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CLINICAL TRIAL REPORT

# Effects of Deep versus Moderate Neuromuscular Blockade on Postoperative Acute and Chronic Pain in Laparoscopic Gynecological Surgery

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**Purpose:** To evaluate the effects of deep neuromuscular blockade (D-NMB) versus moderate NMB (M-NMB) on postoperative pain and chronic postsurgical pain (CPSP) in patients undergoing laparoscopic gynecological surgery.

**Patients and Methods:** Seventy-two patients scheduled for laparoscopic uterine or adnexal surgery were randomly assigned to Group D (D-NMB, post-tetanic count 1–2) or Group M (M-NMB, train-of-four count 1–2). Postoperative pain was assessed using the visual analogue scale (VAS) at multiple time points. Surgeon satisfaction score (SRS), opioid consumption, Quality of Recovery-15 (QoR-15) score, and CPSP incidence at 3 and 6 months were compared.

**Results:** The VAS score at 0.5 hours postoperatively was significantly lower in Group D than in Group M (4.18±1.40 vs. 5.42±1.61, P=0.001). Postoperative opioid consumption and the proportion requiring additional analgesia were significantly reduced in Group D (P=0.011 and P=0.019, respectively).SRS and QoR-15 scores were significantly higher in Group D (P<0.001 and P=0.022, respectively). No significant differences were observed in CPSP incidence or adverse reactions between the two groups.

**Conclusion:** D-NMB improves early postoperative pain control, reduces opioid requirements, and enhances surgeon satisfaction and early recovery quality without increasing adverse events, but does not reduce CPSP incidence.

**Keywords:** neuromuscular blockade, postoperative pain, deep neuromuscular blockade, chronic postsurgical pain

## Introduction

With the development of minimally invasive surgical techniques, laparoscopic uterine and adnexal surgeries have become mainstream surgical approaches for benign gynaecological diseases. Although this surgical method can accelerate patient recovery and reduce postoperative pain, some patients still experience postoperative pain, of which acute and chronic postoperative pain in female patients is particularly prominent.[1] Optimal anaesthetic management, including the selection of the neuromuscular blockade type, can optimise the surgical process and exert a positive impact on perioperative and long-term outcomes. Thus, the rational selection of neuromuscular blockade (NMB) depth has important clinical significance.

The advantages of deep NMB in laparoscopic surgery have not been fully confirmed. A study on laparoscopic hernia repair surgery indicated that under the guidance of pulse oxygen saturation index, deep neuromuscular blockade (D-NMB) anaesthesia can reduce the total requirement of remifentanil compared with moderate neuromuscular blockade (M-NMB) anesthesia;[2] another randomised controlled trial on laparoscopic hysterectomy showed that D-NMB can reduce postoperative shoulder pain, but there was no difference in surgical duration and postoperative recovery compared with M-NMB.[3] In addition, clinical studies on the effects of D-NMB anaesthesia on postoperative chronic pain in patients are still relatively scarce.

This study aimed to evaluate the effects of D-NMB and M-NMB anaesthesia on postoperative pain intensity and the incidence of chronic postsurgical pain (CPSP) in patients undergoing laparoscopic pelvic surgeries for benign uterine or

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adnexal diseases. It is hoped that through the precise selection of the NMB depth, the anaesthetic management strategy can be improved, and the diagnosis, treatment quality, and prognosis of patients undergoing laparoscopic gynaecological surgery can be further enhanced.

## Materials and Methods

This study was a single-center, randomized controlled trial, and patients were randomly assigned to two parallel study groups at a 1:1 ratio. The study was approved by the Ethics Committee of The Second People's Hospital of Wuhu City (Approval No.: 2024-KY-47) and prospectively registered at the Chinese Clinical Trial Registry (ChiCTR; https://www.chictr.org.cn/) with the registration number ChiCTR2400087777. Informed consent was obtained from all patients. For those who were unable to sign their own names, the research team specifically obtained informed consent from their legally authorized representatives. Prior to study enrollment, the research team assessed each patient's capacity to provide informed consent via a standardized communication ability evaluation.This study was conducted in accordance with the principles of the Declaration of Helsinki.

## Inclusion Criteria

Patients scheduled for elective laparoscopic surgery in the Department of Gynecology of our hospital from September 2024 to January 2025, aged 18–65 years, with a body mass index (BMI) of 18–30 $kg/m^2$, and American Society of Anesthesiologists (ASA) physical status classification I or II.

## Exclusion Criteria

Pregnant or lactating women; predicted difficult airways; preoperative comorbidities of severe cardiovascular and cerebrovascular diseases or endocrine system diseases; hepatic or renal insufficiency; allergies to rocuronium, neostigmine, or sugammadex; history of chronic pain or preoperative allodynia; comorbid neuromuscular diseases; peripheral neuropathy caused by diabetes; history of drug or alcohol abuse; and inability to cooperate with the study or communication disorders due to severe visual, hearing, speech impairments, or other reasons.

