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*Original Article*

# Efficacy of a pubic superior ramus approach versus a distal approach for obturator nerve block in transurethral bladder tumor resection: a randomized controlled trial

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**Abstract:** Objective: This study aimed to compare the clinical efficacy and safety of a modified pubic superior ramus (PSS) approach for pericapsular nerve group block against the conventional distal technique in obturator nerve blockade during transurethral resection of bladder tumor (TURBT), with a focus on preventing intraoperative obturator nerve reflex. Methods: We conducted a prospective, randomized, single-blind trial involving 70 patients scheduled for TURBT under general anesthesia. Participants were randomly assigned to one of two groups: Group P (n = 34) received ultrasound-guided obturator nerve block via the pubic superior ramus approach, while Group O (n = 34) underwent blockade via the distal approach. The primary outcome measures were the incidence and severity of obturator nerve reflex. Secondary outcomes encompassed block performance time and success rate, postoperative pain profiles (assessed by VAS scores), recovery quality, perioperative inflammatory biomarker levels, hemodynamic fluctuations, functional recovery metrics, as well as long-term bladder function and oncological outcomes evaluated at 6 and 12 months postoperatively. Results: Group P demonstrated significantly faster onset and greater reduction in adductor muscle strength at all measured time points ($P < 0.05$), with shorter block performance times (175.5 ± 34.2 vs. 223.7 ± 39.6 seconds, $P < 0.001$) and fewer needle passes ($P < 0.001$). While the incidence of the obturator reflex was similar between the groups, Group P had superior postoperative analgesia with lower pain scores, reduced morphine consumption (15.2 ± 4.8 vs. 24.5 ± 6.1 mg, $P < 0.001$), and a longer time to first analgesia. The quality of recovery scores was significantly greater in Group P at 24 and 48 hours ($P < 0.001$), along with an attenuated systemic inflammatory and neurochemical stress response (e.g., IL-6, Substance P, and c-Fos), improved hemodynamic stability, faster quadriceps recovery, and better short- and long-term bladder function. At the 12-month follow-up, Group P exhibited superior urodynamic parameters (Qmax and PVR, $P < 0.01$) and a trend towards lower tumor recurrence (94.1% vs. 85.3% recurrence-free survival, $P = 0.218$). Conclusion: Compared with the distal approach, the pubic superior ramus approach for obturator nerve block provides more efficient blockade and superior multidimensional perioperative benefits, making it an optimal technique for TURBT within enhanced recovery protocols.

**Keywords:** Obturator nerve block, PENG block, transurethral resection, bladder tumor, ultrasound-guided

## Introduction

Bladder cancer represents one of the most frequently diagnosed urological malignancies. As a standard treatment, transurethral resection of bladder tumor (TURBT) serves as a foundational surgical procedure, acclaimed for its minimal invasiveness and favorable patient acceptance [1, 2]. Various anesthetic modalities can be employed for TURBT, such as general anesthesia, neuraxial anesthesia, or regional nerve blocks. Despite these options, a recurring intraoperative challenge is the obturator nerve reflex, which manifests as an involuntary contraction of the thigh adductor muscles in response to electrical resection currents. This phenomenon poses significant surgical risks, as it may provoke abrupt leg movement, there-

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by elevating the likelihood of bladder perforation, injury to surrounding organs, and potential damage to major vasculature or nerves [3, 4]. Additionally, bladder perforation carries an oncological hazard by potentially promoting tumor dissemination and subsequent implantation metastases.

To mitigate this risk, multiple preventive strategies have been investigated. These encompass the optimization of anesthetic regimens, the use of combined obturator nerve block (ONB) techniques, advances in surgical instrumentation, and the application of laser-based resection technologies [5-7]. In particular, ultrasound-guided ONB has emerged as a focal intervention for suppressing the adductor motor response and enhancing operative safety. However, identifying the most effective anatomical approach for ONB, which optimally reconciles block efficacy, procedural reliability, and technical feasibility, continues to be a point of active clinical discourse. The obturator nerve originates from the ventral branches of the L2-L4 spinal nerves, descends through the psoas major muscle, exits the pelvis via the obturator canal, and courses between the pectineus and obturator externus muscles before dividing into anterior and posterior branches. Typically, the anterior branch runs within the fascial plane between the adductor longus and brevis muscles, whereas the posterior branch lies between the adductor brevis and magnus muscles. Although the obturator nerve does not directly innervate the bladder, its pelvic segment runs anterolaterally along the pelvic sidewall in close proximity to the posterolateral bladder wall. During TURBT, bladder distension brings the bladder wall and the nerve even closer. Consequently, resection of lateral wall tumors may stimulate the obturator nerve, inducing strong adductor muscle contractions and the obturator nerve reflex.

First described for regional anesthesia by Prentiss et al. in 1965 [2], obturator nerve block now features classic clinical approaches such as the pubic and inguinal methods [4]. More recently, cystoscopy-guided intravesical blockade has been proposed [8]. The pubic and inguinal approaches involve depositing local anesthetic around the obturator nerve, whereas the cystoscopic technique involves injecting local anesthetic at the tumor base via endoscopy to achieve the block. Systematic reviews indicate varying success rates for classic approaches [4, 9], potentially limited historically by the lack of ultrasound guidance. Although widely used with generally good safety and efficacy, classic ONB is not without risks, including hematoma formation, nerve injury, and local anesthetic systemic toxicity [10, 11]. Even with ultrasound guidance, proximal and distal obturator nerve blocks present challenges such as technical complexity, incomplete blockade, or potential vascular and nerve injury.

The pericapsular nerve group (PENG) block is a newer ultrasound-guided regional anesthesia technique designed to target the articular branches of the femoral nerve, obturator nerve, and accessory obturator nerve innervating the anterior hip capsule, primarily for analgesic management in hip surgery. The PENG block specifically targets sensory innervation around the hip joint capsule. This approach is designed to deliver potent analgesia while largely preserving motor function in the lower limb, a distinct clinical advantage. In a cadaveric investigation [12], injection of 20 mL of methylene blue dye via the PENG technique resulted in consistent staining of the obturator nerve's articular branches across all 18 hip specimens. These results imply that local anesthetic delivered through this route may spread caudally along the pectineus muscle, potentially reaching not only the primary obturator nerve trunk situated between the pectineus and obturator externus muscles, but also the accessory obturator nerve that supplies the pectineus. Such anatomical spread supports its potential utility in achieving reliable obturator nerve blockade during TURBT for obturator reflex prevention. Moreover, the PENG block injection site lies relatively remote from major vascular structures, which may lower the risk of hematoma formation and systemic local anesthetic toxicity, thereby improving its safety profile for anticoagulated patients.

Based on this rationale, the present study was conducted to evaluate the efficacy and safety of a modified PENG block employing a pubic superior ramus approach for obturator nerve blockade in preventing obturator nerve reflex during TURBT. We further sought to comprehensively examine its effects on essential perioperative outcomes, including postoperative

pain control, recovery quality, physiological stress markers, hemodynamic variations, and functional recuperation, thus assessing its role in improving patient management within an enhanced recovery protocol.

## Methods

### *Anatomical feasibility study*

A preliminary anatomical study was carried out in the anatomy laboratory of Nanjing Medical University to assess the staining pattern achievable with the PENG block. A fresh cadaver was placed in the supine position, and a high-frequency linear ultrasound transducer (6-13 MHz, Sonosite Edge II, USA) was aligned parallel to the inguinal ligament and directed toward the anterior superior iliac spine (ASIS) until clear sonographic visualization of the iliopubic eminence and the ASIS was attained. Using an in-plane or out-of-plane technique, a needle was advanced toward the pubic ramus, medial to the pectineus muscle, while carefully avoiding the femoral artery, vein, and nerve. After confirming needle tip placement on the superior pubic ramus and negative aspiration for blood, 30 mL of 0.2% methylene blue solution was injected into the potential space between the pectineus muscle and the pubic bone. This procedure was performed bilaterally. Sixty minutes post-injection, the corresponding regions were dissected to assess the extent of staining of the obturator nerve (main trunk, anterior and posterior branches), the accessory obturator nerve, and the femoral nerve.

### *Study design and ethical approval*

This study was a prospective, single-center, randomized controlled trial designed to compare the efficacy and safety of PENG block with those of conventional distal obturator nerve block in patients who underwent transurethral resection of bladder tumors (TURBTs). The study protocol was approved by the Institutional Review Board of our hospital (Ethics Approval No: KY20240724-01) and was registered with the Chinese Clinical Trial Registry. The trial was conducted and reported in accordance with the Consolidated Standards of Reporting Trials (CONSORT) 2010 guidelines [13]. Written informed consent was obtained from all participants prior to enrollment.

### *Study population*

Patients scheduled for elective TURBT were screened for eligibility. The inclusion criteria were as follows: (1) scheduled for elective TURBT; (2) American Society of Anesthesiologists (ASA) physical status I-III [14]; and (3) bladder tumor located on the lateral wall(s) as confirmed by preoperative imaging or cystoscopy. The exclusion criteria were as follows: (1) coagulation abnormalities; (2) preexisting obturator nerve injury; (3) neurological diseases affecting the central nervous system; (4) history of allergy to local anesthetics; (5) prior surgical history in the hip or inguinal region; (6) inguinal lymphadenopathy; or (7) active infection or hematoma at the puncture site.

