intraoperative blood loss, fluid volume, and postoperative analgesic block procedure time between groups showed no significant differences in surgical duration or fluid volume (P=0.499, P=0.585); intraoperative blood loss difference did not reach statistical significance (P=0.067), showing a non-significant increasing trend in the TPVB group. Only postoperative

Table 7. Comparison of surgical duration, intraoperative blood loss, fluid volume, and postoperative analgesic block procedure time between TAPB and TPVB after PSM

Factor	Total	TAPB (n=161)	TPVB (n=161)	Test Statistic	*P*-value
Surgical Duration (min)	96.50 (80.00, 114.00)	95.00 (80.00, 110.00)	97.00 (80.00, 115.00)	0.676	0.499
Intraoperative Blood Loss (mL)	64.42±9.24	63.48±9.56	65.37±8.84	1.84	0.067
Intraoperative Fluid Volume (mL)	1198.77±156.50	1193.99±145.00	1203.55±167.53	0.547	0.585
Postoperative Analgesic Block Procedure Time (min)	27.50 (20.00, 35.00)	20.00 (17.00, 25.00)	35.00 (31.00, 39.00)	14.44	<0.001

Note: TAPB: Transversus abdominis plane block, TPVB: thoracic paravertebral block, PSM: propensity score matching.

Table 8. Comparison of postoperative 24-hour sufentanil dosage and initial self-control analgesia time between TAPB and TPVB after PSM

Factor	Total	TAPB (n=161)	TPVB (n=161)	Test Statistic	*P*-value
Postoperative 24-hour sufentanil dosage (μg)	20.50 (18.38, 22.60)	19.30 (17.70, 20.98)	21.50 (19.80, 23.58)	-6.707	<0.001
Initial self-control analgesia time (h)	8.00 (7.00, 9.00)	8.00 (7.00, 9.00)	8.00 (7.00, 9.00)	0.985	0.325

Note: TAPB: Transversus abdominis plane block, TPVB: thoracic paravertebral block, PSM: propensity score matching.

Table 9. Comparison of 24-Hour sufentanil consumption and time to first PCA demand between TAPB and TPVB after PSM

Factor	Total	TAPB (n=161)	TPVB (n=161)	Test Statistic	*P*-value
Preoperative NRS	1.00 (1.00, 2.00)	1.00 (1.00, 2.00)	1.00 (1.00, 2.00)	1.08	0.28
6 h Postoperative NRS	3.00 (3.00, 4.00)	4.00 (3.00, 4.00)	3.00 (2.00, 3.00)	8.039	<0.001
12 h Postoperative NRS	3.00 (2.00, 4.00)	3.00 (2.00, 4.00)	2.00 (2.00, 3.00)	6.903	<0.001
24 h Postoperative NRS	3.00 (2.00, 3.00)	3.00 (2.00, 3.00)	2.00 (2.00, 3.00)	5.351	<0.001
Preoperative Ramsay	2.00 (2.00, 2.00)	2.00 (2.00, 2.00)	2.00 (2.00, 2.00)	0.788	0.431
6 h Postoperative Ramsay	3.00 (2.00, 3.00)	3.00 (3.00, 3.00)	3.00 (2.00, 3.00)	4.46	<0.001
12 h Postoperative Ramsay	3.00 (2.00, 3.00)	3.00 (3.00, 3.00)	3.00 (2.00, 3.00)	3.738	<0.001
24 h Postoperative Ramsay	2.00 (2.00, 3.00)	2.00 (2.00, 3.00)	2.00 (2.00, 3.00)	0.633	0.527

Note: NRS: Numerical Rating Scale, PSM: Ramsay score, propensity score matching.

analgesic block procedure time showed a significant difference (P<0.001), with TPVB requiring longer duration (**Table 7**).

Comparison of 24-hour analgesic medication and PCA initiation time between TAPB and TPVB after PSM

After PSM, comparison of 24-hour sufentanil consumption and time to first PCA demand between groups showed a significant difference in sufentanil consumption (P<0.001), with the TPVB group consuming more than the TAPB group. Time to first PCA demand showed no significant difference (P=0.325) (**Table 8**).

