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ORIGINAL RESEARCH

Influence of Transverse Abdominis Plane Block on Intraoperative Diaphragmatic and Respiratory Functions in Patients Receiving Laparoscopic Colorectal Surgery

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Background: The positive roles of deep muscle relaxation in abdominal surgeries and transversus abdominis plane block (TAPB) in the postoperative analgesia. This study aimed to discuss the effects of TAPB on abdominal muscle relaxation, the intraoperative diaphragmatic, and the respiratory functions.

Methods: The patients were randomly divided into the TAPB group who received single-shot TAPB bilaterally (n=30), and the control group who did not receive TAPB (n=30). Both groups keep the same steps for other procedures in the surgeries and anesthesia. Four time points for monitoring were defined: The moment when pneumoperitoneum pressure stabilized following endotracheal intubation and anesthetic induction (T0), appearance of the first incisure in the pressure-volume (P-V) loop (T1), appearance of the second incisure in the P-V loop (T2), and the moment with single stimulation (SS) =20% (T3). Primary observation parameters were SS1 measured by muscle relaxation monitoring at T1, and SS2 at T2. Secondary observation parameters included surgeon's satisfaction with surgical field and respiratory dynamics at the four time points.

Results: The two groups were comparable in age, gender, BMI, ASA grade, and operation time. The TAPB group had a dramatic reduction in the total dose of intraoperative sufentanil (0.73±0.21 ug/kg) compared with the control group (0.87±0.18 ug/kg) (P=0.023); Other use of drug did not differ between the two groups. The two groups did not differ significantly in SS at either T1 (SS1) or T2 (SS2). In either group, surgeon's satisfaction with surgical field at T1 and T2 decreased dramatically compared with T0 and T3 (all P<0.05). At each time point, the respiratory dynamics and the surgeon's satisfaction with surgical field did not differ significantly between the two groups.

Conclusion: TAPB reduced the use of intraoperative analgesics without altering the degree of abdominal relaxation, or affecting surgeon's satisfaction with surgical field in the patients receiving laparoscopic colorectal surgery.

Keywords: Transversus abdominis plane block, deep muscle relaxation, analgesia, laparoscopic colorectal surgery

Background

Laparoscopic surgeries are performed in confined spaces, involving the use of carbon dioxide to establish artificial pneumoperitoneum and offer adequate surgical field visualization and a working space for maneuvering surgical instruments.[1] Pneumoperitoneum pressure usually reaches 12 to 15 mmHg during laparoscopic surgery in the upper abdomen and 10–12 mmHg in the lower abdomen. However, high-pressure pneumoperitoneum may cause compression of large blood vessels in the abdomen, resulting in ischemia of abdominal organs and disrupting intraoperative hemodynamic stability.[2–4] High-pressure pneumoperitoneum is associated with the risks of absorption atelectasis, hypoxemia, and postoperative pulmonary complications.[2–4]

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The degree of intraoperative abdominal muscle relaxation is one of the most important conditions for laparoscopic surgery, as it directly determines the size of space available for surgical manipulation. Deep muscle relaxation[2–4] is defined as no response to train-of-four stimulation (TOF), though posttetanic stimulation count is detectable That is, posttetanic stimulation count ≥ 1, TOF=0. Many clinical studies and data analyses have confirmed that deep muscle relaxation improves surgical field, allows for lower-pressure pneumoperitoneum, reduces intraoperative body movement and other risks, and facilitates faster, safer and easier manipulations for surgeries.[2,3,5–7] After the laparoscopic surgery, suturing for abdominal closure usually takes less than 10 min or even shorter due to equipment assistance.[8,9] For this reason, intraoperative maintenance of deep muscle relaxation may lead to postoperative residual neuromuscular block (PRNB), which in turn results in various conditions: hypoxemia, systemic discomfort, visual impairment, inarticulate speech, hypercapnia, difficulty swallowing, upper airway obstruction, tachypnea, and severe respiratory events. All these conditions may delay postoperative recovery and worsen the prognosis.[10,11] Most clinical evidence indicates the positive role of deep muscle relaxation in surgery.

In laparoscopic surgeries, tension of respiratory muscles (including abdominal muscles, diaphragm, and intercostal muscles) is the primary factor influencing surgical space and surgeon's satisfaction with surgical field. Among them, diaphragm is the major muscle of respiration and plays a key role in respiratory recovery. At present, the mainstream method for muscle relaxation monitoring is measuring the degree of relaxation of the adductor pollicis muscle.[12] Electromyography is a more direct method to measure the responses of specific muscles,[4] though it cannot be applied to abdominal surgeries due to the position being operated. Transversus abdominis plane block (TAPB) is to inject local anesthetics to the transversus abdominis plane (TAP), the plane between transversus abdominis (TA) and internal oblique (IO) muscles, thereby blocking the innervation of muscles and skins in the abdominal wall. TAPB proves to be an effective intraoperative and postoperative analgesic method for trans-abdominal wall surgeries, as it can relieve pain and reduce opioid use.[13,14]

It is very important to precisely monitor and regulate of patient characteristics, position, and muscle relaxation to provide an adequate surgical field in laparoscopic surgery while minimizing the risk of PRNB. However, considering the hazards of PRNB, no consensus has been reached as to the optimal degree of muscle relaxation in clinical practice.[5,7,10,11] Moreover, few studies have discussed the effects of TAPB on abdominal muscle relaxation. Will TAPB alter the intraoperative tension of abdominal muscles and diaphragm, which further affects the surgical field? To fix these questions, a comparison was made between patients with and without TAPB, so as to determine the influence of TAPB on the degree of abdominal muscle relaxation in patients receiving laparoscopic surgery.

