Bilateral transversus thoracis muscle plane block provides effective analgesia and enhances recovery after open cardiac surgery

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Abstract
Background: The mid-sternum is the main source of pain after open cardiac surgery. The aim of this study was to investigate the effect of bilateral transversus thoracis muscle plane (TTMP) blocks on open cardiac surgery.

Methods: Sixty patients were randomly divided into two groups: bilateral TTMP blocks (TP group) or no nerve block (CO group). The primary endpoint was perioperative sufentanil consumption. The secondary outcome measures included postoperative pain, flurbiprofen axetil administration, quality of sleep after extubation, time to extubation, time to the return of gastrointestinal function, time to drain removal, the Intensive Care Unit (ICU) stay time, and hospital stay.

Results: The TP group reported significantly less sufentanil and flurbiprofen axetil consumption than the CO group. The CO group had higher Numerical Rating Scale (NRS) pain scores at 1, 2, 6, 12, and 24 h after extubation both at rest and during movement than the TP groups. Compared with the CO group, time to extubation, time to the first bowel movement, ICU stay time, and hospital stay were significantly decreased in the TP group. The TP group was rated as better in the quality of the two nights of sleep after extubation.

Conclusion: Bilateral TTMP blocks can provide good perioperative analgesia for patients undergoing open cardiac surgery and promote postoperative recovery.

Keywords
Numerical Rating Scale, open cardiac surgery, postoperative pain, sufentanil, the length of hospital stay, the transversus thoracis muscle plane block

1 | INTRODUCTION

Postoperative pain is severe in patients undergoing cardiac surgery, especially from the median sternotomy incision. According to a previous study, 705 patients undergoing open cardiac surgery suffer from pain, scoring between 5.3 and 6.5 out of 10 and 24 h postoperatively. The mid-sternum is the main source of pain after cardiac surgery. The current analgesia regimen with the use of oral and intravenous analgesics has a limited effect. Poor postoperative analgesia in patients undergoing cardiac surgery increased morbidity and a longer hospital stay than patients without pain. High-dose opioids can provide good postoperative analgesia for patients undergoing heart surgery. However, opioids have some side effects, such as nausea and vomiting, pruritus, and respiratory depression, as well as increased risk of chronic...
pain. Therefore, the implementation of neuraxial and paravertebral block techniques may be a superior choice.

Paravertebral block and thoracic epidural anesthesia result in significantly low pain scores after open cardiac surgery. Epidural hematoma caused by postoperative coagulopathy and anticoagulation, hemodynamic instability and arterial or venous epidural puncture have limited the wide application of regional techniques in cardiac surgery patients. The effect of continuous infusion of local anesthetics on postoperative analgesia in cardiac surgery patients is mainly related to the concentration of local anesthetics and the position of catheters, thus the application of this technology might be limited. So it seems that ultrasound-guided peripheral nerve block might be the safest and the most effective method for postoperative analgesia in cardiac surgery patients.

The transversus thoracis muscle plane (TTMP) block is a newly developed technique that was first reported by Ueshima in 2015. The TTMP block covers the anterior branches of intercostal nerves from T2 to T6 to provide effective analgesia in the internal mammary area. Therefore, bilateral TTMP block may provide an effective analgesic alternative during median sternotomy in cardiac surgery patients. The purpose of this study was to observe whether bilateral TTMP blocks can provide good postoperative analgesia and promote postoperative rehabilitation for patients undergoing open-heart surgery.

2 METHODS

This randomized, double-blind study was approved by the ethics committee of our hospital, and it was registered in the Chinese Clinical Trial Registry (ChiCTR1900024933).

2.1 Patients and design

This study included patients aged 18–70 years, American Society of Anesthesiologists physical status II–III, who underwent median open-heart surgery. The exclusion criteria were patient refusal, hepatic or renal failure, unable to cooperate and communicate, ejection fraction less than 35%, allergy to ropivacaine, secondary surgery, urgent surgery, hemodynamic instability, and drug addiction.

2.2 Surgery and anesthesia

All patients received 200 ml carbohydrate loading before entering the operating room. General anesthesia was induced with 0.1 mg/kg midazolam, 0.3 mg/kg etomidate, 0.15 mg/kg cisatracurium, and 0.6–1 µg/kg sufentanil. Then, endotracheal intubation was performed. Total intravenous anesthesia was maintained with propofol and cisatracurium, and the BIS was maintained between 45 and 55. The administration of sufentanil during surgery was decided according to clinical need. According to the demands of the patients, postoperative analgesia was performed with continuous infusion of sufentanil. If patients complained of additional pain (Numerical Rating Scale [NRS] score ≥ 4), 50 mg flurbiprofen axetil was injected intravenously at 6 h intervals. No other analgesic drugs were used in any of the patients during the perioperative period.

The patients undergoing cardiac surgery were randomly divided into two groups after providing written informed consent. Patients in the TP group underwent bilateral TTMP blocks after endotracheal intubation, whereas in the other group (the CO group), no nerve block was performed (the same volume of saline was injected as the TTMP block in the experimental group). All operations were performed by the same group of surgeons, and all patients were sent to Intensive Care Unit (ICU).