Comparison of postoperative scores between TAPB and TPVB after PSM

After PSM, comparison of NRS and Ramsay scores at preoperative and various postoperative timepoints between groups showed no significant differences in preoperative NRS or Ramsay scores (all P>0.05). Postoperative NRS showed significant differences at 6, 12, and 24 hours (all P<0.001), with the TPVB group showing lower pain scores (**Table 9**). Ramsay scores showed significant differences at 6 and 12 hours postoperatively (all P<0.001), with TPVB lower; no difference occurred at 24 hours (P= 0.527) (**Table 9**).

Comparison of postoperative adverse events between TAPB and TPVB after PSM

The TPVB group still showed slightly a higher incidence of nausea, vomiting, and dizziness than TAPB group, (nausea: P=0.033; vomiting: P=0.017; dizziness: P=0.041). Incidence of abdominal distension and cognitive dysfunction showed no statistical differences (abdominal distension: P=0.720; cognitive dysfunction: P= 0.477) (**Table 10**).

Table 10. Comparison of postoperative adverse events between TAPB and TPVB after PSM

Factor	Total	TAPB (n=161)	TPVB (n=161)	Test Statistic	*P*-value
Nausea				4.54	0.033
Yes	24 (8.2%)	7 (4.8%)	17 (11.6%)		
No	268 (91.8%)	139 (95.2%)	129 (88.4%)		
Vomiting				5.692	0.017
Yes	15 (5.1%)	3 (2.1%)	12 (8.2%)		
No	277 (94.9%)	143 (97.9%)	134 (91.8%)		
Dizziness				4.156	0.041
Yes	21 (7.2%)	6 (4.1%)	15 (10.3%)		
No	271 (92.8%)	140 (95.9%)	131 (89.7%)		
Abdominal Distension				0.129	0.72
Yes	8 (2.7%)	5 (3.4%)	3 (2.1%)		
No	284 (97.3%)	141 (96.6%)	143 (97.9%)		
Cognitive Dysfunction				0.507	0.477
Yes	19 (6.5%)	11 (7.5%)	8 (5.5%)		
No	273 (93.5%)	135 (92.5%)	138 (94.5%)		

Note: TAPB: Transversus abdominis plane block, TPVB: thoracic paravertebral block, PSM: propensity score matching.

mFI-5 subgroup interaction analysis (pre-PSM)

After stratifying the population into non-frail and frail subgroups based on mFI-5, we tested interactions between TAPB and TPVB across multiple outcomes. Overall, except for ASA classification, interactions did not reach statistical significance, suggesting effect direction and magnitude of both block methods remained consistent across frailty states (**Figure 2**). ASA classification interaction test showed borderline significance (p_interaction=0.059), indicating association strength within subgroups might differ, but considering this analysis was based on pre-PSM data and represents baseline characteristics; clinical significance requires cautious interpretation. Additionally, a trend of "more pronounced effect in the frail group" was observed in 12-hour postoperative Ramsay scores (interaction p≈0.102), though not significant. Other continuous and binary outcomes (including NRS at various postoperative timepoints, 24-hour sufentanil consumption, time to first PCA demand, intraoperative blood loss/fluid volume, and adverse events) showed no significant interactions, supporting consistency of the main conclusions across frailty states.

mFI-5 subgroup interaction analysis (post-PSM)

After PSM, the population was stratified into non-frail and frail subgroups based on mFI-5 to evaluate interaction effects between block methods and outcomes. Overall, interaction tests for continuous and binary outcomes did not reach statistical significance, suggesting effect direction and magnitude of both block methods remained consistent across frailty states (**Figure 3**). ASA classification interaction showed borderline significance (p_interaction= 0.073), indicating that association strength within strata might differ, but evidence was insufficient for definitive inference. For Ramsay scores at 6/12 hours postoperatively, NRS at various timepoints, 24-hour sufentanil consumption, time to first PCA demand, intraoperative blood loss/fluid volume, and adverse events (nausea, vomiting, dizziness, abdominal distension, cognitive dysfunction), interaction tests showed no significant effect modification, supporting robustness of the main conclusions across frailty states.