Materials and Methods

Subjects

The present study was approved by the Ethics Committee of Qingpu Branch of Zhongshan Hospital Affiliated to Fudan University (registry number: Qingyi.2021–33, approved on Dec. 22, 2021) and was conducted in accordance with the ethical principles of the Declaration of Helsinki. Dr Junzou Fu was affiliated with Qingpu Branch of Zhongshan Hospital Affiliated to Fudan University before the study started. Hence the ethics approval was obtained from this affiliation. Written informed consent was obtained from each patient. The clinical trial has been registered on the Chinese Clinical Trial Registry (http://www.chictr.org.cn) on Feb 18, 2022, register ID: ChiCTR2200056826.

Patients who received elective laparoscopic colorectal surgery at our hospital February 2022 to February 2023 were recruited. The patients, aged 45 to 75 years old, were classified as grade I–II according to the American Society of Anesthesiologists (ASA) classification system. Exclusion criteria: Serious diseases of the heart, liver, kidneys, lungs and brain and coagulation abnormalities; disorders of neuromuscular transmission; puncture site infection; mental or cognitive dysfunction; history of allergy to related drugs; receiving Miles surgery. Withdrawal criteria: The operation time shorter than 60 min; termination of pneumoperitoneum with conversion to open surgery, or a change of the original muscle relaxant prescription, resulting in a deviation; difficult airway resulting in difficult intubation.

Sample Size Calculation and Grouping Scheme

We have found through our clinical practice that the pressure-volume (P-V) loop is sensitive to diaphragmatic activity. An incisure may appear in the P-V loop when the diaphragmatic tone is restored to the level for autonomous breathing.

According to our previous study (not published yet), we observed a fixed single stimulation (SS) upon peripheral nerve stimulation that corresponded to the incisure in the P-V loop during the monitoring of respiratory dynamics. The SS value was 24.3 for surgery in low head position and 22.5 for surgery in high head position. Besides, incisure appearing in the P-V loop was stably related to muscle relaxation monitoring by peripheral nerve stimulation. Specifically, the incisure in the P-V loop usually corresponded to a decline in surgeon's satisfaction with surgical field ($P<0.05$). Data were collected from 10 patients in the TAPB group and the control group, respectively, according to the pre-clinical trial. SS values upon first incisure in the P-V loop were estimated. The mean SS values were 20.2 and 24.1 in the TAPB and the control group, respectively, the sample standard deviation being 4.95. The sample size was calculated as follows: $n = 2 \times (U_\alpha+U_\beta)^2\sigma^2/d^2$, where n is the sample size in each group; α and β are the type I error rate and the type II error rate, respectively, with α=0.05 and β=0.20 in this study; the corresponding standard normal deviates were U_α=1.960 and U_β =0.842, respectively, using lookup tables. σ is the estimated population standard deviation; d is the difference between the means of the two groups. By substituting the above values into the sample size formula, we obtained n=25. With the incidence of loss to follow up being about 20%, the sample size was finally set to 30 for each group.

The patients were randomly divided into two groups using the random number table, with 30 patients in each group: A random array of integers from 1 to 60 was generated using computer, corresponding to patients No. 1 to No. 60. Patients, numbered 1 to 30, were included in the TAPB group, and those above 30 were in the control group. The TAPB group received single-shot TAPB bilaterally, and the control group did not receive TAPB.

After the grouping was completed, the grouping personnel gave the anesthesia operator the finished preparation of the drug solution or saline used for TAPB. The intraoperative anesthesia administrator, surgeon, postoperative care nurse and the personnel who summarized the data were from the same medical group. These medical personnel were all blinded in this study to better control the differences in intraoperative anesthesia drug dosage between groups. The above personnel did not exchange any information related to the clinical trial during the study.

Method for Muscle Relaxation Monitoring

TOF-Watch® SX monitor (Organon, Finland) was used for intraoperative muscle relaxation monitoring. The distal electrode was placed at the intersection between the radial margin of the flexor carpi ulnaris and the proximal margin of the wrist curve. The proximal electrode was placed at 3–6 cm from the distal electrode. By placing the two electrodes on the two sides of the estimated ulnar nerve location, we expected to reduce the effects of misjudgment of ulnar nerve location (Supplemental Figure 1).

The transducer was placed at the flattest position of the thumb and perpendicular to the direction of movement. The guide wire of the transducer was fixed where thumb movement was not impeded by muscle contraction. The more distal the transducer placed in the thumb, the stronger the acceleration signals would be (Supplemental Figure 2).

Method for Monitoring Respiratory Dynamics

Side-stream spirometry was performed for continuous monitoring of respiratory dynamics, which consisted of ventilation pressure, volume, resistance, and pulmonary compliance. P-V and flow-volume (F-V) loop were measured dynamically and in real-time to assess pulmonary function. The P-V loop, also known as the compliance loop, reflects the dynamic relationship between pressure and volume. Figure 1 shows the P-V loop and an incisure appearing in the P-V loop. The respiratory dynamics monitoring device was connected between the connection of the threaded pipe and the tracheal tube and the anesthesia monitor (GE Carescape B650 Patient Monitor, the United States). Parameters of respiratory dynamics were recorded on the monitor after intubation: tidal volume (VT), minute ventilation (MV), plateau airway pressure (Pplat), mean pressure (Pmean), positive end expiratory pressure (PEEP), airway peak inspiratory pressure (Ppeak), peak inspiratory flow (FImax), peak expiratory flow (FEmax), and end tidal CO_2 ($ETCO_2$). Dynamic compliance (Cdyn) and static compliance (Cst) were calculated as follows: Cdyn=VT/(Ppeak-PEEP); Cst=VT/(Pplat-PEEP).