## Withdrawal Criteria

Operation duration less than 60 minutes; conversion to open surgery during the operation; reoperation during the observation period; failure to complete visual analogue scale (VAS) pain assessment as required; and voluntary withdrawal from the study or loss to follow-up during the observation period.

## Grouping and Intervention

Patients were randomly divided into the D-NMB group (Group D) and the M-NMB control group (Group M) using the random number table method. Continuous neuromuscular function monitoring was performed after induction of general anaesthesia. During key surgical procedures, Group M maintained a train-of-four (TOF) count of 1–2, while Group D maintained a post-tetanic count (PTC) of 1–2.

## Blinding

All study interventions were performed under general anaesthesia, and the participants were unaware of their group assignment. Neuromuscular relaxation monitoring and administration of muscle relaxants were performed by anaesthesiologists, while surgeons, post-anaesthesia care unit (PACU) nurses, ward nurses, and follow-up personnel were blinded (unaware of the group assignment).

## Anesthesia Method

All patients fasted for 8 hours and abstained from clear liquids for 2 hours before surgery. After entering the operating room, oxygen was inhaled via a nasal cannula, and routine monitoring of electrocardiogram (ECG), blood pressure (BP), heart rate (HR), blood oxygen saturation ($SpO_2$), and body temperature (T) was performed. Radial artery puncture and catheterisation were performed under local anaesthesia for invasive blood pressure monitoring.

## Anaesthesia Induction

Etomidate (0.2–0.3 mg/kg) and sufentanil (0.2–0.3 μg/kg) were intravenously injected sequentially. After the patient lost consciousness, rocuronium (0.6–0.9 mg/kg) was intravenously administered, and tracheal intubation was performed 2 minutes later, followed by volume-controlled ventilation with an anaesthesia machine. Continuous intraoperative monitoring included Bispectral Index (BIS), end-tidal carbon dioxide ($PetCO_2$), and neuromuscular transmission (NMT) function.

## Anaesthesia Maintenance

Propofol and remifentanil were continuously infused intravenously, and sevoflurane was inhaled to maintain haemodynamic stability, with the BIS value controlled within 40–60. Under the volume-controlled ventilation mode, the tidal volume was set to 6–8 mL/kg, and the respiratory rate was adjusted to maintain $PetCO_2$ at 35–45 mmHg. The infusion rate was adjusted according to the HR, mean arterial pressure (MAP), and urine output. Before the use of rocuronium, the electromyography instrument was calibrated and stabilised. Both groups received additional rocuronium at divided doses as needed during the key surgical steps to maintain a TOF count of 1–2 in Group M and a PTC count of 1–2 in Group D. At the end of surgery, a blinded chief surgeon evaluated the surgical field scores.

## Management During the Anesthesia Recovery Period

If the TOF count was < 2, sugammadex (2 mg/kg) was intravenously administered; if the TOF count was ≥ 2, neostigmine (0.04–0.07 mg/kg) was given. Extubation was performed only when the train-of-four ratio (TOFr) was ≥ 90% and the patient was able to open their eyes and follow commands to shake hands. After extubation, high-flow oxygen was provided, and the patient was transferred to the post-anaesthesia care unit (PACU) for routine monitoring once $SpO_2$ stabilised at ≥ 95%.

Postoperative analgesia was standardised across both groups using a multimodal regimen. Patient-controlled intravenous analgesia (PCIA) was delivered with sufentanil 100 μg and ondansetron 8 mg diluted in normal saline to a total volume of 100 mL, using a bolus dose of 0.5 mL, a lockout interval of 15 minutes, and no continuous background infusion. If the VAS score was ≥ 4, rescue analgesia with intravenous flurbiprofen axetil (50 mg) was administered. Nonsteroidal anti-inflammatory drugs (NSAIDs) were not routinely administered unless required as rescue analgesia.

## Outcome Measures

### Primary Outcome Measures

VAS pain scores at 0.5, 2, 4, 6, and 24 hours postoperatively and the incidence of CPSP. CPSP was defined as persistent or recurrent pain lasting more than 3 months after surgery, assessed by telephone follow-up. Patients were considered to have CPSP if they reported (1) any pain in the surgical area, (2) a VAS score ≥ 1, and (3) continued use of analgesics or interference with daily activities attributable to the pain.

### Secondary Outcome Measures

Demographic characteristics; surgeon's satisfaction with the surgical field (assessed by a 5-point Likert scale: 1 = Poor, 2 = Fair, 3 = Acceptable, 4 = Good, 5 = Excellent);[4] duration of surgery (from skin incision to suture completion, unit: min); postoperative extubation time (from the end of surgery to extubation, unit: min); total intraoperative and postoperative opioid consumption (converted to morphine equivalent, unit: mg); number of patients requiring additional postoperative analgesia; 24-hour postoperative patient's overall recovery satisfaction (assessed by the Quality of Recovery-15 (QoR-15) scale); and adverse reactions.