Discussion

This study compared analgesic efficacy and safety of TAPB versus TPVB following laparoscopic total hysterectomy through PSM. Results showed that TPVB produced significantly lower NRS scores at 6, 12, and 24 hours postoperatively compared with TAPB, though 24-hour opioid consumption and incidence of nausea, vomiting, and dizziness were higher. mFI-5 stratified analysis showed no difference in analgesic effect across frailty states, indicating that

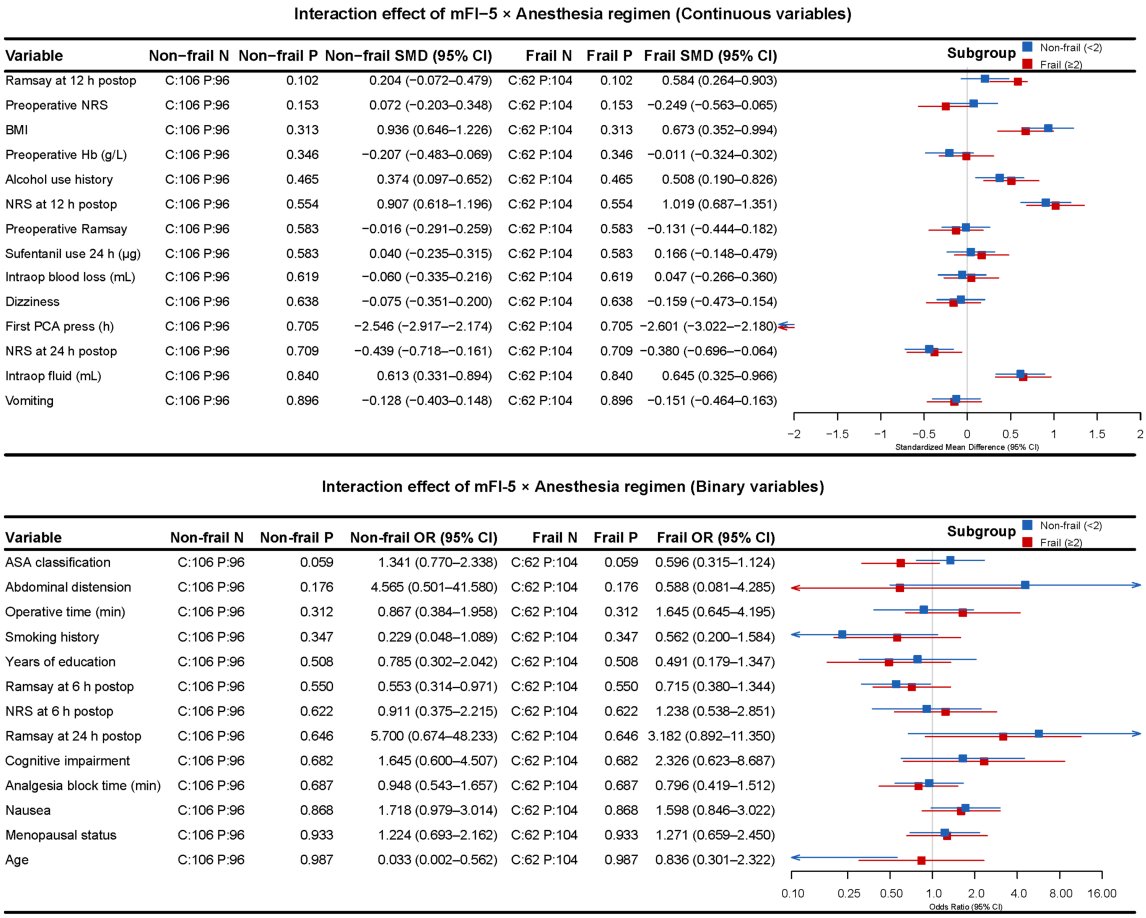

Figure 2. mFI-5 subgroup interaction analysis (pre-PSM). Note: C, non-frail subgroup; P, frail subgroup. TAPB: Transversus abdominis plane block, TPVB: thoracic paravertebral block, mFI-5: modified frailty index-5, BMI: body mass index, ASA: American Society of Anesthesiologists classification, NRS: Numerical Rating Scale, PCA: patient-controlled analgesia, Hb: hemoglobin, PSM: propensity score matching, p_interaction: interaction test *P*-value.

the relative effect of these two methods remained constant across frailty states.