TAPB Procedures

After conventional disinfection and draping, the surgeon held a sterile linear ultrasound probe (S-Nerve Ultrasound System, SonoSite, the United States) in the left hand and an 8 cm continuous nerve block catheter needle (Tuoren

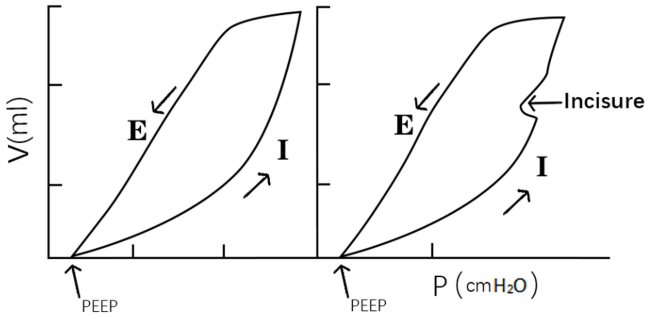

Figure 1 Before and upon the appearance of incisure in the P-V loop.
Abbreviations: E, Expiratory phase; I, Inspiratory phase; P, Pressure; V, Volume; PEEP, positive end expiratory pressure.

Holding Group Co., Ltd., Xinxiang, China) in the right hand. The ultrasound probe was localized to the midaxillary line, between the iliac crest and the costal margin. Three layers of muscles (external oblique muscle, internal abdominal oblique, and transversus abdominis muscle) and the TAP were clearly differentiated. A continuous nerve block catheter needle was inserted perpendicularly along the midaxillary line at 1–2 cm from the ultrasound probe using in-plane scanning (parallel with the long axis of the ultrasound probe) combined with the water separation technology at a constant speed along the TAP fascia. After confirming that the needle tip was located in the TAP, 20 mL of 0.375% ropivacaine (lot number: LBSD, AstraZeneca Pharmaceutical Co., Ltd. 75 mg/vial, the United Kingdom). A wedge-shaped area of drug diffusion was observed. The same procedures were repeated for the contralateral side. After bilateral administration in the TAPB group, the scope of the plane being blocked was determined by stimulating the abdominal skin with a needle. TAPB was completed once the nerve block efficacy was confirmed. The control group did not receive TAPB.

During this trial, after the completion of TAPB, a coarse blunt needle was used to measure along the axillary midline from the T6-L1 innervation area at a spacing of 2 cm per point, and the areas of normal and pain reduction or disappearance were observed, and the results showed that the effect of the T10-T12 plane block was satisfactory in the patients, and all of them successfully completed the TAPB.

Anesthetic Method

No pain medication was used in any patients. The patients were fasted from solid food for 6 h before surgery and from clear liquid for 2 h before surgery. Venous access was established in the upper limb after the patient was wheeled into the operating time. Lactated Ringer's solution was transfused at a rate of 10 mL/kg/h. Conventional ECG, heart rate (HR) monitoring, non-invasive blood pressure (NIBP), and oxygen saturation (SpO_2) measurement at the fingertip were performed. The rotary joint of the continuous muscle relaxation monitor (TOF-Watch® SX Monitor) was immobilized to patient's left palm. The accelerometer was placed on the thumb, with abduction of the upper limbs. The palm was properly immobilized. The 3M electrode plate was used as a stimulation electrode and placed on the ulnar side of the ipsilateral arm. After the immobilization of the muscle relaxation monitor and oxygen delivery through a nasal cannula, midazolam 0.2 mg/kg (lot number: 20180401, Jiangsu Nhwa Pharmaceutical Co., Ltd., 5 mg/vial, China) was administered. The TAPB group received ultrasound-guided TAPB. Anesthetic induction: After oxygen supply and nitrogen removal, intravenous administration of sufentanil 0.3–0.5 ug/kg (lot number: 91A10371, Yichang Humanwell Pharmaceutical Co., Ltd., 50 ug/vial, China) and propofol 2 mg/kg (lot number: 10NH1679, Fresenius SE & Co. KGaA, 200 mg/vial, Germany) was performed successively. The muscle relaxation monitor was switched on after the anesthesia was successfully induced. The CAL button was pushed for 1 s for calibration. The stimulus intensity was 60 mA for single twitch stimulation to achieve 100% blockade. Otherwise, the stimulus intensity was increased incessantly until reaching 100% blockade. Then, the patient received an intravenous administration of rocuronium bromide 0.6 mg/kg (lot number: 21170804, Organon, 50 mg/vial, Holland). Intubation was performed when SS<10% upon single twitch stimulation. Whether the patient was successfully intubated or not was judged by end-tidal carbon dioxide and P-V loop.

The cannula was connected to the anesthetic machine (GE Aespire 7900 Vent Anesthesia Machine, the United States) for mechanical ventilation after successful intubation.

Intravenous administration of sufentanil 5–10 ug was performed before skin incision. Deflurane 7–9% (lot number: H20170089, Baxter International Inc., 240 mL/bottle, the United States) was continuously inhaled during surgery to maintain minimum alveolar concentration (MAC) at 1.0–1.2. Additional doses of rocuronium bromide 0.15 mg/kg were given in case of man-machine counteraction and body movement. Additional doses of sufentanil 5–10 ug were given if HR and BP increased by over 20%. Intravenous administration of ephedrine 3–6 mg (lot number: 190602–2, 30 mg/vial, Northeast Pharmaceutical Group Shenyang No.1 Pharmaceutical Co. Ltd., China) was performed if the systolic blood pressure<90 mmHg or the mean arterial pressure decreased by 30%.

Atropine was given at 0.5 mg per injection if HR was below 50 beats/min. The inspired oxygen concentration was maintained at 60% during surgery, with a flow rate of 1.0 L/min and an inspiratory to expiratory ratio of 1:1.5. The tidal volume was adjusted to 6–10 mL/kg, and $PetCO_2$ was maintained at 30–40 mmHg.