## Statistical Analysis

Based on a preliminary pilot study, the incidence of VAS pain score ≥ 4 within half an hour after tracheal extubation was 4/7 (57.1%) and 2/8 (25.0%) in the two groups, with an absolute difference of approximately 32%. Setting the two-tailed Type I error rate $\alpha = 0.05$, Type II error rate $\beta = 0.2$ (power = 0.8), and assuming equal sample sizes in the two groups,

the calculated total required sample size was 60 patients. Considering the long postoperative follow-up period and a 15% attrition rate, 72 patients (36 in each group) were enrolled in this study.

All data were statistically analysed using SPSS 27.0. Quantitative data were tested for normality. Data conforming to a normal distribution were expressed as mean ± standard deviation ($\bar{x} \pm s$), and comparisons between the two groups were performed using the independent samples *t*-test. Data with non-normal distribution are expressed as median (interquartile range) [M (Q1, Q3)], and comparisons between groups were conducted using the Mann–Whitney *U*-test. Repeated-measures data were analysed using a two-way repeated-measures analysis of variance (ANOVA), and comparisons at different time points within the same group were corrected using the Bonferroni method. Categorical data were presented as numbers (percentages) [n (%)], and comparisons between groups were performed using the Chi-square test or Fisher's exact test. A significance level of $\alpha = 0.05$ was adopted, and a P value < 0.05 was considered statistically significant.

## Results

Between September 2024 and February 2025, a total of 72 patients who met the indications for laparoscopic gynaecological surgery underwent eligibility assessment. Among them, two patients met the exclusion criteria, two refused to participate, and three patients in Group M were excluded because of a surgical duration of less than 1 hour or loss to follow-up. Finally, 65 patients were enrolled: 34 in Group D and 31 in Group M (Figure 1). No significant differences were observed in age, BMI, ASA physical status classification, surgical type, or surgical duration between the two groups (all P>0.05), indicating that the baseline data were balanced and comparable (Table 1).

There was no significant difference in the overall VAS pain scores between the two groups (P=0.204), with the highest pain score observed at 0.5 hours postoperatively. At 0.5 hours postoperatively, the VAS score in Group M was significantly higher than that in Group D (5.42±1.61 vs 4.18±1.40, mean difference 1.24, t=3.33, P=0.001, 95% CI: 0.50~1.99)., while no significant differences were found between the two groups at 2, 4, 6, and 24 hours postoperatively (all P>0.05) (Figure 2). The incidence of CPSP at 3 months postoperatively was 2.94% (1/34) in Group D and 9.68% (3/

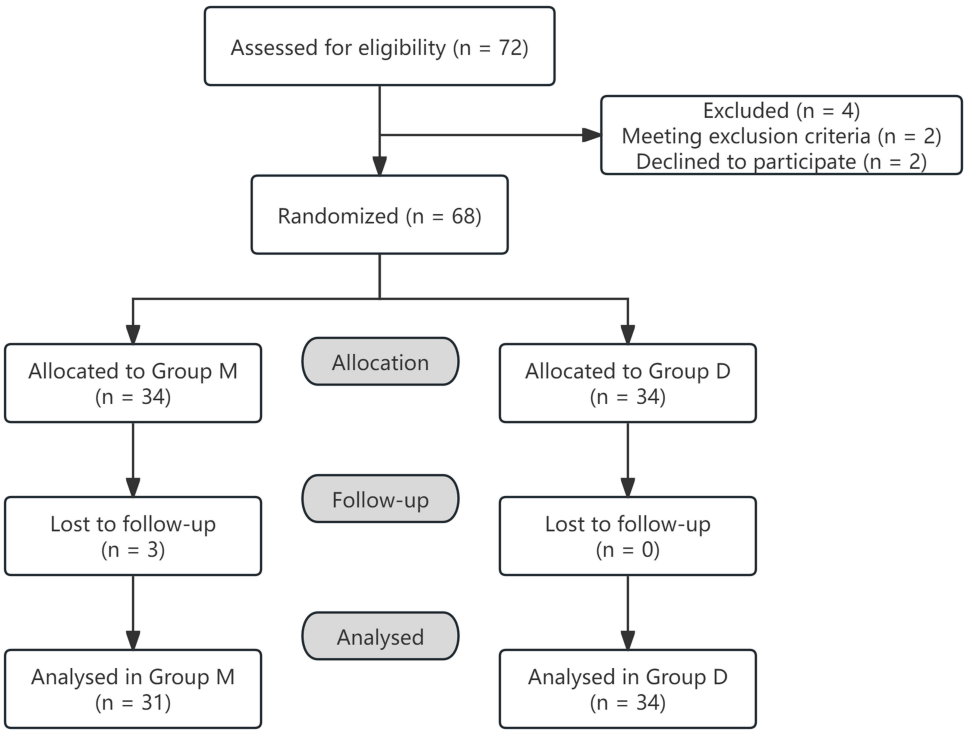


**Figure 1** CONSORT flow diagram of patient recruitment and randomization. A total of 72 patients were assessed for eligibility. After excluding those who did not meet the inclusion criteria (n = 2), refused to participate (n = 2), and those lost to follow-up or with surgical duration < 1 hour in Group M (n = 3), 65 patients were finally included in the analysis (34 in Group D and 31 in Group M).