### *Randomization and blinding*

Eligible patients were randomly allocated at a 1:1 ratio into either the PENG block group (Group P, n = 35) or the distal obturator nerve block group (Group O, n = 35) via a computer-generated random number table. The allocation sequence was concealed in sequentially numbered, opaque, sealed envelopes. While the anesthesiologist performing the block was not blinded to the group assignment, the surgeon, postoperative outcome assessors, and patients were blinded to the intervention received. To validate the success of blinding, patients were asked at the end of the postoperative period (48 hours) to guess which nerve block approach they had received. The proportion of correct guesses was similar to that expected by chance (50%), with no significant difference between groups ($P > 0.05$), confirming that blinding was effectively maintained. Similarly, surgeons and outcome assessors reported no awareness of the intervention type during the study, as the block sites were covered with standardized dressings, and patients exhibited no discernible sensory or motor differences that could reveal group assignment.

### *Anesthesia and intervention procedures*

Upon arrival at the operating room, standard monitoring, including heart rate (HR), noninvasive blood pressure (BP), electrocardiography (ECG), and peripheral oxygen saturation ($SpO_2$), was initiated. An intravenous line was established, and supplemental oxygen was provided.

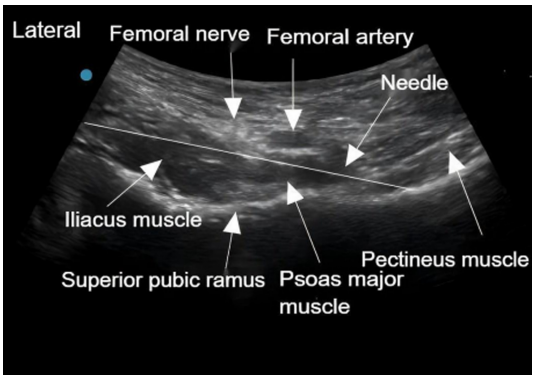


**Figure 1.** Suprapubic approach for obturator nerve block under ultrasound guidance.

All nerve blocks were performed by a single experienced anesthesiologist.

In Group P, patients were placed in the supine position. After sterile preparation of the inguinal region, a low-frequency convex ultrasound transducer (2-5 MHz) was placed parallel to the inguinal ligament and oriented toward the ASIS to visualize the iliopubic eminence. An in-plane or out-of-plane needle approach was used to guide the needle tip to the superior pubic ramus, deep to the pectineus muscle, while avoiding the femoral neurovascular bundle. Following negative aspiration, 30 mL of 0.375% ropivacaine was injected (**Figure 1**).

In Group O, patients were placed in a supine position with the operative-side thigh abducted and externally rotated. A high-frequency linear transducer was placed at the inguinal crease and moved medially to identify the adductor longus, brevis, and magnus muscles while avoiding the femoral vessels. A needle was inserted in-plane between the adductor longus and brevis muscles, and 15 mL of 0.375% ropivacaine was injected after negative aspiration. The needle was then advanced to the fascial plane between the adductor brevis and magnus muscles, where another 15 mL of 0.375% ropivacaine was administered.

Following the block, general anesthesia was induced with propofol (1-2 mg/kg) and sufentanil (10 μg). After 5 minutes of mask ventilation, a laryngeal mask airway was inserted. Anesthesia was maintained with a continuous infusion of propofol (4-6 mg/kg/h) and remifentanil (0.1-0.3 μg/kg/min), with the depth of anesthesia titrated to maintain a bispectral index (BIS) between 40 and 60.

*Outcome measures*

A series of primary and secondary outcomes were assessed by trained investigators who were blinded to the group allocation.

The primary intraoperative outcome was the incidence and severity of the obturator nerve reflex, which was graded as follows: no reflex, mild reflex (slight thigh adduction not interfering with surgery), or severe reflex (strong thigh adduction forcing surgical interruption).

The secondary outcome measures included the following: (1) block performance time and the number of needle passes required for successful block; (2) incidence of block-related complications such as hematoma, local anesthetic systemic toxicity, numbness, or paresthesia; (3) duration of surgery; (4) postoperative analgesic consumption, measured as the total intravenous morphine equivalent consumption within the first 48 hours post-surgery, postoperative pain intensity, assessed via the numerical rating scale (NRS, 0-10) at rest and during movement (e.g., coughing) at 1, 2, 6, 12, 24, and 48 hours post-operatively [15]; (5) time to first rescue analgesia, defined as the time from the end of anesthesia to the first patient request for pain relief; (6) motor function recovery, assessed via the Medical Research Council (MRC) scale for muscle strength [16] for the quadriceps and adductor muscles at 6 and 24 hours post-surgery; (7) quality of postoperative recovery, which was evaluated at 24 and 48 hours via the 40-item quality of recovery questionnaire (QoR-40) [17], which assesses five dimensions: physical comfort, emotional state, physical independence, psychological support, and pain; (8) long-term functional and oncological outcomes, assessed at 6 and 12 months postoperatively, including bladder urodynamics (maximum flow rate [Qmax] and post-void residual volume [PVR] measured via non-invasive uroflowmetry), the incidence of chronic pelvic pain (NRS ≥ 4), and tumor recurrence rate confirmed by cystoscopy and/or imaging; and (9) mechanistic biomarkers, including serum levels of neuropeptides (Substance P, Calcitonin Gene-Related Peptide [CGRP]) and a surrogate marker of neuronal

activation (c-Fos), measured preoperatively and at 6, 24, and 48 hours post-operatively.

*Data collection*

At the time of enrollment, detailed baseline information was documented to verify comparability between the two groups. This encompassed demographic profiles (age, sex, body mass index), American Society of Anesthesiologists (ASA) physical status classification [14], relevant comorbidities such as hypertension and diabetes mellitus along with medication use, smoking history, tumor features (size, number, lateral wall involvement), baseline laboratory results (hemoglobin, coagulation profile), preoperative resting pain scores on the Numerical Rating Scale (NRS 0-10) [15], and baseline recovery quality as measured by the QoR-40 questionnaire [17].

An independent observer recorded intraoperative variables, which covered hemodynamic parameters, surgical details, and block execution characteristics including performance time and number of needle passes. A research nurse blinded to patient group assignment collected postoperative outcomes at pre-specified intervals. These measures comprised pain NRS scores at rest and during movement, total intravenous morphine consumption converted to morphine equivalents over 48 hours, time to first rescue analgesia, muscle strength of the adductors and quadriceps assessed with the Medical Research Council (MRC) scale [16], quality of recovery (QoR-40) at 24 and 48 hours, bladder function evaluated using the Incontinence Quality of Life (IC-QOL) instrument [18] at 1 week and 1 month postoperatively, and long-term urodynamic parameters (Qmax, PVR) together with chronic pelvic pain assessment at 6 and 12 months. Any adverse events and tumor recurrence data were also documented throughout the follow-up period.

Serum concentrations of C-reactive protein (CRP), interleukin-6 (IL-6), and cortisol were quantified before surgery and at 6, 24, and 48 hours after surgery [19]. For mechanistic exploration, additional blood samples were obtained in serum separator tubes concurrently with the stress biomarker specimens. Serum was aliquoted into cryovials and maintained at -80°C until batch processing. Using standardized laboratory protocols and commercially available high-sensitivity ELISA kits per manufacturer guidelines, serum levels of Substance P, calcitonin gene-related peptide (CGRP), and c-Fos were determined.

*Statistical analysis*

The sample size was estimated a priori via G*Power 3.1 software. On the basis of preexperimental data indicating a 71% success rate (defined as a 50% reduction in adductor muscle strength [20]) 15 minutes after block completion in Group P versus 31% in Group O, a total of 64 patients (32 per group) were required to achieve 90% power ($1-\beta = 0.9$) at a two-sided $\alpha$ level of 0.05. Accounting for a potential 10% dropout rate, a final sample size of 70 patients (35 per group) was targeted. All the statistical analyses were performed via SPSS Statistics version 27.0. Normally distributed continuous data are presented as the means ± standard deviations and were compared between groups via the independent samples t test. Nonnormally distributed continuous data are presented as medians (interquartile ranges, IQRs) and were compared via the Mann-Whitney U test. Categorical data are presented as numbers (proportions, %) and were compared via the chi-square test or Fisher's exact test, as appropriate. For outcomes measured repeatedly over time (e.g., adductor strength, NRS scores, the QoR-40, and biomarker levels), two-way repeated-measures analysis of variance (RM-ANOVA) was employed to analyze the main effects of time and group, as well as the time-by-group interaction effect. For the analysis of tumor recurrence over the 12-month follow-up period, survival analysis was conducted using the Kaplan-Meier method, and between-group comparisons were made with the log-rank test. The assumption of sphericity in RM-ANOVA was checked using Mauchly's test, and the Greenhouse-Geisser correction was applied if violated. Post-hoc analyses following significant RM-ANOVA interactions were performed with Bonferroni corrections for multiple comparisons.