After surgery, granisetron 3 mg (lot number: 19100002, Taiji Group Sichuan Taiji Pharmaceutical Co., Ltd., 3 mg/vial, China) was given by injection to prevent postoperative nausea and vomiting. The inhaled anesthetics was discontinued. The patient received antagonists for muscle relaxant when SS≥25%: intravenous administration of neostigmine 0.04–0.07 mg/kg (lot number: 1820804, Shanghai Sine Jinzhu Pharmacy Co., Ltd., 1 mg/vial, China) and atropine 0.015 mg/kg (lot number: 18090171, Shanghai Harvest Pharmaceutical Co., Ltd., 0.5 mg/vial, China) was performed. The endotracheal tube was removed after the patient resumed spontaneous breathing and consciousness, with TOF>0.9. The patient was sent to the resuscitation room.

Surgical Procedure

Laparoscopic Colectomy Procedure

Channeling Establishment: When anaesthesia was completed, routine disinfection was done and the towels were layed. The longitudinal incision (10mm) at the upper edge of the umbilical orifice was made, and CO_2 was injected to establish pneumoperitoneum after successful puncture of pneumoperitoneum needle. The 10mm Trocar was put in and the first channel was established. The laparoscope was put in to make sure there was no organ or vascular injury. Then the second channel (Right pre-skeletal superior spine in line with umbilical foramen, lateral border of rectus abdominis muscle, 12mm) was gradually established under laparoscopic guidance. The third access (lateral edge of the stone rectus abdominis muscle flat at the level of the umbilicus, 5 mm), the fourth access (lateral edge of the left rectus abdominis muscle flat at the level of the umbilicus, 5 mm) and the fifth access (left anterior superior iliac spine and umbilical foramen connected to the lateral edge of the rectus abdominis muscle, 5 mm) and the surgical instrumentation were placed gradually.

Separation of abdominal adhesions: The sigmoid colon was first lifted laterally and its right peritoneum was incised down to just above the peritoneal fold. The colonic mesentery was incised at the root of the sigmoid and rectal mesentery, and the sigmoid colon, the upper part of the rectum and its mesentery were freed from the posterior abdominal wall. Take care not to make damage to the right ureter. The sigmoid colon was retracted medially, and a combination of sharp and blunt detachment along the left paracolic groove was used to cut the lateral peritoneum, up to the lower part of the descending colon and down to the peritoneal fold. The posterior sigmoid colon tissue was separated and the lymphoid fatty tissue in front of the left iliac vessels was excised. Take care to reveal the left ureter and spermatic vessels without injury. The sigmoid artery and the superior rectal vessels were severed and ligated after careful dissection at the root of the sigmoid colon and rectal mesentery.

Incision of focus of infection: The sigmoid colon was lifted and the mesentery was cut in the upper rectum (5 cm above the peritoneal fold) and 10 cm above the tumour to determine the site of bowel resection. The mesentery was cut at the upper rectum (5cm below the tumour) with a cutting anastomosis. A 5cm longitudinal incision was made in the lower abdomen, and the proximal colon was dragged out, and the colon was cut off in the upper sigmoid colon (10cm above the tumour), and the lesion and mesentery were resected for about 5cm. After the proximal intestinal tube was inserted and fixed with a nail janitor, the intestinal tube was retracted, and the incision was closed, and the lower part of descending colon was anastomosed to the upper part of the rectum with the anastomotic device under the laparoscopic procedure.

Stop bleeding: Thorough hemostasis was achieved and one flat drain was placed posterior to the pelvic anastomosis. After counting the number of gauze and instruments, the abdomen was closed layer by layer.

Laparoscopic Resection of Rectal Lesions Plus Regional Lymph Node Dissection

Channeling Establishment: After satisfactory anaesthesia, routine disinfection and laying of towel, around the umbilical abdomen in the middle of a small incision layer by layer into the abdomen. Single-port laparoscopic instruments were placed, and CO_2 was injected to establish an artificial pneumoperitoneum. The second access (right anterior superior iliac spine in line with the umbilical foramen and lateral margin of the rectus abdominis muscle, 10 mm) and the third access (left anterior superior iliac spine in line with the umbilical foramen and lateral margin of the rectus abdominis muscle, 5 mm) were established and the surgical instruments were placed stepwise under laparoscopic guidance. Intraoperative exploration was performed as described above.

Surgical procedures: Firstly, the sigmoid colon was lifted to the lower left, and the right peritoneum was incised with an ultrasonic scalpel along the yellow-self junction line, freeing upwards to the parietal abdominal aorta, and freeing upwards to the peritoneal folds along the Tolt hiatus; the sigmoid colon, the upper part of the rectum, and its mesentery were free from the posterior abdominal wall. Attention to protect the right ureter, in the sigmoid colon and rectal mesentery root carefully dissected to free the mesenteric arteries and veins, respectively, given to the upper plastic clips and then cut off.

The sigmoid colon is retracted medially and the lateral peritoneum is clipped by a combination of sharp and blunt detachment along the left paracolic groove, up to the lower part of the descending colon and down to the peritoneal fold. The left ureter and genital vessels are protected. The rectum was carefully isolated posteriorly, and the intrinsic fascia of the rectum together with the lymphoid adipose tissue therein was separated from the presacral area, and some of the lateral rectal ligaments were severed on both sides. After determining the site of bowel resection, the rectum was dissected with a linear cutting anastomosis 5 cm distal to the tumour. The sigmoid colon is lifted and the mesentery is severed from the upper sigmoid colon. A small incision is made in the middle of the abdomen to drag out the proximal rectum and sigmoid colon. The rectum is severed about 10 cm from the proximal section of the tumour and the specimen is removed. An end-to-end sigmoid-rectal anastomosis was performed with a 29-gauge tubular anastomosis. A flat tube was placed next to the left pelvic floor anastomosis.

Suture the incision: After rinsing the pelvis with saline, the gauze instruments were counted for accuracy, and the abdominal incision and puncture hole skin were sutured layer by layer.