The analgesic benefit of TPVB is due to its extensive nerve blockade that affects fibers carrying pain impulses from somatic and partly visceral origin, thus decreasing pain scores drastically in the early postoperative period. The explanation for this is found at the anatomical level. It is believed that, at least partly, the TPVB blocks the ventral rami of spinal nerves (providing somatic analgesia) as well as the sympathetic chain and rami communicantes in the paravertebral space [6]. Sympathetic blockade can interrupt the transmission of noxious impulses of visceral origin that travel with sympathetic fibers. On the other hand, TAPB inhibits the thoracolumbar nerves (T6-L1) within the neurovascular plane between the transversus abdominis and internal oblique muscles [5]. Thus, it blocks the somatic pain from the anterolateral abdominal wall without reaching the sympathetic pathway responsible for visceral pain transmission. Evidence shows [15] that TPVB is better than OSTAP in terms of analgesia, with lower tramadol consumption and significantly lower VAS scores at several time points.

This increase in analgesic effect came with needing more opiod doses. This is contradictory but possibly due to many interconnected reasons. Initially, although the sympathetic blockade significantly prevents visceral pain, physiological compensatory mechanisms such as hypotension and altered baroreceptor sensitivity can set in causing dizziness and nausea. Patients may use PCA more when they experience these unpleasant feelings, as their goal is better overall comfort and not pain relief *per se*