## Results

*Anatomical study*

Dissection of a cadaver after bilateral methylene blue injection revealed that the obturator nerve trunk and accessory obturator nerve

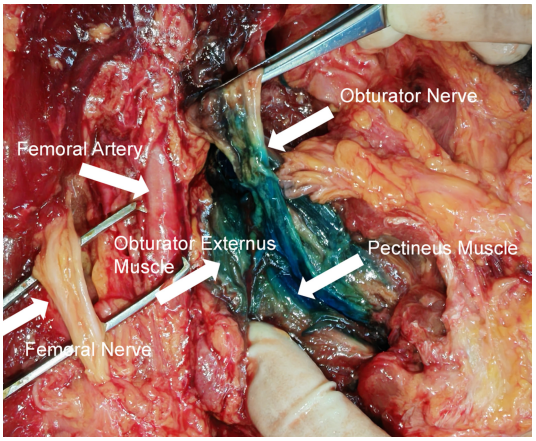


**Figure 2.** Methylene blue staining of the suprapubic branch approach for obturator nerve block.

were completely stained on both sides, with no staining of the femoral nerve (**Figure 2**).

*Baseline characteristics and patient demographics*

A total of 70 patients were initially enrolled in this study. One patient in Group P had a change in surgical plan, and one patient in Group O refused muscle strength testing; thus, 68 patients (34 in each group) were included in the final analysis. The flow of participants throughout the study is summarized in **Figure 3** (anticipated: a CONSORT-style flow diagram). As detailed in **Table 1**, there were no statistically significant differences between the two groups in any of the collected baseline demographic, clinical, or tumor-related characteristics (all $P > 0.05$), indicating successful randomization and good comparability at baseline.

*Block characteristics and intraoperative outcomes*

The efficacy and efficiency of the nerve block procedures are summarized in **Table 2**. Two-way repeated-measures ANOVA revealed a statistically significant interaction effect between time and group for the percentage reduction in adductor muscle strength ($F(6, 396) = 9.84$, $P < 0.001$). This significant interaction indicates that the trajectory of motor block development and recovery differed between the two groups over time. Simple effects analysis revealed that the reduction in adductor muscle strength was significantly greater in Group P than in Group O at all the measured time points (5, 10, 15, 20, 25, 30 min, and 3 h; all $P < 0.05$), indicating faster onset and more profound motor block.

The block performance in Group P was also more efficient. The block performance time was significantly shorter in Group P than in Group O (175.5 ± 34.2 s vs. 223.7 ± 39.6 s; $t = -5.432$, $P < 0.001$). Furthermore, the number of needle passes required was significantly lower in Group P (median [IQR]: 2.0 [1.0-2.0]) than in Group O (3.0 [2.0-4.0]; $U = 245.000$, $P < 0.001$).

With respect to the primary outcome, the incidence and severity of the obturator nerve reflex during surgery did not differ significantly between the two groups ($\chi^2 = 0.000$, $P > 0.999$). The majority of patients in both groups experienced no reflex (32/34 in each group), with only two patients in each group exhibiting a mild reflex that did not interfere with surgery. No instances of severe reflexes were recorded in either group. Furthermore, there were no block-related complications, such as hematoma or local anesthetic systemic toxicity, in any patient. Both the surgeon and patient satisfaction scores were high and comparable between the two groups.

*Postoperative analgesia*

The analgesic efficacy of the two nerve block regimens in the postoperative period is summarized in **Table 3** and **Figure 4**. Patients receiving pubic superior ramus approach block (Group P) experienced significantly superior analgesia than those receiving distal obturator nerve block (Group O).

The total consumption of rescue morphine equivalents within the first 48 hours post-surgery was significantly lower in Group *P* than in Group O (15.2 ± 4.8 mg vs. 24.5 ± 6.1 mg; $t = -7.102$, $P < 0.001$). The time to the first request for rescue analgesia was substantially prolonged in Group P, with a median time of 480 minutes (IQR: 360-655) compared with 185 minutes (IQR: 120-270) in Group O (log-rank test, $\chi^2 = 25.34$, $P < 0.001$).

For postoperative pain scores, two-way repeated-measures ANOVA revealed a significant interaction effect between time and group for

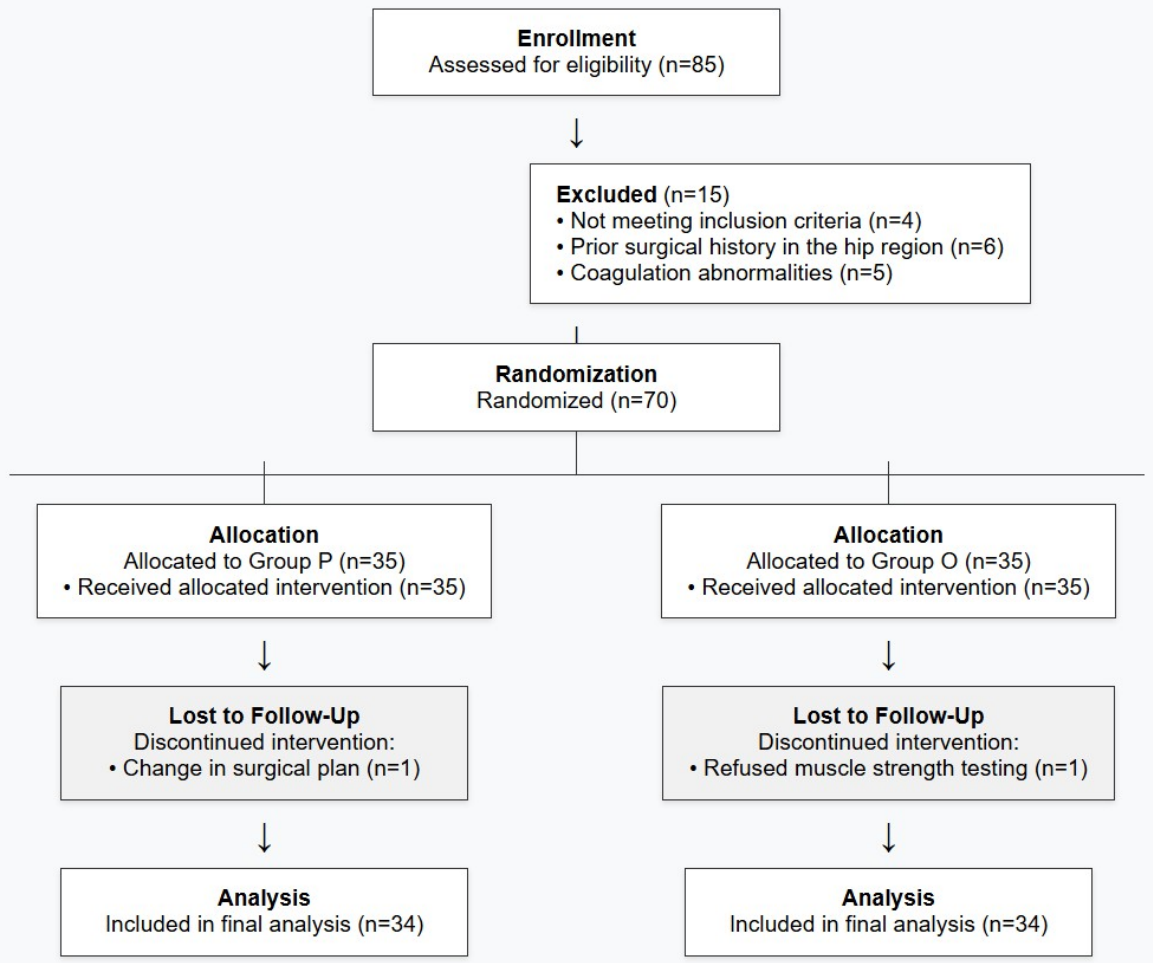


**Figure 3.** Inclusion and exclusion flowchart.

both the NRS score at rest ($F(5, 330) = 10.25$, $P < 0.001$) and the NRS score during movement ($F(5, 330) = 8.93$, $P < 0.001$). This finding indicates that the patterns of pain resolution over time were significantly different between the two groups. Simple effects analysis confirmed that pain scores were consistently and significantly lower in Group P at all measured time points, both at rest and during movement (all $P < 0.05$), with the differences being most pronounced during the early postoperative period (1-12 hours).

*Postoperative recovery quality*

The quality of patient recovery, as assessed by the QoR-40 questionnaire, was significantly superior in Group P across both time points (**Table 4**). Two-way repeated-measures ANOVA revealed a statistically significant interaction effect between time and group for the global QoR-40 score ($F(1, 66) = 5.12$, $P = 0.027$), indicating that the improvement in recovery quality from 24-48 hours was greater in Group P than in Group O. The main effect of group was also highly significant ($F(1, 66) = 45.11$, $P < 0.001$), confirming an overall higher quality of recovery in Group P (**Figure 5A**).