Observation Parameters

Primary Observation Parameters

SS1 was measured by muscle relaxation monitoring in the adductor pollicis (AP) when the first incisure appeared in the P-V loop (at time T1). Additional doses of rocuronium bromide 0.15 mg/kg were given when an incisure appeared in the P-V loop which was accompanied by man-machine counteraction. At this time (T2), that is, the appearance of the second incisure in the P-V loop, SS2 was recorded by muscle relaxation monitoring.

Secondary Observation Parameters

Four time points for monitoring were defined: The moment when pneumoperitoneum pressure stabilized following endotracheal intubation and anesthetic induction (T0), appearance of the first incisure in the P-V loop (T1), appearance of the second incisure in the P-V loop (T2), and the moment with SS=20% (T3). Surgeon's satisfaction with surgical field was assessed for each group at the four time points by the same surgeon-in-charge (the same surgeon treating the patients in this study) in a blinded way. Four levels of surgeon's satisfaction were defined: Excellent (1 point), good but not optimal (2 points), poor but acceptable (3 points), and unacceptable and unable to proceed (4 points). The following parameters were recorded at each time point: VT, MV, Pplat, Pmean, PEEP, Ppeak, FImax, FEmax, and $etCO_2$. Parameters of respiratory dynamics, namely, Cdyn and Cst, were calculated as follows: Cdyn=VT/(Ppeak-PEEP); Cst=VT/(Pplat-PEEP).

Statistical Analysis

All statistical analyses were performed using SPSS 20.0 (IBM Corp., Armonk, NY, USA). Normality was assessed using the Kolmogorov–Smirnov (K-S) test for measurements. The normally distributed measurements were expressed as mean ±standard deviation ($\overline{x}$±s) and compared between the two groups using the independent-samples *t*-test. Measurements at different time points were first compared using the repeated-measures analysis of variance. Mauchly's sphericity test was applied to the observations. If $P<0.05$ for the primary time effect, it was believed that the population means were not completely equal at different time points. The Bonferroni's method was used for pairwise comparison. Measurements not normally distributed were expressed as medians (interquartile ranges [M (Q)]). The Mann–Whitney *U*-test was used to compare whether there was a difference between the two groups. Enumeration data were expressed as numbers (percentages) and analyzed using the chi-square test. P<0.05 was considered to indicate statistical significance.

Results

Baseline Information of Patients

The two groups did not differ significantly in age, gender, BMI, ASA grade, and operation time (all $P>0.05$). See Table 1.

Comparison of the Dose of Muscle Relaxant and Muscle Recovery Between the Two Groups

The two groups did not differ significantly in the total dose of intraoperative rocuronium bromide ($P<0.05$). However, the TAPB group had a dramatic reduction in the total dose of intraoperative sufentanil (0.73±0.21 ug/kg) compared with the control group (0.87±0.18 ug/kg) ($P=0.023$). The time interval between the appearance of the first incisure in the P-V loop (T1) and the appearance of the second incisure in the P-V loop (T2) did not differ significantly between the two groups ($P>0.05$). Neither was there a significant difference in the time to SS recovery to 20% ($P>0.05$). See Table 2.

Intergroup and Intra-Group Comparisons of SS Values

Intra-Group Comparisons of SS1 at T1 and SS2 at T2

SS values at T1 and T2 were recorded by TOF-Watch Monitor to compare them at two time points between the two groups, that is, the moment when the first incisure appeared in the P-V loop (T1) and the moment when the second incisure appeared in the P-V loop (T2). The results showed that the two groups did not differ significantly in SS at either T1 (SS1) or T2 (SS2) (all $P>0.05$). See Table 3 and Figure 2.

Comparison of SS1 and SS2 Between the Two Groups

The two groups were further compared in SS values at T1 and T2, based on recording by the TOF-Watch Monitor. The results showed that compared with the control group, SS1 and SS2 did not differ significantly in the TAPB group (all $P>0.05$). See Table 4 and Figure 3.

Table 1 Comparison of Baseline Information

Baseline Information	TAPB Group (n=30)	Control Group (n=30)	P-value
Age (year)*	58.7±10.4	59.5±11.5	0.778
Gender (male/female ratio)#	15/15	13/17	0.496
Operation time (min)*	168±45.7	159±57.1	0.699
BMI (kg/m^2)*	22.9±2.9	22.8±2.0	0.833
ASA grade (I/II)#	7/23	8/22	0.294

Notes: The results were expressed as mean±standard deviation (x±S) or numbers of cases (n). * indicates the use of independent-samples *t*-test, and # the use of chi-square test. The differences between the two groups were not statistically significant.

Abbreviations: TAPB, transversus abdominis plane block; BMI, Body Mass Index; ASA, American Society of Anesthesiologists.

Table 2 Comparison of the Dose of Muscle Relaxant and Muscle Recovery Between the Two Groups

Item	TAPB Group (n=30)	Control Group (n=30)	P-value
Dose of rocuronium bromide (mg)	59.8±10.89	61.2±9.54	0.984
Dose of sufentanil (ug/kg)	0.73±0.21	0.87±0.18	0.023*
Interval between T1 and T2 (min)	40.4±8.56	37.5±9.74	0.652
Time to SS recovery to 20% (min)	62.5±19.95	60.8±21.56	0.842

Notes: The results were expressed as mean±standard deviation (x±S) and analyzed using independent-samples *t*-test. *The differences between the two groups were statistically significant ($P<0.05$). T1: Appearance of the first incisure in the pressure-volume loop; T2: appearance of the second incisure in the pressure-volume loop.
Abbreviation: TAPB, transversus abdominis plane block.