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**Table 1** Demographic Characteristics and Surgery-Related Data of Patients

| Index | Group D (n=34) | Group M (n=31) | Statistic | p value |
|---|---|---|---|---|
| Age (years) | 42.21±8.98 | 43.23±9.68 | t=0.009 | 0.993 |
| BMI (kg/m$^2$) | 24.03±2.47 | 22.97±2.84 | t=1.602 | 0.114 |
| ASA classification (I/II) | 27/7 | 26/5 | $\chi^2$=0.214 | 0.643 |
| Surgery type (n, %) | | | $\chi^2$=1.237 | 0.539 |
| Uterine surgery | 12(35.3) | 10(32.3) | | |
| Adnexal surgery | 10(29.4) | 13(41.9) | | |
| Combined uterine and adnexal surgery | 12(35.3) | 8(25.8) | | |
| Surgical duration (min) | 111.97±38.48 | 122.13±43.82 | t=0.995 | 0.323 |

**Notes**: Table 1 summarizes demographic characteristics and surgery-related data of enrolled patients. Group D (n=34) and Group M (n=31) represent the two study groups. Continuous variables (age, body mass index [BMI], surgical duration) are reported as mean ± standard deviation, with between-group comparisons conducted using the *t*-test (corresponding statistic is denoted as "t"). Categorical variables (ASA classification, surgery type) are reported as counts (percentages) or ratios, with between-group comparisons conducted using the chi-square test (corresponding statistic is denoted as "$\chi^2$").

31) in Group M, with no significant difference (P=0.341, Fisher's exact test; odds ratio 0.28, 95% CI: 0.03~2.86). The incidence of CPSP in both groups was zero at 6 months postoperatively (Table 2).

The intraoperative dosage of rocuronium in Group D was significantly higher than that in Group M (77.91±14.80 mg vs 65.54±15.43 mg, t=3.30, P=0.002, 95% CI: 4.88~19.87) (Figure 3A). The usage rate of sugammadex sodium in Group D was also significantly higher than that in Group M [29.41% (10/34) vs. 6.45% (2/31), P=0.001, 95% CI: 7.84% ~38.08%] (Figure 3B). There was no significant difference in the extubation time between the two groups (P=0.148) (Figure 3C). The surgeon's satisfaction score (SRS) in Group D was significantly higher than that in Group M (4.74±0.45 vs 3.94±0.68, t=5.648, P<0.001, 95% CI: 0.52~1.08).

No significant difference was found in the intraoperative morphine equivalent consumption between the two groups (282.21±89.38 mg vs 309.62±89.38 mg, t=1.00, P=0.321, 95% CI: −82.17~27.36)(Figure 4A). The postoperative morphine equivalent in Group D was significantly lower than that in Group M (29.81±16.86 mg vs 41.42±18.68 mg, t=2.63, P=0.011, 95% CI: 2.80~20.42)(Figure 4B). The proportion of patients requiring additional analgesics was significantly lower in Group D than in Group M [35.29% (12/34) vs. 64.52% (20/31), Chi-square =5.54, P=0.019, 95% CI: –51.79%~–6.67%] (Figure 4C).

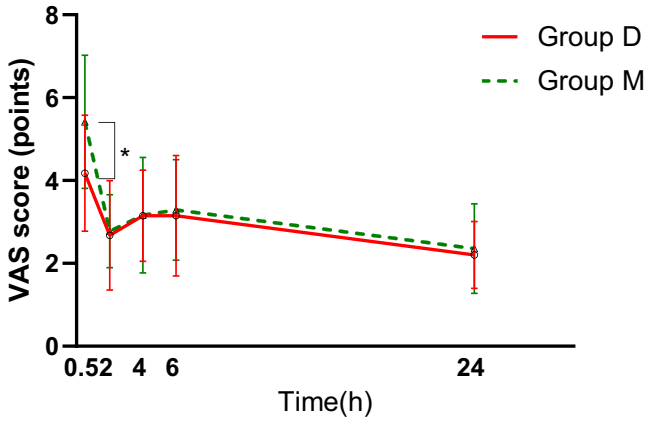


**Figure 2** Comparison of VAS scores at different time points between the two groups. FIGURE 2 illustrates the comparison of Visual Analog Scale (VAS) scores between Group D (solid red line) and Group M (dashed green line) at different postoperative time points (0.5, 2, 4, 6, and 24 hours). VAS scores (expressed as pain intensity in points) are presented as mean ± standard deviation (SD), with error bars representing the standard deviation. Statistical analysis was conducted using repeated-measures analysis of variance (ANOVA) for overall comparisons of VAS scores over time, followed by post-hoc independent samples t-tests to compare differences between the two groups at each individual time point. The asterisk (*) denotes a statistically significant difference between Group D and Group M at the corresponding time point (P < 0.05).