Analysis of the five distinct dimensions of the QoR-40 revealed specific areas of benefit. Significant interaction effects between time and group were observed for the domains of physical comfort ($F(1, 66) = 4.25$, $P = 0.043$) and physical independence ($F(1, 66) = 6.18$, $P = 0.015$), indicating faster recovery in these aspects within Group P. For the domains of pain and emotional state, the main effects of group were highly significant (both $P < 0.001$), with Group P reporting consistently better scores at both time points, although the rate of improvement (interaction effect) was not significantly

**Table 1.** Comparison of baseline demographic and clinical characteristics between groups

| Characteristic | Group P (n = 34) | Group O (n = 34) | Statistical Value | *P* value |
|---|---|---|---|---|
| Demographics | | | | |
| Age (years) | 65.7 ± 9.1 | 67.0 ± 9.7 | t = -0.587 | 0.559 |
| Gender (Male/Female) | 28/6 | 28/6 | $\chi^2$ = 0.000 | > 0.999 |
| BMI (kg/m$^2$) | 23.1 ± 3.0 | 22.9 ± 2.5 | t = 0.299 | 0.766 |
| Clinical Status | | | | |
| ASA Classification (I/II/III) | 1/27/6 | 0/27/7 | FET | 0.742 |
| Comorbidities, n (%) | | | | |
| Hypertension | 12 (35.3) | 14 (41.2) | $\chi^2$ = 0.250 | 0.617 |
| Diabetes Mellitus | 5 (14.7) | 4 (11.8) | FET | 0.723 |
| Coronary Heart Disease | 3 (8.8) | 2 (5.9) | FET | 0.642 |
| Smoking History, n (%) | 9 (26.5) | 11 (32.4) | $\chi^2$ = 0.287 | 0.592 |
| Tumor Characteristics | | | | |
| Tumor Size (cm) | 2.1 ± 0.8 | 2.3 ± 0.9 | t = -1.002 | 0.320 |
| Multiple Tumors, n (%) | 8 (23.5) | 10 (29.4) | $\chi^2$ = 0.288 | 0.591 |
| Bilateral Involvement, n (%) | 5 (14.7) | 7 (20.6) | $\chi^2$ = 0.405 | 0.525 |
| Preoperative Assessments | | | | |
| Preoperative NRS at rest (0-10) | 0.2 ± 0.6 | 0.3 ± 0.7 | t = -0.629 | 0.532 |
| Preoperative QoR-40 Global Score | 186.5 ± 8.2 | 184.8 ± 9.1 | t = 0.827 | 0.411 |
| Laboratory Values | | | | |
| Hemoglobin (g/L) | 132.5 ± 14.2 | 135.1 ± 15.8 | t = -0.724 | 0.472 |

Note: Data are presented as the mean ± standard deviation or number (n) of patients (%). Abbreviations: BMI, body mass index; ASA, American Society of Anesthesiologists; NRS, numerical rating scale; QoR-40, 40-item quality of recovery questionnaire. Statistical tests: Independent samples t test (t); chi-square test ($\chi^2$); Fisher's exact test (FET).

**Table 2.** Comparison of nerve block characteristics and intraoperative outcomes between groups

| Outcome Measure | Group P (n = 34) | Group O (n = 34) | Statistical Value | *P* value |
|---|---|---|---|---|
| Block Performance | | | | |
| Block Performance Time (s) | 175.5 ± 34.2 | 223.7 ± 39.6 | t = -5.432 | < 0.001 |
| Number of Needle Passes | 2.0 (1.0-2.0) | 3.0 (2.0-4.0) | U = 245.000 | < 0.001 |
| Adductor Muscle Strength Reduction (%) | Interaction: Time × Group F(P) | F(6, 396) = 9.84 (< 0.001) | | |
| 5 min | 54.2 ± 11.3 | 49.2 ± 7.6 | | |
| 10 min | 61.1 ± 11.7 | 52.2 ± 8.0 | | |
| 15 min | 68.4 ± 12.1 | 54.8 ± 8.2 | | |
| 20 min | 69.8 ± 11.6 | 56.0 ± 8.2 | | |
| 25 min | 70.8 ± 10.8 | 56.5 ± 8.3 | | |
| 30 min | 71.1 ± 10.9 | 56.0 ± 8.4 | | |
| 3 h | 67.0 ± 10.4 | 52.6 ± 9.0 | | |
| Obturator Nerve Reflex, n | | | $\chi^2$ = 0.000 | > 0.999 |
| None | 32 | 32 | | |
| Mild | 2 | 2 | | |
| Severe | 0 | 0 | | |
| Block-Related Complications, n | 0 | 0 | - | - |
| Satisfaction Score | | | | |
| Surgeon Satisfaction (1-4) | 1.0 ± 0.0 | 1.0 ± 0.2 | U = 561.500 | 0.317 |
| Patient Satisfaction (1-4) | 1.0 ± 0.0 | 1.0 ± 0.0 | U = 578.000 | > 0.999 |

Note: Data are presented as the mean ± standard deviation, median (interquartile range), or number (n). Abbreviations: s, seconds. Statistical tests: Independent samples t test (t); Mann-Whitney U test (U); chi-square test ($\chi^2$); two-way repeated-measures ANOVA for adductor muscle strength.

**Table 3.** Comparison of postoperative analgesic outcomes between groups

| Outcome Measure | Group P (n = 34) | Group O (n = 34) | Statistical Value | *P* value |
|---|---|---|---|---|
| Total Morphine Consumption (0-48 h, mg) | 15.2 ± 4.8 | 24.5 ± 6.1 | t = -7.102 | < 0.001 |
| Time to First Analgesia (min) | 480 (360-655) | 185 (120-270) | U = 185.500 | < 0.001 |
| Postoperative NRS Pain Scores | Interaction: Time × Group F(P) | | | |
| NRS at Rest | | | F(5, 330) = 10.25 (< 0.001) | |
| 1 hour | 1.2 ± 0.8 | 2.8 ± 1.1 | | |
| 2 hours | 1.5 ± 0.9 | 3.0 ± 1.0 | | |
| 6 hours | 1.8 ± 0.8 | 2.9 ± 0.9 | | |
| 12 hours | 1.6 ± 0.7 | 2.4 ± 0.8 | | |
| 24 hours | 1.2 ± 0.6 | 1.8 ± 0.7 | | |
| 48 hours | 0.8 ± 0.5 | 1.1 ± 0.6 | | |
| NRS On Movement | | | F(5, 330) = 8.93 (< 0.001) | |
| 1 hour | 2.5 ± 1.0 | 4.1 ± 1.2 | | |
| 2 hours | 2.8 ± 1.1 | 4.3 ± 1.1 | | |
| 6 hours | 3.0 ± 1.0 | 4.2 ± 1.0 | | |
| 12 hours | 2.7 ± 0.9 | 3.6 ± 0.9 | | |
| 24 hours | 2.1 ± 0.8 | 2.8 ± 0.8 | | |
| 48 hours | 1.5 ± 0.7 | 1.9 ± 0.7 | | |

Note: Data are presented as the mean ± standard deviation or median (interquartile range). Abbreviations: NRS, numerical rating scale (0-10); min, minutes. Statistical tests: Independent samples t test (t) for total morphine consumption; Mann-Whitney U test (U) for time to first analgesics; two-way repeated-measures ANOVA for NRS scores.

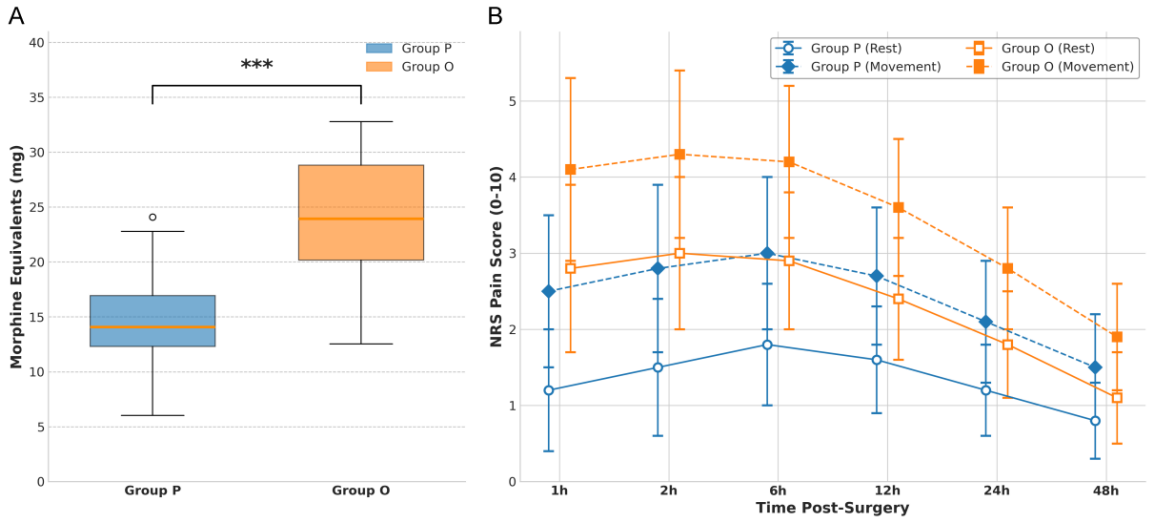


**Figure 4.** Comparison of postoperative analgesic outcomes between the proximal (Group P) and distal (Group O) nerve block groups. A. Boxplot of total morphine equivalent consumption within the first 48 postoperative hours. The horizontal line denotes the median, the box represents the interquartile range (IQR), the whiskers represent the data range, and the circles represent outliers. B. Postoperative numerical rating scale (NRS) pain scores over time at rest and during movement. The data points represent the means, and the error bars indicate the standard deviations. ***P < 0.001.

different between groups. No significant interaction or main group effect was found for psychological support (**Figure 5B**).