Table 3 Intra-Group Comparisons of SS1 at T1 and SS2 at T2

Group	SS1 (%)	SS2 (%)	P-value
TAPB group	23.5±4.7	22.8±5.0	0.625
Control group	22.8±4.5	24.1±4.1	0.278

Notes: The results were expressed as mean±standard deviation (x±S) and analyzed using independent-samples *t*-test. The differences between the two groups were not statistically significant. SS: single stimulation; T1: Appearance of the first incisure in the pressure-volume loop; T2: appearance of the second incisure in the pressure-volume loop.
Abbreviation: TAPB, transversus abdominis plane block.

Comparison of the Degree of Satisfaction with Surgical Field

The surgical field satisfaction scale was administered at four time points, namely, T0, T1, T2, and T3. The results showed that the two groups did not differ significantly in surgeon's satisfaction with surgical field at either T1 or T2 (all $P>0.05$). In either group, surgeon's satisfaction with surgical field at T1 and T2 decreased dramatically compared with T0 and T3 (all $P<0.05$). At each time point, surgeon's satisfaction with surgical field did not differ significantly between the two groups (all $P>0.05$). See Table 5 and Figure 4.

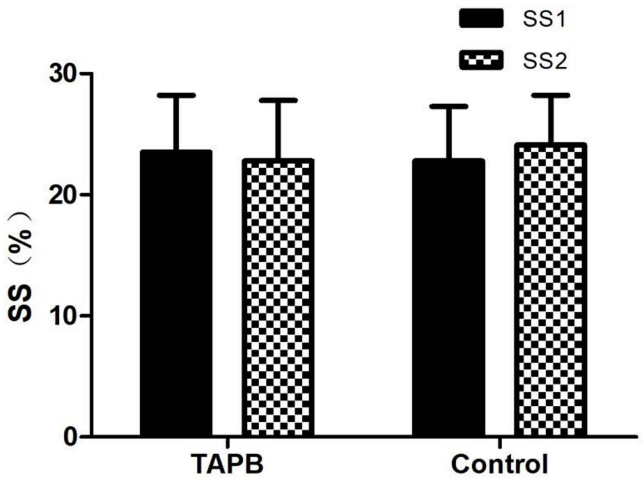

Figure 2 Comparison of SS values at T1 (SS1) and T2 (SS2) between the two groups SS values at T1 and T2 were recorded using TOF-Watch Monitor for the two groups and compared using the independent-samples *t*-test. SS1 and SS2 were not significantly different in the TAPB group ($P>0.05$). The difference was not statistically significant for the control group, either ($P>0.05$).

Table 4 Comparison of SS Values Between the Two Groups at T1

SS value	TAPB Group (n=30)	Control Group (n=30)	P-value
SS1 (%)	23.5±4.7	22.8±4.5	0.724
SS2 (%)	22.8±5.0	24.1±4.1	0.629

Notes: The results were expressed as mean±standard deviation ($\bar{x} \pm s$) and analyzed using independent-samples *t*-test. The differences between the two groups were not statistically significant. T1, Appearance of the first incisure in the pressure-volume loop; T2: appearance of the second incisure in the pressure-volume loop.
Abbreviations: TAPB, transversus abdominis plane block; SS, single stimulation; SS1, single stimulation at T1; SS2, single stimulation at T2.

Parameters of Respiratory Dynamics

The following parameters of respiratory dynamics were observed in the two groups at different time points, namely, the moment when the pneumoperitoneum pressure stabilized (T0), the appearance of the first incisure in the P-V loop (T1), the appearance of the second incisure in the P-V loop (T2), and the moment with SS=20% (T3): Pplat, Pmean, PEEP, Ppeak, FImax, FEmax, $PetCO_2$, Cdyn, and Cst. The results showed that compared with T0, Ppeak, Pplateau, Pmean, and $PetCO_2$ were increased significantly at T1 in either group (all $P<0.05$), while FImax, FEmax, Cdyn, and Cst decreased dramatically (all $P<0.05$). For either group, Ppeak, Pplateau, Pmean, $PetCO_2$, FImax, FEmax, Cdyn, and Cst did not change considerably at T2 than at T1 (all $P>0.05$). Compared with the control group, there were no significant changes in Ppeak, Pplateau, Pmean, $PetCO_2$, FImax, FEmax, Cdyn, and Cst in the TAPB group at the four time points ($P>0.05$). See Table 6.

Discussion

The results in this study showed that, the TAPB group had a dramatic reduction in the total dose of intraoperative sufentanil (0.73±0.21 ug/kg) compared with the control group (0.87±0.18 ug/kg). But there were no significant differences between the two groups in SS, muscle relaxant, the respiratory dynamics, and the surgeon's satisfaction with surgical field.

The present study found that the total dose of intraoperative sufentanil was lower in the TAPB group than in the control group, with the baseline conditions of the two groups being comparable. This result confirmed the analgesic effect of intraoperative TABP and its role in reducing the use of intraoperative analgesics. As a medium-potency muscle

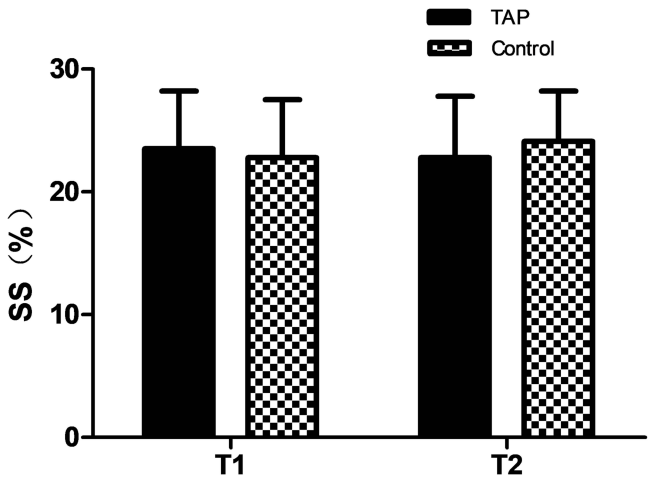

Figure 3 Comparison of SS values at T1 (SS1) and T2 (SS2) between the two groups. SS1 and SS2 were recorded using TOF-Watch Monitor and compared using the independent-samples *t*-test. SS1 values were not significantly different between the two groups ($P>0.05$). The difference was not statistically significant in SS2, either ($P>0.05$).