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**Table 2** Chronic Postoperative Pain (CPSP) at 3 and 6 Months Postoperatively

| Index | Group D (n=34) | Group M (n=31) | OR | 95% CI | p value |
|---|---|---|---|---|---|
| CPSP at 3 months postoperatively (n, %) | 1(2.94) | 3(9.68) | 0.28 | 0.03, 2.86 | 0.341 |
| CPSP at 6 months postoperatively (n, %) | 0(0.00) | 0(0.00) | NA | NA | NA |

**Notes**: Table 2 presents the incidence of chronic postoperative pain (CPSP) in Group D (n=34) and Group M (n=31) at 3 and 6 months postoperatively. Data are reported as counts (percentages). Between-group comparisons of categorical data were performed using the Fisher's exact test. CPSP = Chronic Postoperative Pain "NA" denotes "Not Applicable" (no valid statistical result due to zero events in both groups).

The Quality of Recovery-15 (QoR-15) score in Group D was significantly higher than that in Group M (105.15±9.03 vs 100.13±8.10, t=2.350, P=0.022, 95% CI: 0.75~9.29). There were no significant differences in the incidence of postoperative adverse reactions, such as cough and expectoration, nausea and vomiting, dizziness, pruritus, and urinary retention, between the two groups (all P>0.05) (Table 3).

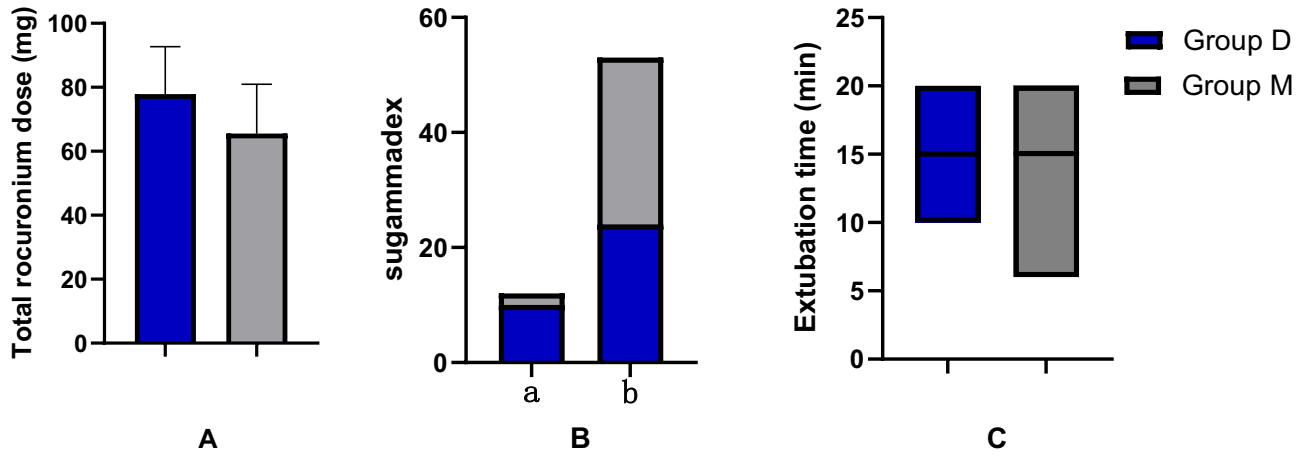


**Figure 3** Total rocuronium dose, sugammadex administration status, and extubation time in Group D and Group M. FIGURE 3 presents the total rocuronium dose, sugammadex administration status, and extubation time between Group D (n=34) and Group M (n=31): (**A**) Total rocuronium dose, displayed as mean ± standard deviation (SD); statistical comparison was performed using independent samples *t*-test (t=3.30, P=0.002). (**B**) Sugammadex administration status: in this subfigure, " a" indicates patients who received sugammadex, while " b " indicates those who did not receive sugammadex; statistical analysis was conducted using chi-square test ($\chi^2$=4.256, P=0.001). (**C**) Extubation time, presented as median with interquartile range; statistical comparison was carried out using Mann–Whitney *U*-test (Z=−1.446, P=0.148). In the figure, blue bars represent Group D, and gray bars represent Group M.