*Physiological stress response*

The perioperative physiological stress response, as measured by serial serum biomarkers, was significantly attenuated in Group P compared with Group O (**Table 5**). Two-way repeated-measures ANOVA revealed a statistically significant interaction effect between time and group for all three biomarkers: CRP ($F(3, 198) = 8.45$, $P < 0.001$), IL-6 ($F(3, 198) = 12.71$, $P < 0.001$), and cortisol ($F(3, 198) = 10.29$, $P < 0.001$). This significant interaction

**Table 4.** Comparison of postoperative recovery quality (QoR-40 scores) between groups

| QoR-40 Domain (Range) | Time Point | Group P (n = 34) | Group O (n = 34) | Main Effect: Group F(P) | Interaction: Time × Group F(P) |
|---|---|---|---|---|---|
| Global Score (40-200) | 24 hours | 182.5 ± 6.8 | 170.2 ± 8.4 | F = 45.11 (< 0.001) | F = 5.12 (0.027) |
| | 48 hours | 189.4 ± 5.1 | 180.3 ± 7.0 | | |
| Physical Comfort (12-60) | 24 hours | 54.2 ± 2.5 | 48.8 ± 3.6 | F = 67.15 (< 0.001) | F = 4.25 (0.043) |
| | 48 hours | 57.1 ± 1.8 | 53.9 ± 2.9 | | |
| Pain (7-35) | 24 hours | 30.5 ± 2.1 | 25.9 ± 2.8 | F = 72.34 (< 0.001) | F = 2.98 (0.089) |
| | 48 hours | 32.8 ± 1.5 | 29.7 ± 2.3 | | |
| Emotional State (9-45) | 24 hours | 38.1 ± 3.0 | 35.2 ± 3.5 | F = 16.98 (< 0.001) | F = 0.12 (0.734) |
| | 48 hours | 40.5 ± 2.5 | 38.3 ± 3.0 | | |
| Physical Independence (12-60) | 24 hours | 52.1 ± 4.2 | 50.8 ± 4.8 | F = 5.89 (0.018) | F = 6.18 (0.015) |
| | 48 hours | 56.8 ± 2.1 | 55.4 ± 2.8 | | |
| Psychological Support (4-20) | 24 hours | 18.2 ± 1.5 | 17.9 ± 1.7 | F = 0.55 (0.461) | F = 0.08 (0.783) |
| | 48 hours | 18.5 ± 1.2 | 18.3 ± 1.4 | | |

Note: Data are presented as the means ± standard deviations. A higher QoR-40 score indicates a better quality of recovery. Analysis was performed via two-way repeated-measures ANOVA. The table presents the F statistics and *P* values for the main effect of Group and the interaction effect between Time and Group. A significant time × group interaction indicates that the pattern of change over time differs between groups.

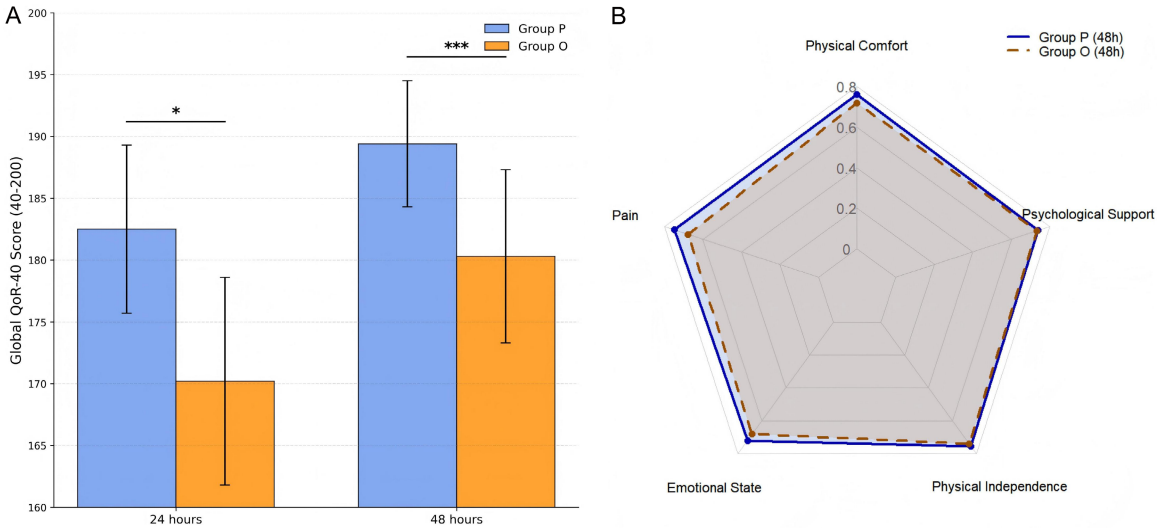


**Figure 5.** Comparison of postoperative quality of recovery, assessed by the 40-item Quality of Recovery (QoR-40) questionnaire, between the proximal (Group P) and distal (Group O) block groups. A. Bar chart comparing the global QoR-40 scores at 24 and 48 hours post-surgery. The bars represent the mean score, and the error bars indicate the standard deviation. B. Radar chart illustrating the normalized scores across the five dimensions of the Qo-R 40 at 48 hours post-surgery, providing a visual comparison of the recovery profile between the groups. *P < 0.05; ***P < 0.001.

indicates that the trajectory of change in these biomarkers over time differed between the two intervention groups.

Simple effects analysis, which was conducted to interpret this interaction, revealed that at baseline, there were no significant differences between the groups for any biomarker (all P > 0.05), confirming comparable starting points. Following surgery, both groups exhibited an increase in all biomarkers, but this increase was markedly blunted in Group P. Specifically, the IL-6 and cortisol levels were significantly lower in Group P than in Group O at the 6-, 24-, and 48-hour time points (all P < 0.01). The CRP response, which increased more slowly, was significantly lower in Group P at the 24- and 48-hour time points (both P < 0.001),

**Table 5.** Comparison of perioperative inflammatory and stress biomarkers between groups

| Biomarker | Time Point | Group P (n = 34) | Group O (n = 34) | Main Effect: Group F(P) | Interaction: Time × Group F(P) |
|---|---|---|---|---|---|
| CRP (mg/L) | Baseline | 3.1 ± 1.2 | 3.4 ± 1.5 | F = 15.82 (< 0.001) | F = 8.45 (< 0.001) |
| | 6 hours | 12.5 ± 3.8 | 13.8 ± 4.2 | | |
| | 24 hours | 35.2 ± 6.8 | 45.1 ± 8.3 | | |
| | 48 hours | 68.5 ± 12.4 | 85.3 ± 15.1 | | |
| IL-6 (pg/mL) | Baseline | 5.8 ± 2.1 | 6.1 ± 2.4 | F = 32.56 (< 0.001) | F = 12.71 (< 0.001) |
| | 6 hours | 45.2 ± 8.1 | 58.9 ± 10.5 | | |
| | 24 hours | 32.5 ± 7.5 | 41.8 ± 9.2 | | |
| | 48 hours | 15.8 ± 5.2 | 22.4 ± 6.8 | | |
| Cortisol (nmol/L) | Baseline | 285.5 ± 65.4 | 275.8 ± 70.1 | F = 21.93 (< 0.001) | F = 10.29 (< 0.001) |
| | 6 hours | 385.4 ± 45.2 | 452.7 ± 52.1 | | |
| | 24 hours | 320.1 ± 55.3 | 385.6 ± 61.0 | | |
| | 48 hours | 295.8 ± 49.7 | 325.4 ± 58.2 | | |

Note: Data are presented as the means ± standard deviations. Analysis was performed via two-way repeated-measures ANOVA. The table presents the F statistics and *P* values for the main effect of Group and the interaction effect between Time and Group. A significant time × group interaction indicates that the pattern of change over time differs between groups. Post hoc simple effects analysis confirmed that the groups were not different at baseline, but Group P had significantly lower levels at subsequent time points. Abbreviations: CRP, C-reactive protein; IL-6, interleukin-6.

**Table 6.** Comparison of intraoperative hemodynamic stability and vasopressor requirements between groups

| Outcome Measure | Group P (n = 34) | Group O (n = 34) | Statistical Value | *P* value |
|---|---|---|---|---|
| Hemodynamic Fluctuation during Resection | | | | |
| Δ Mean Arterial Pressure, MAP (mmHg) | 8.5 ± 3.1 | 15.2 ± 4.8 | t = -7.102 | < 0.001 |
| Δ Heart Rate, HR (beats per minute) | 10.4 ± 3.8 | 18.7 ± 5.9 | t = -7.250 | < 0.001 |
| Vasopressor Requirements | | | | |
| Patients Requiring Phenylephrine, n (%) | 5 (14.7) | 15 (44.1) | $\chi^2$ = 7.240 | 0.007 |
| Total Phenylephrine Dose (μg) | 0 (0-0) | 50 (0-100) | U = 380.500 | 0.002 |

Note: Data are presented as the mean ± standard deviation, median (interquartile range), or number (%). Abbreviations: MAP, mean arterial pressure; HR, heart rate. Δ values represent the maximum change (increase in HR, absolute change in MAP) from the pre-resection baseline value during the tumor resection period. Statistical tests: Independent samples t test (t) for hemodynamic fluctuations; chi-square test ($\chi^2$) for the proportion of patients requiring phenylephrine; Mann-Whitney U test (U) for total phenylephrine dose.

whereas the difference at 6 hours was not significant (P = 0.174). These results demonstrate that the pubic superior ramus approach (Group P) effectively attenuated the surgical stress response compared with distal obturator nerve block (Group O).