Table 5 Surgical Field Satisfaction Scores Between the Two Groups at Different Time Points

	T0	T1	T2	T3
TAPB group (n=30)	1.0±0*#	3.3±0.7^	3.2±0.8^	1.8±0.5*#^
Control group (n=30)	1.0±0*#	3.5±0.5^	3.4±0.6^	1.5±0.6*#^

Notes: The results were expressed as mean±standard deviation (x±S) and analyzed using repeated-measured analysis of variance. *indicates statistically significant difference compared with T1 ($P<0.05$). # indicates statistically significant difference compared with T1 ($P<0.05$). ^ indicates statistically significant difference compared with T0 ($P<0.05$). T0: Pneumoperitoneum pressure stabilized following endotracheal intubation and anesthetic induction; T1: Appearance of the first incisure in the pressure-volume loop; T2: appearance of the second incisure in the pressure-volume loop; T3: the moment with single stimulation (SS) =20%.
Abbreviation: TAPB, transversus abdominis plane block.

relaxant, rocuronium bromide takes effect rapidly, and intermittent intravenous bolus is the preferred administration method. Compared with target-controlled infusion and continuous infusion, there is no significant difference in the average dose of intraoperative rocuronium bromide administered by intermittent intravenous bolus. In this study, the intravenous dose of rocuronium bromide was twice the ED95 (0.6 mg/kg). A single additional dose was 0.15 mg/kg, which was 1/2 the ED95. The two groups did not differ significantly in the total dose of intraoperative rocuronium bromide and achieved similar degree of muscle relaxation. This result indicated the absence of influence of TAPB on the dose of intraoperative muscle relaxant to maintain abdominal muscle relaxation. The SS values at different time points were basically consistent in the two groups. The dose of muscle relaxant was also comparable in the two groups, and so was the time to the recovery of SS to 20%. The action of muscle relaxant was not particularly prolonged by additional doses of muscle relaxant. The above results indicated that TAPB had no obvious impact on abdominal muscle relaxation compared with the control group.

The time interval between T1 and T2 was also compared between the two groups. Following an additional dose of the muscle relaxant at T1, the second incisure appeared in the P-V loop at an average time interval of 40.4 min in the TAPB group vs a time interval of 37.5 min in the control group. There was no significant difference between the two groups in this aspect. That is, the additional dose of muscle relaxant maintained muscle relaxation to a similar degree with and without TAPB. TAPB is believed to prolong the action of muscle relaxant and reduce short-term postoperative analgesic use.[15,16] But according to our study, TAPB did not prolong the effect of the muscle relaxant, which may be explained by nerve distribution in TAP. Previous reports demonstrated that the local anesthetics diffusing in TAP may block the

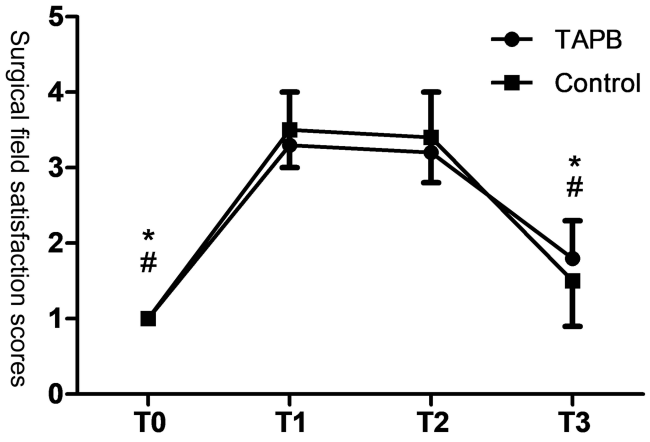

Figure 4 Comparison of surgical field satisfaction scores between the two groups at different time points. Surgeon's satisfaction with surgical field was scored using the scale for the two groups at T0, T1, T2, and T3. The scores were then subject to repeated-measures analysis of variance. The satisfaction scores did not differ significantly between the two groups at each time point ($P>0.05$). Specifically, the satisfaction scores were not significantly different between the two groups at either T1 and T2 ($P>0.05$), and a reduction was observed for each group at T1 and T2 than at T0 and T3 ($P<0.05$).

Table 6 Comparison of Respiratory Dynamics at Different Time Points Between the Two Groups

	T0	T1	T2	T3
Ppeak (cmH_2O) TAPB group Control group	22.81±3.09 23.01±3.87	24.97±4.01* 25.27±3.96*	24.80±3.91* 24.87±3.93*	22.78±4.14 23.07±4.21
Pplateau (cmH_2O) TAPB group Control group	21.10±3.86 20.97±3.59	23.13±4.57* 22.83±3.99*	22.93±4.01* 22.78±3.75*	22.03±3.57 21.07±3.99
Pmean (cmH_2O) TAPB group Control group	8.77±1.29 8.23±1.42	9.45±2.41* 9.30±2.10*	9.91±1.96* 9.33±1.84*	8.53±1.46 8.67±1.84
$PetCO_2$ (cmH_2O) TAPB group Control group	33.35±2.73 34.07±2.03	36.48±2.33* 35.59±1.22*	36.23±1.43* 35.98±2.02*	36.21±2.45 35.79±2.02
FImax (L/min) TAPB group Control group	21.93±2.43 22.29±2.21	18.34±1.97* 19.43±2.05*	18.76±1.93* 19.44±2.21*	20.89±2.14 21.55±2.33
FEmax (L/min) TAPB group Control group	38.83±2.13 39.15±2.06	34.11±1.94* 33.28±2.04	33.56±1.77* 34.18±2.43*	37.95±2.04 38.12±2.11
Cdyn (mL/cmH_2O) TAPB group Control group	23.10±1.98 24.01±1.54	21.33±2.32* 22.41±2.49*	21.63±2.42* 22.01±2.33*	22.74±2.33 23.93±2.56
Cst (mL/cmH_2O) TAPB group Control group	24.19±3.14 25.01±3.28 22.81±3.09	22.16±3.34* 23.18±2.98* 24.97±4.01*	23.17±3.14* 23.09±2.95* 24.80±3.91*	23.59±3.25 24.88±2.91 22.78±4.14