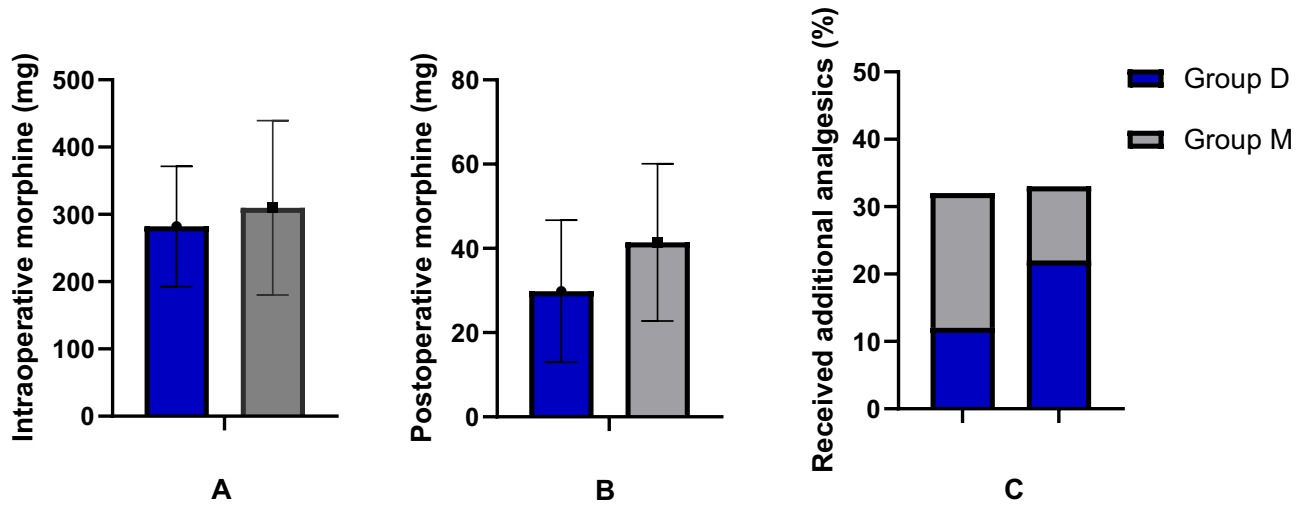


**Figure 4** Perioperative opioid consumption and postoperative additional analgesia in Group D and Group M. FIGURE 4 displays the perioperative opioid dosage and postoperative additional analgesia status in Group D (n=34) and Group M (n=31): (**A**) Intraoperative morphine equivalent dose, presented as mean ± standard deviation (SD); statistical analysis was performed using independent samples *t*-test (t=1.00, P=0.321). (**B**) Postoperative morphine equivalent dose, presented as mean ± SD; statistical analysis was performed using independent samples *t*-test (t=2.63, P=0.011). (**C**) Incidence of postoperative additional analgesic administration, presented as percentage; statistical analysis was performed using chi-square test ($\chi^2$=5.54, P=0.019). In the figure, blue bars represent Group D, and gray bars represent Group M.


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**Table 3** Postoperative Adverse Reactions

| Index | Group D (n=34) | Group M (n=31) | p value |
|---|---|---|---|
| Sore throat (n, %) | 2(5.88) | 3(9.68) | 0.663 |
| Nausea and vomiting (n, %) | 2(5.88) | 2(6.45) | 1.000 |
| Dizziness (n, %) | 3(8.82) | 4(12.90) | 0.701 |
| Pruritus (n, %) | 0(0.00) | 0(0.00) | NA |
| Urinary retention (n, %) | 3(8.82) | 1(3.23) | 0.615 |

**Notes**: Table 3 displays the incidence of postoperative adverse reactions in Group D (n=34) and Group M (n=31). Data are presented as counts (percentages). Between-group comparisons of categorical variables were conducted using the Fisher's exact test. "NA" indicates "Not Applicable": since no pruritus events occurred in either group, valid statistical analysis could not be performed for this adverse reaction.

## Discussion

Laparoscopic surgery is superior to open surgery in reducing the inflammatory response, immune suppression, and bleeding, as well as in promoting rapid recovery; however, postoperative pain remains common. This pain originates from peritoneal stretching, inflammatory response, postoperative gas retention, and muscle spasm and manifests as incision, visceral, and shoulder pain.[5] According to the World Health Organization's International Classification of Diseases (ICD-11), pain lasting more than 3 months is defined as chronic pain, which is difficult to treat and mostly persistent.[6] Therefore, an effective perioperative pain management strategy is crucial to improve postoperative recovery and reduce the risk of chronic pain.

NMB is an important component of general anaesthesia. M-NMB is commonly used in clinical practice for laparoscopic surgery; however, M-NMB may increase surgical difficulty owing to patient movement or frequent additional administration of muscle relaxants. In recent years, the clinical application of sugammadex sodium has promoted research on D-NMB, which has the potential advantages of reducing intraoperative and postoperative bleeding and promoting postoperative recovery.[7] Huang et al showed that D-NMB can better protect the intestinal mucosal barrier and intestinal flora and significantly promote the recovery of intestinal function after laparoscopic gastrectomy.[8] Currently, evidence of the effect of D-NMB on postoperative pain is limited, and studies on postoperative chronic pain in patients undergoing gynaecological laparoscopic surgery are particularly scarce. This study hypothesised that D-NMB could reduce the incidence of perioperative acute pain and CPSP in patients undergoing laparoscopic surgery, with the aim of providing a reference for clinical anaesthetic management.

Women have a higher risk of chronic pain and lower pain tolerance.[9] The incidence of postlaparoscopic pain syndrome (STP) is closely related to the duration of surgery.[1] Therefore, this study selected patients undergoing gynaecological laparoscopic surgery with a surgical duration of > 60 minutes as research participants.