*Intraoperative hemodynamic stability*

The intraoperative hemodynamic profiles of the two groups are summarized in **Table 6**. Patients in Group P demonstrated significantly greater hemodynamic stability during the critical phase of bladder tumor resection than did those in Group O.

The fluctuation in MAP from baseline (defined as the value immediately before the start of resection) was significantly smaller in Group P than in Group O (ΔMAP: 8.5 ± 3.1 mmHg vs. 15.2 ± 4.8 mmHg; t = -7.102, *P* < 0.001). Similarly, the peak increase in HR during resection was also significantly attenuated in Group P (ΔHR: 10.4 ± 3.8 bpm vs. 18.7 ± 5.9 bpm; t = -7.250, *P* < 0.001).

This enhanced stability was reflected in the reduced requirement for vasopressor support. The proportion of patients requiring intravenous phenylephrine to treat hypotension during the procedure was significantly lower in

**Table 7.** Comparison of motor function recovery and bladder function between groups

| Outcome Measure | Time Point | Group P (n = 34) | Group O (n = 34) | Statistical Value | *P* value |
|---|---|---|---|---|---|
| Motor Function Recovery (MRC ≥ 4), n (%) | | | | | |
| Quadriceps Muscle | 6 hours | 28 (82.4) | 10 (29.4) | $\chi^2$ = 18.579 | < 0.001 |
| | 24 hours | 32 (94.1) | 25 (73.5) | $\chi^2$ = 5.314 | 0.021 |
| Adductor Muscles | 6 hours | 2 (5.9) | 25 (73.5) | $\chi^2$ = 33.632 | < 0.001 |
| | 24 hours | 20 (58.8) | 32 (94.1) | $\chi^2$ = 11.429 | < 0.001 |
| Bladder Function (IC-QOL Score) | 1 week | 25.8 ± 5.2 | 24.6 ± 5.8 | t = -1.224 | 0.225 |
| | 1 month | 32.5 ± 4.1 | 29.8 ± 4.8 | t = 2.509 | 0.015 |

Note: Data are presented as the number (n) of patients with a percentage (%) or mean ± standard deviation. Abbreviations: MRC, Medical Research Council scale; IC-QOL, Interstitial Cystitis Quality of Life instrument (a higher score indicates better quality of life and fewer bladder symptoms). Statistical tests: Chi-square test ($\chi^2$) for proportions of patients with MRC scores ≥ 4; independent samples t test (t) for IC-QOL scores.

Group P (5/34, 14.7%) than in Group O (15/34, 44.1%; $\chi^2$ = 7.240, *P* = 0.007). Consequently, the total intraoperative dose of phenylephrine was also significantly lower in Group P (median [IQR]: 0 [0-0] μg vs. 50 [0-100] μg; U = 380.500, P = 0.002).

*Functional recovery and bladder function*

The recovery profiles for motor function and long-term bladder symptoms are detailed in **Table 7**. Consistent with the motor-sparing characteristic of the PENG block, patients in Group P exhibited significantly faster recovery of quadriceps muscle strength. At 6 hours post-surgery, a significantly greater proportion of patients in Group P than in Group O achieved a quadriceps muscle strength of MRC grade ≥ 4 (82.4% vs. 29.4%; $\chi^2$ = 18.579, P < 0.001), an advantage that persisted at 24 hours (94.1% vs. 73.5%; $\chi^2$ = 5.314, P = 0.021). In contrast, and as expected from an effective obturator nerve block, the recovery of adductor muscle strength was significantly delayed in Group P, with a lower proportion of patients reaching MRC grade ≥ 4 at both 6 and 24 hours (both *P* < 0.001). This favorable profile of preserved quadriceps function was associated with better patient-reported outcomes. While IC-QOL scores were comparable between groups at 1-week post-surgery, the score was significantly greater in Group P at the 1-month assessment (32.5 ± 4.1 vs. 29.8 ± 4.8; t = 2.509, *P* = 0.015), indicating superior recovery of bladder function with fewer symptoms of urinary frequency and urgency.

*Long-term follow-up outcomes*

To evaluate the sustained clinical benefits of the novel block technique, we conducted a comprehensive follow-up at 6- and 12-months post-surgery. The long-term outcomes pertaining to bladder function, chronic pain, and oncology surveillance are summarized in **Table 8**. Analysis of urodynamic parameters revealed significantly better bladder emptying function in Group P compared to Group O. At both the 6- and 12-month follow-ups, patients in Group P exhibited a higher Qmax (6 m: 18.5 ± 3.1 vs. 15.8 ± 3.8 mL/s, P = 0.002; 12 m: 19.2 ± 2.9 vs. 16.5 ± 3.5 mL/s, P < 0.001) and a lower PVR (6 m: 28.4 ± 10.2 vs. 38.1 ± 12.5 mL, P < 0.001; 12 m: 25.1 ± 8.8 vs. 35.7 ± 11.9 mL, P < 0.001). The incidence of chronic pelvic pain, assessed via the NRS, was also significantly lower in Group P at both time points (NRS ≥ 4 at 6 m: 2.9% vs. 17.6%, P = 0.044; at 12 m: 0% vs. 14.7%, P = 0.021). Furthermore, oncological follow-up demonstrated a clinically relevant, though not statistically significant, trend towards a lower tumor recurrence rate in Group P (12-month recurrence-free rate: 94.1% vs. 85.3%; Log-rank test, $\chi^2$ = 1.52, P = 0.218), as visually anticipated in the Kaplan-Meier curve (**Figure 6**). These long-term data suggest that the pubic superior ramus approach for obturator nerve block may not only confer superior perioperative recovery but also contribute to improved long-term bladder functional outcomes and a potentially more favorable oncological trajectory.

**Table 8.** Comparison of long-term follow-up outcomes at 6 and 12 months

| Outcome Measure | Time Point | Group P (n = 34) | Group O (n = 34) | Statistical Value | *P* value |
|---|---|---|---|---|---|
| Urodynamics | | | | | |
| Qmax (mL/s) | 6 months | 18.5 ± 3.1 | 15.8 ± 3.8 | t = 3.25 | 0.002 |
| | 12 months | 19.2 ± 2.9 | 16.5 ± 3.5 | t = 3.58 | < 0.001 |
| PVR (mL) | 6 months | 28.4 ± 10.2 | 38.1 ± 12.5 | t = -3.53 | < 0.001 |
| | 12 months | 25.1 ± 8.8 | 35.7 ± 11.9 | t = -4.22 | < 0.001 |
| Chronic Pelvic Pain (NRS ≥ 4), n (%) | 6 months | 1 (2.9) | 6 (17.6) | FET | 0.044 |
| | 12 months | 0 (0) | 5 (14.7) | FET | 0.021 |
| Tumor Recurrence, n (%) | 6 months | 1 (2.9) | 3 (8.8) | FET | 0.300 |
| | 12 months | 2 (5.9) | 5 (14.7) | FET | 0.231 |
| 12-month Recurrence-free Rate, % | 12 months | 94.1 | 85.3 | Log-rank $\chi^2$ = 1.52 | 0.218 |

Note: Data are presented as the mean ± standard deviation or number (n) of patients with percentage (%). Abbreviations: Qmax, maximum urinary flow rate; PVR, post-void residual urine volume; NRS, numerical rating scale; FET, Fisher's Exact Test. The recurrence-free rate was analyzed using the Kaplan-Meier method with the Log-rank test.