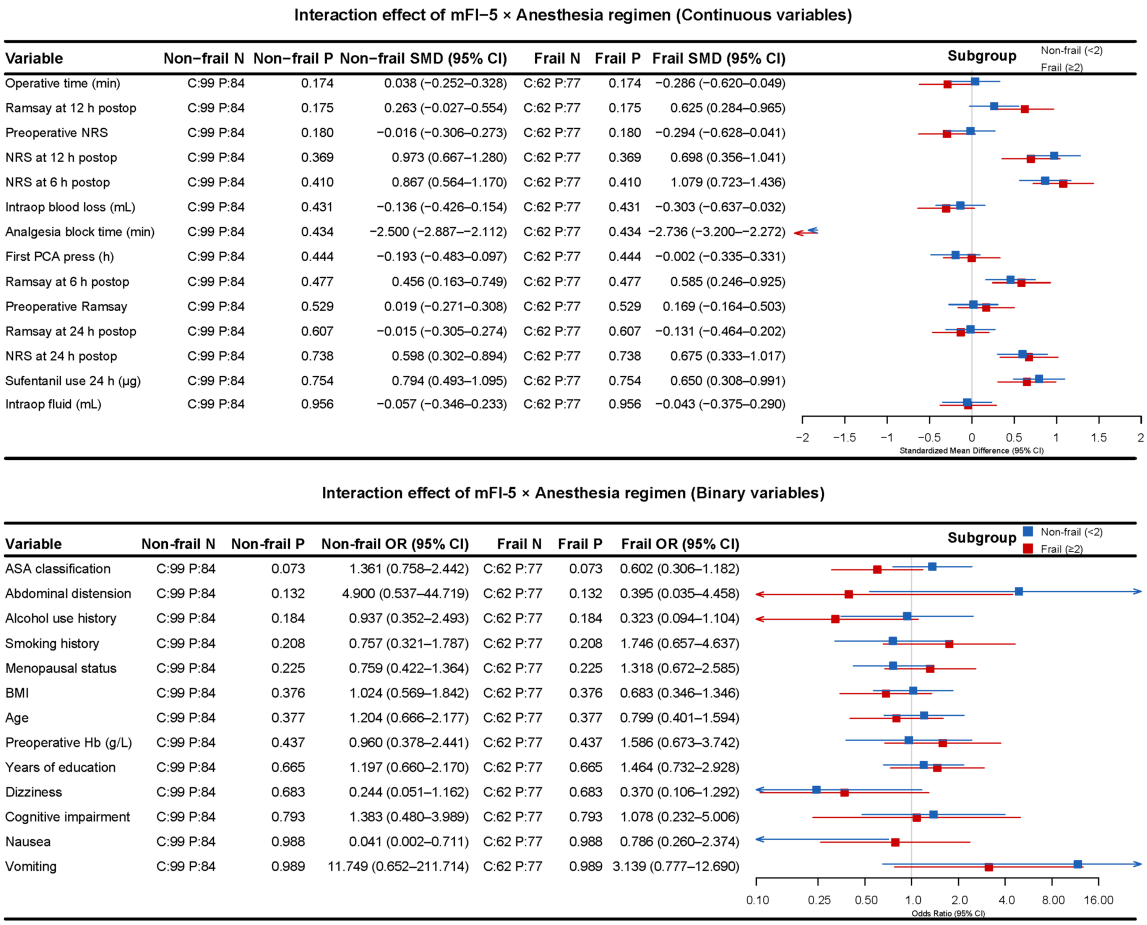

Figure 3. Interaction analysis between mFI-5 subgroups and block methods after PSM. Note: C, non-frail subgroup; P, frail subgroup. TAPB: Transversus abdominis plane block, TPVB: thoracic paravertebral block, mFI-5: modified frailty index-5, BMI: body mass index, ASA: American Society of Anesthesiologists classification, NRS: Numerical Rating Scale, PCA: patient-controlled analgesia, Hb: hemoglobin, PSM: propensity score matching, p_interaction: interaction test *P*-value.

[16]. Additionally, the increased depth of sympathetic blockade with TPVB may increase opioid-related side effects by decreasing compensatory sympathetic tone and therefore reducing the threshold for opioid PONV. Third, TPVB patients have been found to have lower baseline pain scores compared to their counterparts. This may lead to patient awareness of other distress such as nausea or anxiety. This in turn may lead to the patients using PCA for something other than pain relief. According to Liu et al [16], the TEA group showed a significantly higher incidence of PONV than the TAPB group due to sympathetic blockade and increased opioid dosage. Therefore, the TPVB group consumed more opioids and used PCA more often not because their analgesia was inadequate but due to various factors acting on each other. These include sympathetic-mediated side effects, increased opioid sensitivity owing to less sympathetic compensation and patients' perception of overall comfort (not just pain intensity).

Our findings are consistent with some existing literature that shows TPVB can have better analgesia. Both Jindal et al [15] and Jiang et al [17] demonstrated the superiority of TPVB over TAPB for postoperative analgesia. The literature has not been consistent regarding the increased consumption of opioids and risk of PONV. Studies [18] indicated that TAPB analgesia after laparoscopic hysterectomy is doubtful, with some studies failing to confirm clinical relevance. Various aspects including study design, population features, surgical procedure choice, and postoperative care protocol vary. Likewise, Torup et al, [19] did not find any reduction in

postoperative opioid consumption and improvement of VAS score with TAPB. Similarly, Hutchins et al, [20] found significantly reduced consumption of opioids in TAPB group over 72 hours. Some studies may have used different opioid management strategies or not strictly controlled postoperative analgesia protocols, leading to different results. We think that one of the innovations of this study is the use of propensity score matching (PSM) to balance baseline differences, as well as the introduction of mFI-5 stratification. The use of mFI-5 stratification allows a more objective exploration of the effect of frailty on analgesic effects.

The analysis investigated the role of frailty on the analgesic effect of TAPB and TPVB. The stratified analysis with respect to mFI-5 indicated that although frail patients may have more challenges in the postoperative recovery period, response to the two analgesic techniques was not significantly different across frailty levels [21]. Evidence shows that mFI-5 is an independent predictor of postoperative complications, first-cycle dose reductions, and chemotherapy completion among gynecologic oncology patients. In regard to benign and oncologic hysterectomies, the mFI-5 has good predictive value to identify high-risk patients as per Hermann et al [22] AlHilli et al [23] and Schipa et al [24] confirmed that in minimally invasive surgery for endometrial cancer, frailty is significantly associated with intraoperative complications but has limited association with early and delayed postoperative complications. One need not base analgesic choice on frailty alone, but it is a useful consideration. The overall postoperative recovery strategy, patient individualisation, and PONV risk are also important.