In this study, the maximum pain score was analysed as the highest value of abdominal pain, movement-induced pain, cough-induced pain, and shoulder pain in the participants at each postoperative time point. The pain peak was reached at 0.5 hours postoperatively in both groups, and the pain intensity in Group D was significantly lower than that in Group M at this time point. The difference in VAS scores at 0.5 hours postoperatively (1.24 points) was statistically significant. The minimal clinically important difference (MCID) for VAS in acute postoperative pain is generally reported to be between 1.0 and 1.5 cm on a 10-cm scale. Thus, this difference approaches or meets the threshold for clinical relevance, particularly in the early postoperative period when pain is most severe and may influence early recovery milestones. There were no significant differences in VAS scores between the two groups at the other four time points, which is speculated to be related to the timely supplementary administration of additional analgesics. Data showed that the proportion of patients requiring additional postoperative analgesia in Group D (35.29%) was significantly lower than that in Group M (64.52%), and the total postoperative opioid consumption (converted to morphine equivalents) was also significantly lower, suggesting that intraoperative D-NMB can reduce the degree of postoperative acute pain. This result is consistent with the study by Corrado Terranova et al[5] which also confirmed that the use of deep neuromuscular relaxation in gynaecological laparoscopic surgery can optimise pain control and recovery indicators. This consistency enhances the clinical credibility of the results of this study.

The mechanism by which D-NMB reduces postoperative acute pain may be related to more effective relaxation of the abdominal muscles by deep neuromuscular relaxation, which reduces traction stimulation of the abdominal wall and diaphragm caused by pneumoperitoneum.[10] A study in a rat model,[11] revealed the relevant pathological mechanism: muscle contraction can significantly activate nociceptive dorsal horn neurones (DHN), and D-NMB can inhibit DHN activation and pain transmission by improving abdominal wall compliance and reducing intraoperative muscle contraction, thereby exerting a potential analgesic effect.

In this study, the surgeon satisfaction score (SRS) was significantly higher in the D-NMB group than in the M-NMB group, indicating that deep neuromuscular blockade provided better surgical field visibility and working space. This finding aligns with the notion that optimized abdominal wall relaxation under D-NMB facilitates laparoscopic exposure and reduces the need for excessive retraction or high pneumoperitoneum pressure. In a broader surgical context, Güner et al demonstrated that enhanced abdominal wall manipulation during gynecologic laparoscopy—specifically using a median umbilical ligament lift-up technique—improved surgical efficiency and safety compared with conventional Veress needle entry.[12] Although their study focused on entry technique rather than neuromuscular blockade, both approaches underscore the importance of optimizing abdominal wall dynamics to achieve superior surgical conditions. Integrating these perspectives, D-NMB may contribute to a cohesive perioperative framework in which improved surgical exposure not only supports the surgeon's technical performance but also reduces intraoperative tissue trauma, potentially mitigating postoperative pain and enhancing recovery outcomes.

The pathological mechanisms underlying acute postoperative pain include inflammatory cell infiltration, the activation of spinal pain pathways, and reflex muscle spasms, which are mostly relieved during the postoperative recovery period. However, in some patients, if preoperative pain persists and activates pain pathways, it may progress to CPSP,[13] and the higher the degree of acute pain, the higher the risk of chronicization. The results of telephone follow-ups at 3 and 6 months postoperatively in this study showed that at 3 months postoperatively, 3 out of 31 patients (9.68%) in Group M had persistent analgesic needs, while only 1 out of 34 patients (2.94%, P=0.341) in Group D had such needs; neither group had analgesic needs at 6 months postoperatively. There was no significant difference in the incidence of CPSP between the two groups, which may be related to the timely control of postoperative acute pain. This suggests that acute pain is only a potential inducer of chronic pain and that the risk of chronic pain can be reduced through effective acute-phase management and individualised intervention.

Multiple studies have shown that low pneumoperitoneum pressure can significantly reduce postoperative pain compared to standard pneumoperitoneum pressure;[14] however, it remains unclear whether this benefit stems from low intra-abdominal pressure itself or D-NMB.[15] To reduce the interference of intra-abdominal pressure and the series of pathophysiological changes caused by high intra-abdominal pressure, the intraoperative pneumoperitoneum pressure in both groups was set to 10–12 mmHg in this study. By unifying these variables, it can be confirmed that the observed pain reduction phenomenon can be attributed to differences in NMB depth rather than intra-abdominal pressure. In this study, the intraoperative dose of rocuronium in Group D was significantly higher than that in Group M, and D-NMB had a more significant effect on improving abdominal wall compliance and surgical space expansion, with a statistically significant difference in surgical condition scores between the two groups. A study on obese patients receiving D-NMB showed that D-NMB can increase the range of diaphragmatic movement and improve surgical conditions,[16] which is consistent with the results of this study. However, a study on laparoscopic renal surgery indicated that D-NMB did not improve surgical conditions compared with conventional NMB,[17] which is speculated to be related to the fact that renal surgery is located in the retroperitoneum rather than the abdominal cavity.