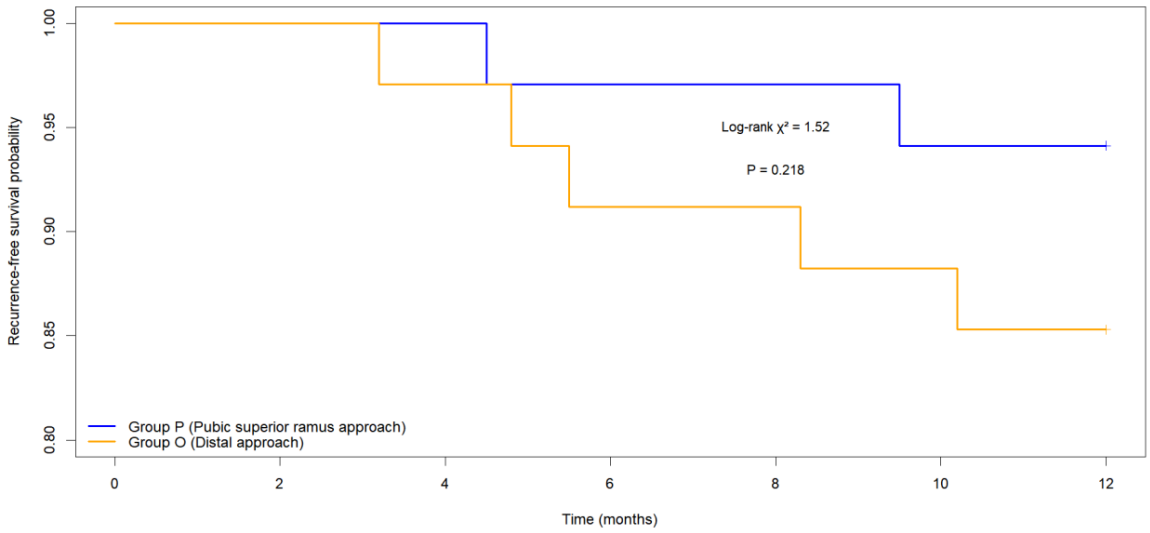


**Figure 6.** Kaplan-Meier survival curves for tumor recurrence-free survival. Comparison of 12-month recurrence-free survival between Group P (pubic superior ramus approach, n = 34) and Group O (distal approach, n = 34). Group P showed higher recurrence-free rates at both 6 months (97.1% vs. 91.2%) and 12 months (94.1% vs. 85.3%), though the difference was not statistically significant (Log-rank $\chi^2$ = 1.4, P = 0.218). Shaded areas indicate 95% confidence intervals.

*Molecular mechanism analysis*

To investigate the neurophysiological mechanisms underlying the superior clinical outcomes, we analyzed serum levels of key pain-related neuropeptides and a surrogate marker of neuronal activation. As detailed in **Table 9**, the systemic concentrations of substance P, CGRP, and c-Fos were significantly modulated by the block technique. Two-way repeated-measures ANOVA revealed statistically significant interaction effects between time and group for substance P ($F(3, 198) = 15.32$, $P < 0.001$), CGRP ($F(3, 198) = 11.89$, $P < 0.001$), and c-Fos ($F(3, 198) = 12.45$, $P < 0.001$). Post-hoc analysis demonstrated that the surgically induced rise in serum levels of all three biomarkers was markedly attenuated in Group P compared to Group O. Specifically, the concentrations of substance P and CGRP were significantly lower in Group P at the 6-hour and 24-hour time points (all $P < 0.01$). Similarly, the serum level of c-Fos, a widely recognized surrogate marker reflecting activity in central pain pathways

**Table 9.** Comparison of serum neuropeptide and neuronal activation marker levels

| Biomarker | Time Point | Group P (n = 34) | Group O (n = 34) | Main Effect: Group F(P) | Interaction: Time × Group F(P) |
|---|---|---|---|---|---|
| Substance P (pg/mL) | Baseline | 35.2 ± 8.1 | 33.9 ± 7.5 | F = 28.45 (< 0.001) | F = 15.32 (< 0.001) |
| | 6 hours | 68.5 ± 12.4 | 92.1 ± 15.3 | | |
| | 24 hours | 52.1 ± 10.8 | 70.3 ± 13.2 | | |
| | 48 hours | 40.8 ± 9.5 | 45.5 ± 10.1 | | |
| CGRP (pg/mL) | Baseline | 50.5 ± 11.2 | 48.8 ± 10.6 | F = 22.18 (< 0.001) | F = 11.89 (< 0.001) |
| | 6 hours | 95.8 ± 18.5 | 125.4 ± 22.1 | | |
| | 24 hours | 75.3 ± 16.1 | 98.7 ± 19.4 | | |
| | 48 hours | 58.1 ± 12.9 | 65.9 ± 14.3 | | |
| c-Fos (pg/mL) | Baseline | 8.2 ± 2.1 | 8.5 ± 2.3 | F = 25.67 (< 0.001) | F = 12.45 (< 0.001) |
| | 6 hours | 18.5 ± 4.2 | 25.1 ± 5.6 | | |
| | 24 hours | 12.1 ± 3.0 | 16.8 ± 4.1 | | |
| | 48 hours | 9.5 ± 2.5 | 11.2 ± 3.0 | | |

Note: Data are presented as the mean ± standard deviation. Analysis was performed via two-way repeated-measures ANOVA. Abbreviations: CGRP, calcitonin gene-related peptide. Serum c-Fos is used as a surrogate marker for neuronal activation in central pain pathways, including the spinal dorsal horn.

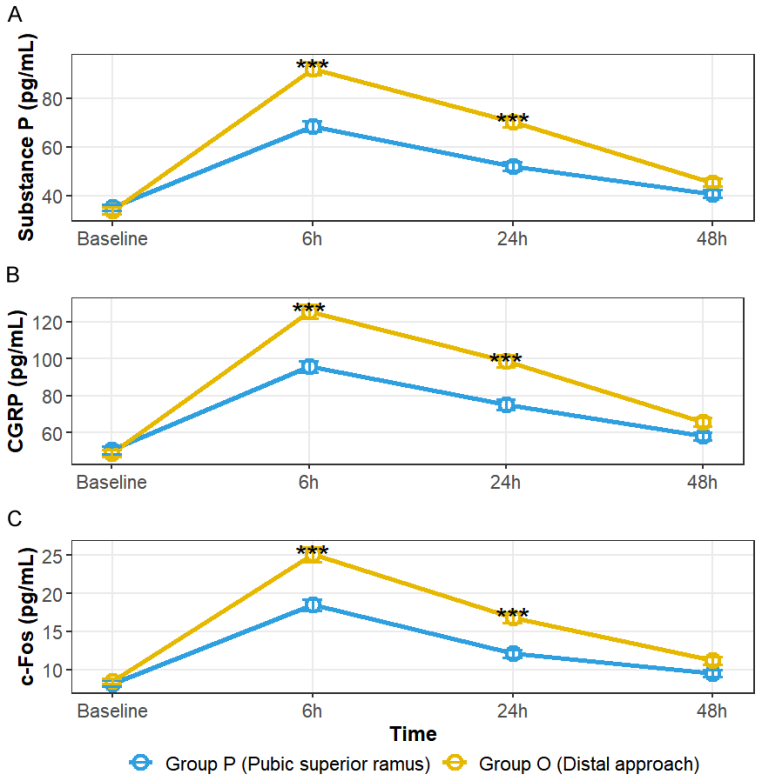


**Figure 7.** Temporal changes in serum biomarker levels. Line graphs showing the concentrations of (A) Substance P, (B) CGRP (calcitonin gene-related peptide), and (C) c-Fos at baseline, 6 hours, 24 hours, and 48 hours post-surgery in Group P (blue line, pubic superior ramus approach, n = 34) and Group O (orange line, distal approach, n = 34). Data are presented as mean ± standard error. ***P < 0.001 between groups at the indicated time points.

including the spinal dorsal horn, was significantly lower in Group P at its 6-hour peak (18.5 ± 4.2 vs. 25.1 ± 5.6 pg/mL, P < 0.001) and at the 24-hour time point (12.1 ± 3.0 vs. 16.8 ± 4.1 pg/mL, P < 0.001). The dynamic changes of these molecular markers are visually synthesized in **Figure 7**. Collectively, these findings provide mechanistic evidence that the pubic superior ramus approach leads to a more effective suppression of pain-related neuropeptide release and a reduction in central neuronal activation, which aligns with the observed superior analgesic and recovery profiles.

## Discussion

Our randomized controlled trial demonstrates that the ultrasound-guided modified PENG block using a pubic superior ramus approach offers multidimensional advantages over conventional distal obturator nerve blockade for patients undergoing TURBT. This technique achieved more efficient surgical conditions through rapid motor blockade, provided superior postoperative analgesia, enhanced recov-

ery quality, attenuated physiological stress response, improved hemodynamic stability, and promoted better functional outcomes. Interestingly, the primary endpoint of obturator nerve reflex incidence and severity showed no significant difference between groups. This apparent paradox likely reflects the high efficacy of both ultrasound-guided techniques in achieving the primary clinical goal of preventing significant adductor contractions that compromise surgical safety. The comparable success rates suggest a "ceiling effect" where both approaches provide adequate protection against clinically relevant reflexes [21]. However, this finding should not overshadow the consistent benefits of the pubic superior ramus approach across numerous secondary outcomes critically important to perioperative care. Our study's major contribution lies in providing not only robust perioperative data but also novel long-term follow-up and mechanistic insights that collectively redefine this technique's clinical value.

The procedural efficiency of the pubic ramus approach derives from its consistent ultrasonographic anatomy. The pubic ramus serves as a reliable bony landmark that facilitates precise needle placement deep to the pectineus muscle. Our cadaveric study confirmed that injectate at this site consistently stained both the main obturator nerve trunk and accessory obturator nerve, enabling comprehensive neural blockade through a single injection. This contrasts with distal approaches that require separate targeting of anterior and posterior branches, often necessitating multiple injections and carrying higher risk of incomplete blockade [22]. The significantly greater and more rapid reduction in adductor muscle strength observed in Group P aligns with the principle of proximal neural blockade before branch division, supported by previous comparative studies [23]. These findings reinforce existing literature indicating proximal obturator nerve blockade produces more effective adductor motor blockade than distal techniques [24]. By targeting the nerve proximal to its division, complete motor inhibition occurs with greater efficiency and faster onset, eliminating the need for intraoperative management of multiple neural branches.