Notes: The results were expressed as mean±standard deviation (x±S) and analyzed using repeated-measured analysis of variance. * indicates statistically significant difference compared with T0 ($P<0.05$). T0: Pneumoperitoneum pressure stabilized following endotracheal intubation and anesthetic induction; T1: Appearance of the first incisure in the pressure-volume loop; T2: appearance of the second incisure in the pressure-volume loop; T3: the moment with single stimulation (SS) =20%.

Abbreviations: TAPB, transversus abdominis plane block; Pplat, plateau airway pressure; Pmean, mean pressure; PEEP, positive end expiratory pressure; Ppeak, airway peak inspiratory pressure; FImax, peak inspiratory flow; FEmax, peak expiratory flow; $ETCO_2$, end tidal CO_2 ($ETCO_2$). Cdyn, Dynamic compliance; Cst, static compliance.

conduction of related nerves, providing analgesia for the anterolateral abdominal wall.[17–19] But our study did not report muscle relaxation induced by blocking the motor nerves that innervated the related muscles. Given the disparities between nerve fibers, the blockade of sensory nerves usually occurs earlier than that of motor nerves under the same concentration of local anesthetics. A higher concentration of local anesthetics is required for motor nerve block, and it also takes a longer period of time to achieve the nerve block. The efficacy and scope of TAPB are related to the type, concentration, dosage, and administration route of local anesthetics.[14,20–22]

The traditional view is that the muscle twitch upon single stimulation should be suppressed by at least 90% in abdominal surgeries. But for others, muscle relaxation with the recovery of muscle twitch to 20% upon single stimulation also meets the demand in abdominal surgeries.[23] The time point when SS was 20% was chosen to observe the recovery of muscle relaxation, the duration to recovery, and surgeon's satisfaction with surgical field in laparoscopic colorectal surgery in the present study. The comparison results showed similar trend in the recovery of muscle relaxation in both groups, which indicates that TAPB did not prolong the action of muscle relaxant. The surgeon's satisfaction did not differ

between the two groups at the same time points, which may because surgical field did not interfere with surgical manipulation. These findings agreed with previous researches.[13,14] In other words, SS=20% met the demand for muscle relaxation in most cases.

However, compared with T0 and T3, the degree of satisfaction with surgical field decreased at T1 and T2. That is, the appearance of incisure in the P-V loop in either group corresponded to a dramatic decrease in the degree of satisfaction with surgical field. This result may hinted that the appearance of incisure in the P-V loop may be related to surgeon's satisfaction with surgical field. The appearance of the first incisure in the P-V loop might mark the critical point for satisfaction with surgical field. The degree of muscle relaxation at this moment should not interfere with the surgical field and should be conducive to patients' prognosis. We observed no significant differences in the SS values and the appearance of incisure in the P-V loop between the two groups. Besides, the dose of muscle relaxant used to maintain comparable satisfaction with surgical field was similar in the two groups, indicating that TAPB did not alter the time when incisure appeared in the P-V loop by affecting abdominal muscle relaxation.

The two groups showed a consistent trend in parameters of respiratory dynamics over time. Airway pressure and airway resistance increased over time, accompanied by a reduction in pulmonary compliance, which agreed with other studies.[24–26] In each group, the parameter of respiratory dynamics upon the appearance of the first incisure changed dramatically compared with when pneumoperitoneum was just established. However, it remained unclear whether such changes were caused by the changing degree of abdominal muscle relaxation, or by movements of respiratory muscles, such as intercostal muscles and diaphragm, or by the prolonged operation time. Once the changing abdominal pressure during surgery compresses the thoracic cavity or restricts thoracic movement, the thoracic and pulmonary compliance will decrease, which further affects pulmonary ventilation.[24] One study[24] recorded the following respiratory parameters at five time points, namely, immediately after intubation, immediately after mechanical ventilation, immediately after establishing postural pneumoperitoneum, at 30 min after establishing postural pneumoperitoneum: tidal volume, minute ventilation, peak airway pressure, plateau pressure, pulmonary compliance, and end-tidal carbon dioxide partial pressure. The results showed that the peak airway pressure and plateau pressure increased progressively over time after intubation, and pulmonary compliance decreased significantly in the two groups. In our study, the variations of parameters of respiratory dynamics in the two groups over time were consistent with those reported in previous studies.[24,25] Besides, there were no significant differences in these parameters at different time points between the two groups, indicating that TAPB did not alter respiratory dynamics compared with the control group.

The present study had the following limitations: We did not directly monitor the changes in the degree of abdominal muscle relaxation or the relaxation of other muscles related to respiration, such as intercostal muscles and diaphragm. Therefore, we did not know the changing relaxation of which muscles are more closely related to the appearance of incisure in the P-V loop and respiratory dynamics, such as pulmonary compliance. For these reasons, whether TAPB affects abdominal muscle relaxation or not cannot be fully verified, and further clinical studies are required to answer the above questions.

Conclusions

TAPB did not alter the degree of abdominal relaxation in patients receiving laparoscopic colorectal surgery, or affect surgeon's satisfaction with surgical field. TAPB reduced the use of intraoperative analgesics in laparoscopic surgery.

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Disclosure

The authors report no conflicts of interest in this work.

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