The incidence of residual NMB remains as high as 41% after the use of intermediate-acting neuromuscular relaxants.[18] Therefore, adequate intraoperative neuromuscular monitoring and complete postoperative antagonism are required. The emergence of sugammadex sodium, a new type of NMB antagonist, has made the management of the recovery period after NMB safer.[19] In this study, patients in both groups received drug antagonism based on the results of TOF monitoring at the end of surgery (TOF count < 2, sugammadex sodium was administered; if the TOF count > 2, neostigmine was administered). The usage rate of sugammadex sodium in Group D was significantly higher than that in Group M [29.41% (10/34) vs. 6.45% (2/31), Chi-square =4.256, P=0.001], but there was no statistically significant difference in the time for TOF to recover to > 0.9 between the two groups (P=0.148). It should be acknowledged that the

use of sugammadex was significantly more frequent in Group D. Sugammadex may independently contribute to faster recovery of neuromuscular function and potentially influence early postoperative comfort and quality of recovery. Thus, the observed improvement in QoR-15 scores in Group D may reflect a combined effect of deep neuromuscular blockade and the reversal agent used. Future studies with standardized reversal protocols across groups would help clarify the independent contribution of each factor.

In this study, the QoR-15 score in Group D was significantly higher than that in Group M, which may be related to D-NMB improvement in postoperative analgesia and optimisation of surgical experience. Pain is a core factor affecting the quality of postoperative recovery, and effective analgesia can directly improve early activity, sleep, and emotional status, thereby increasing the QoR-15 score. There was no significant difference in post-operative adverse reactions between the two groups, suggesting that in gynaecological laparoscopic surgery, D-NMB can significantly enhance patients' postoperative rehabilitation benefits through the chain effect of "optimizing surgical conditions - reducing postoperative pain - improving overall recovery quality".

This study had certain limitations. First, the sample size was calculated based on acute postoperative pain rather than CPSP, and the low event rates for CPSP (1/34 in Group D vs 3/31 in Group M) indicate that the study was underpowered to detect differences in chronic pain outcomes; therefore, the analysis of CPSP should be considered exploratory. Second, the use of sugammadex was significantly imbalanced between groups (29.41% in Group D vs 6.45% in Group M). As sugammadex enables rapid reversal of neuromuscular blockade and may independently influence postoperative recovery, it represents a potential confounder, and the observed differences cannot be solely attributed to the depth of neuromuscular blockade. Third, the use of postoperative analgesics may have interfered with the pain score results. Fourth, the results of this study are only applicable to patients with ASA grades I–II undergoing laparoscopic hysterectomy, and caution should be exercised when extrapolating to other surgical populations, high-risk patients (such as ASA grades III–IV), or patients undergoing low-pressure pneumoperitoneum surgery.Fifth, although surgeons were formally blinded to group allocation, the nature of surgical conditions may have provided indirect cues about the depth of neuromuscular blockade, potentially influencing the surgeon satisfaction score. This represents an inherent limitation in studies comparing different depths of neuromuscular blockade.

## Conclusion

In conclusion, in gynaecological laparoscopic surgery, D-NMB can more effectively control early postoperative pain, reduce opioid consumption and the need for additional analgesia, and improve doctor-patient satisfaction and patients' early postoperative quality of life than M-NMB, without increasing the risk of adverse reactions. However, there was no significant difference in the incidence of postoperative CPSP between the two. Therefore, the clinical application of D-NMB in such patients helps to optimise early postoperative recovery indicators but does not provide additional benefits for CPSP prevention. Further optimization of the perioperative analgesic regimen is required to achieve the goal of long-term pain management.

## Abbreviations

APOP, Postoperative acute pain; CPSP, Chronic postsurgical pain; NMB, Neuromuscular blockade; VAS, visual analogue scale; D-NMB, deep NMB; M-NMB, moderate NMB; TOF, train-of-four; PTC, post-tetanic count; PACU, post-anaesthesia care unit; ECG, electrocardiogram; BP, blood pressure; HR, heart rate; $SpO_2$, blood oxygen saturation; T, body temperature; BIS, Bispectral Index; $PetCO_2$, end-tidal carbon dioxide; NMT, neuromuscular transmission; QoR-15, Quality of Recovery-15.

## Data Sharing Statement

All data relevant to this study are included in the present manuscript and are available from the corresponding author upon reasonable request.

## Ethics Approval and Informed Consent

The study was approved by the Ethics Committee of The Second People's Hospital of Wuhu City (Approval No.: 2024-KY-47) and prospectively registered at the Chinese Clinical Trial Registry (ChiCTR; https://www.chictr.org.cn/) with the registration number ChiCTR2400087777. Informed consent was obtained from all patients. For those who were unable to sign their own names, the research team specifically obtained informed consent from their legally authorized representatives. Prior to study enrollment, the research team assessed each patient's capacity to provide informed consent via a standardized communication ability evaluation.

## Consent for Publication

All authors have read and approved the final version of this manuscript and consent to its submission and publication in this journal. Written informed consent for the publication of anonymized clinical data and surgical details has been obtained from all individual participants included in the present study. This manuscript is original, has not been published in whole or in part elsewhere, and is not under consideration by any other journal.

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## Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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## Disclosure

The authors declare that they have no competing interests.

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