A crucial extension of these intraoperative advantages is their translation into sustained clinical value, as evidenced by our 12-month follow-up data. The significantly improved urodynamic parameters including higher Qmax and lower PVR in Group P suggest that a more profound initial blockade mitigates secondary trauma to bladder and pelvic floor innervation caused by even minor adductor spasms. This correlation supports the concept that superior surgical quality without neuromuscular disruption promotes better long-term functional organ preservation. Correspondingly, the markedly reduced chronic pelvic pain incidence in Group P underscores the importance of effective acute pain management in preventing pain centralization and chronification. Furthermore, the trend toward reduced tumor recurrence rates in Group P, while not statistically significant, represents a compelling observation that merits discussion. This finding aligns with the emerging "immuno-protection" hypothesis proposing regional anesthesia may confer oncological advantages. Recent meta-analyses and studies from 2024-2025 suggest that through attenuation of surgical stress response, preservation of perioperative immune function, and reduced administration of immunosuppressive opioids, regional anesthesia may create an unfavorable microenvironment for residual cancer cell survival [25-27]. Our demonstration of significantly lower stress biomarkers and opioid consumption in Group P provides direct clinical evidence supporting this promising hypothesis.

When contextualizing the pubic superior ramus approach within broader obturator reflex prevention strategies, it demonstrates distinct advantages over other mainstream techniques. While deep neuromuscular blockade effectively prevents adductor contraction, it provides no postoperative analgesic benefits, carries residual paralysis risks, and offers none of the long-term functional improvements observed in our study. Surgical innovations such as bipolar or Holmium laser resection have demonstrated reduced obturator reflex incidence [28], but these technologies involve substantial costs and limited availability. Our nerve block technique remains compatible with standard resectoscopes, representing an accessible and cost-effective solution that delivers comprehensive postoperative and long-term benefits unattainable through purely surgical or muscle-relaxant-based strategies.

The profound postoperative analgesia in Group P, evidenced by reduced opioid requirements and lower pain scores, constitutes a therapeutic cornerstone. While the obturator nerve has limited sensory distribution, primary post-TURBT pain originates from resected bladder mucosa and detrusor muscle spasms. We propose superior analgesia is achieved indirectly through complete abolition of violent adductor contractions associated with the obturator reflex, thereby eliminating a major noxious intraoperative stimulus. This results in diminished overall surgical trauma and consequent reduction in postoperative pain states [29]. This mechanism finds support in literature confirming that effective obturator nerve blockade prevents adductor spasm, optimizes surgical conditions, minimizes secondary tissue trauma, and reduces postoperative pain levels [4]. Additionally, by reducing somatic pain and muscle spasms, the proximal blockade may have indirectly alleviated postoperative catheter-related bladder discomfort, a frequent contributor to patient agitation [30].

Our molecular analyses provide neurochemical foundation for these superior outcomes, constructing a coherent mechanistic pathway from neural blockade to patient benefit. The significantly attenuated Substance P and CGRP levels in Group P indicate proximal blockade more effectively suppresses peripheral neurogenic inflammation. These neuropeptides represent primary mediators released from nociceptive terminals that promote vasodilation and plasma extravasation, directly contributing to localized inflammation and pain [31]. By interrupting this process, the blockade mitigates tissue injury and postoperative pain. Concurrently, reduced serum c-Fos concentrations strongly suggest proximal blockade diminishes afferent nociceptive barrage to the central nervous system. This effect is crucial for preventing synaptic reorganization and neuronal hyperexcitability underlying central sensitization, a key driver of chronic pain pathogenesis [32]. Consequently, we propose a comprehensive model where more extensive proximal nerve blockade produces more effective afferent signal inhibition, which subsequently suppresses peripheral neuropeptide release to reduce neurogenic inflammation while decreasing spinal c-Fos expression to prevent central sensitization. This dual mechanism explains the observed superior analgesia, accelerated recovery, and reduced chronic pain incidence. These discoveries align with cutting-edge research indicating local anesthetics can directly modulate intracellular inflammatory signaling cascades including the MAPK/ERK pathway following neuronal blockade, providing deeper understanding of their anti-inflammatory and neuroprotective effects [33, 34].

The enhanced patient-reported recovery quality measured by QoR-40 directly results from superior analgesia and reduced opioid burden. Elevated QoR-40 scores particularly in physical comfort and independence domains reflect patients' accelerated return to normal activities [35, 36]. Opioid-sparing methodologies are conclusively linked to improved postoperative recovery quality, with QoR-40 serving as a validated instrument. Research indicates that a 10-point QoR-40 improvement represents clinical significance corresponding to 15% enhancement in recovery quality [37]. The higher QoR-40 scores in Group P objectively demonstrate that proximal blockade through optimized analgesia and diminished opioid requirements provided clinically meaningful recovery advantages. This accelerated trajectory represents a fundamental ERAS objective, positioning our technique as a key enabler in urological surgery.

Furthermore, our study objectively confirms that proximal blockade significantly attenuates surgical stress response. The lower CRP, IL-6, and cortisol concentrations in Group P indicate more effective suppression of neuroendocrine and inflammatory cascades. This observation aligns with literature demonstrating regional anesthesia's capacity to mitigate physiological stress responses [38]. Notably, nerve block efficacy may be influenced by patient demographics and surgical characteristics. One investigation reported peripheral nerve blockade produced no significant effect on postoperative inflammatory response in elderly patients undergoing total knee arthroplasty [39], suggesting future studies should elucidate proximal blockade's applicability across varying clinical scenarios. By delivering denser afferent blockade, the proximal technique appears to more effectively counter this detrimental physiological response.

The improved intraoperative hemodynamic stability characterized by minimized blood

pressure fluctuations and reduced vasopressor requirements likely derives from elimination of both pain-induced sympathetic activation and the abrupt intense stimulation from obturator reflex [22, 40]. Stable hemodynamic conditions enhance patient safety while optimizing surgical conditions for precise resection.

A critical advantage of our approach is the preservation of quadriceps function, anticipated from cadaveric observations and clinically confirmed. Inadvertent femoral nerve blockade causes lower extremity weakness, delays mobilization, and increases fall risk [41]. Our technique's capacity to provide complete surgical anesthesia while maintaining ambulatory function represents a significant advancement directly supporting early mobilization. Within ERAS frameworks, quadriceps preservation constitutes a fundamental objective for promoting safe early patient mobilization. Conventional femoral nerve blockade frequently contradicts ERAS principles due to significant quadricep weakness [42]. Thus, our motor-sparing proximal blockade aligns with contemporary trends favoring motor-sparing regional anesthesia techniques, representing a crucial advancement in ERAS pathway optimization [43].

This study's innovation encompasses multiple dimensions. Technically, it adapts the PENG block concept to achieve targeted proximal obturator nerve blockade for TURBT. This methodology utilizes a single injection onto the pubic ramus to reliably encompass both main and accessory obturator nerves, simplifying the procedure and enhancing comprehensiveness compared to distal branch-level blocks. Second, it provides comprehensive clinical validation by transcending obturator reflex prevention to demonstrate multidimensional superior outcomes including exceptional procedural efficiency, opioid-sparing analgesia, blunted stress response, and marked recovery quality improvement. Particularly significant is the favorable motor-sparing profile facilitating rapid quadricep recovery and early ambulation without compromising surgical conditions, coupled with potential for improved long-term bladder function previously unexplored in TURBT nerve block literature.

Several limitations warrant acknowledgment. First, the anatomical feasibility study utilized a single fresh cadaver bilaterally. Although consistent bilateral staining provides compelling anatomical rationale, this limited sample cannot fully accommodate individual anatomical variations. Future anatomical investigations incorporating larger specimen numbers are necessary to corroborate these findings. Second, this single-center investigation featured non-blinded anesthesiologists performing blocks, potentially introducing performance bias despite blinded outcome assessors. Furthermore, while promising, long-term data and oncological trends require validation through larger multicenter trials. Our mechanistic exploration relied on serum biomarkers reflecting systemic responses; subsequent research could integrate animal models to examine direct histological and molecular changes at spinal cord and peripheral nerve levels. Finally, while we contextualized our technique alongside alternative strategies, this constituted indirect comparison based on existing literature. Prospective randomized trials directly comparing pubic ramus block with deep NMB or contemporary laser techniques are essential to definitively establish its clinical position.

## Conclusion

The ultrasound-guided pubic superior ramus approach for obturator nerve blockade represents a superior alternative to distal techniques for TURBT. It demonstrates enhanced performance efficiency, provides reliable obturator reflex prevention, and delivers comprehensive benefits including superior analgesia, accelerated recovery, attenuated stress response, hemodynamic stability, and faster functional recovery with potential for improved long-term bladder health. Its favorable profile establishes this technique as a valuable ERAS component for TURBT patients, potentially enhancing both immediate perioperative care and long-term functional outcomes.

## Disclosure of conflict of interest

None.

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