When it comes to safety, the incidence of PONV was significantly higher in the TPVB group than in the TAPB group. This was most likely due to the use of high doses of opioids with the TPVB. The observed increase in opioid-related side effects can be understood in the context of the broad pharmacologic actions of opioids, which exert significant effects beyond analgesia through central mechanisms. For instance, even in a different clinical setting such as labor analgesia, intrathecal sufentanil has been demonstrated to markedly increase the incidence of maternal fever, a finding attributed to its action on central thermoregulatory pathways [25]. This underscores how opioid administration, regardless of the specific clinical endpoint (be it fever or PONV), can engage diverse physiologic systems. In addition to direct opioid effects, the intraoperative sympathetic blockade caused by TPVB may have induced physiologic effects, such as hypotension and altered baroreceptor sensitivity, which can further contribute to dizziness and nausea. According to the evidence, this indicates that TEA Activation of the Inflammasome has a possible association with postoperative nausea and vomiting (PONV), although increased consumption of opioids can directly increase the PONV. According to the study by Xu et al [18], although good analgesia was observed with TPVB combined with TAPB, PCEA (like continuous epidural analagesia) had beneficial effects on pulmonary complications. While TPVB can enhance post-operation recovery and early mobilization, the increased PONV and dizziness side effects might hamper this. Thus, TAPB would be a better option for patients having high-risk for PONV. Various studies [26-28] confirm that while TAPB provides slightly inferior analgesia, it is easier to use and has fewer side effects. Kane et al [26] discovered that TAPB did not enhance the scores for quality of recovery after surgery. However, Toker et al [27] and Ji et al [28] found that TAPB could significantly reduce tramadol consumption and incidence of PONV and reduce time to first ambulation and length of stay in the hospital. For most patients, especially those needing faster initiation of recovery from surgery, TAPB is safer and more effective.

This study has limitations that include a retrospective design. Even after using PSM to control for the baseline differences, unobserved confounding is possible. For example, selecting analgesic techniques, clinicians may factor in differences among individual patients and the complexity of the surgery. Additionally, after the implementation of an enhanced recovery after surgery protocol, many variations remained, particularly in the PCA threshold and individualized analgesia, which may have influenced opioid use and post-operative adverse events. Beyond these methodological considerations, the efficacy and safety of both TAPB and TPVB remain fundamentally dependent on the operator's skill in accurately identifying needle placement and nerve structures under ultrasound guidance. Future advancements in regional

anesthesia may lie in reducing this operator dependency. Promising research directions include the integration of artificial intelligence, particularly deep learning (DL)-driven image segmentation models, to assist in the real-time, automated localization of peripheral nerves and fascial planes in ultrasound images, thereby enhancing procedural precision, consistency, and accessibility [29]. Future prospective, randomized controlled trials are warranted to validate our findings and to explore the integration of such assistive technologies into clinical workflows.

TPVB gave better analgesia than other treatments after laparoscopic total hysterectomy but came with higher opioid consumption and adverse events. Evidence indicates that single-injection ultrasound-guided TPVB demonstrates superior pain control at catheter exit sites, while Huang et al showed that TQL block offered visceral pain relief better than OSTAP. The use of TAPB as a simple and safe analgesic technique, although possibly less effective in providing analgesia, is associated with less opioid consumption and lower rates of adverse events. This approach can therefore be considered better for patients at high risk of PONV. Evidence showed that TAPB significantly reduces postoperative pain scores, through multiple meta-analyses. These were, however, inconsistent regarding opioid reduction. According to mFI-5 stratification results, frailty status has very little effect on analgesic method decisonmaking. Therefore, analgesia protocols selection should focus on specific clinical situations, postoperative outcome and PONV risk. Our clinical recommendations are to give priority to TAPB in higher PONV-risk patients or creating stricter opioid control; when TPVB is chosen, one must couple multimodal antiemetic approach with suitable PCA dose adjustment.

Conclusion

Laparoscopic total hysterectomy surgery revealed the use of TPVB significantly reduced postoperative pain scores and early sedation levels as compared to TAPB. However, 24-hour sufentanil consumption was higher with increased incidence of nausea, vomiting and dizziness. Overall safety remained acceptable.

Disclosure of conflict of interest

None.

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