2.3 Randomization and blinding

All enrolled patients were randomly divided into TP group or CO group with either 0.4% ropivacaine or saline for using a computer-generated random number table, and the group allocation was kept in the sealed envelope. The saline and ropivacaine were prepared in the post anesthesia care unit by a nurse, the saline and ropivacaine solutions looked identical. The skilled anesthesiologist injected the liquid into TTMP within 20 min and he did not know whether the liquid is ropivacaine or saline. Postoperative data collection was recorded by another researcher. The patients, surgeons, anesthesiologist, ICU staff, nurses and other investigators were not aware of medication assignment. Thus this was a double-blind, randomized, controlled study.

2.4 Ultrasound-guided TTMP block

We used a real-time high-frequency linear ultrasound probe (Huasheng) to perform bilateral TTMP blocks. After using ultrasonography to determine the anterior T4–T5 interspace, the ultrasound probe parallel to the rib was placed lateral to the sternal border, so that we could find the pectoralis major internal muscle, intercostal muscle, and transversus thoracis muscle (Figure 2). The TTMP was located between the two posterior intercostal muscles. The internal mammary artery and vein also passed through the TTMP, verifying this plane. Then, a 20-gauge, 70 mm needle (Tuoren) was inserted inline with the tip of the needle located in the TTMP, and 0.4% ropivacaine (20 ml) was injected into this plane. After 5 min, we used ultrasonography to observe whether the local anesthetic had spread between the costal cartilage and the transversus thoracis muscle in T2–T6. If ropivacaine had spread poorly, we added local anesthetic in the corresponding plane to ensure an analgesic effect. The methods used on the other side of the TTMP blocks were the same. All nerve blocks were completed by the same skilled anesthesiologist within 15 min. The possible complications of TTMP blocks in this study included ropivacaine allergy, pneumothorax, hematoma, infection, and injury of the internal mammary
artery and vein. The TTMP block was done as previously described\(^\text{16}\) (Figure 2).

### 2.5 Study parameters

The primary endpoint was perioperative sufentanil consumption. The secondary outcome measures included pain at rest and during coughing (exercise pain) at 1, 2, 6, 12, 24, and 48 h after extubation; 48-h flurbiprofen axetil administration; quality of the two nights’ of sleep after extubation; time to extubation; time to return of gastrointestinal function (including the first bowel movement and the first occurrence of flatus); time to drain removal; and the ICU stay time and hospital stay.

Postoperative pain was measured using the NRS score from 0 (no pain) to 10 (worst severe pain).\(^\text{17}\) The sleep quality assessment was performed with a 10-cm visual analog scale (0 = worst sleep quality, 10 = best sleep quality).\(^\text{18}\) Data collection was recorded by an experimental assistant who was also blinded to the experimental grouping.

### 2.6 Statistical analysis

The calculation of the patient sample size was based on a pilot study \((n = 8\) patients in each group), which compared the primary endpoint, that is, perioperative sufentanil consumption during open cardiac surgery. A sample size of 25 patients in each group was required with a type I error of \(\alpha = .05\), a type II error of \(\beta = .1\) and a power of 90%. Considering the possible surgical reasons for exclusion and the possibility of patient dropout during the study, we included 20% additional patients for the final sample size \((n = 30\) in each group).

Pain intensity after extubation was compared between the TP group and CO group with repeated-measures (two-way) analysis of variance. Student’s t-test was used to assess intergroup differences with a normal distribution, whereas the Wilcoxon Mann–Whitney test was used to assess abnormally distributed data. A probability value of less than 5% was considered significant.

### 3 RESULTS

Sixty-six patients have consented in our trial and six patients were excluded for the following reasons: secondary surgery (two); ejection fraction less than 35% (two) and renal failure (two). Ultimately, a total of 60 patients were randomized in our study for data analysis, with 30 in each group (Figure 1). No differences in patients’ characteristics or other factors were noted between the groups (Table 1).

The TP group required significantly less intraoperative and postoperative sufentanil consumption than the CO groups (Table 2). The CO group had higher NRS pain scores than the TP group at 1, 2, 6, and 24 h after extubation both at rest and during movement; time points both at rest and during movement (Figures 3 and 4). Patients in the CO group received significantly more flurbiprofen axetil in the first 48 h than patients in the TP group (Table 2). The time to extubation, time to the first flatus, length of stay in the ICU, and length of hospital stay were significantly decreased in the TP group compared with the CO groups (Table 2). The quality of the two nights’ of sleep after extubation was rated as better in the TP group than in the CO group (Table 2). There were no significant differences between the groups in terms of the time to first feces or the time to drain removal (Table 2). No complications due to the TTMP blocks occurred in our study.

### 4 DISCUSSION

The present study demonstrated that the use of ultrasound-guided TTMP blocks could reduce the perioperative sufentanil consumption, dosage of postoperative flurbiprofen axetil, time to extubation, time to the first flatus, length of stay in the ICU, and length of hospital stay in patients undergoing open cardiac surgery. Furthermore, the TTMP block also provides effective analgesia and good sleep quality for patients who underwent open cardiac surgery.

The use of TTMP blocks has been reported in recent years\(^\text{11,12}\), this type consists of a shallow block, and there were no adverse events in our study, such as hematoma, arterial puncture, ropivacaine allergy, pneumothorax, or infection. A previous study that included 299 patients who underwent TTMP blocks showed that there were only two incidences of "slight infections" around the injection site.\(^\text{19}\) Therefore, TTMP blocks represent a safe technique that can be widely used in patients who undergo open cardiac surgery.\(^\text{20}\) Ueshima et al.\(^\text{15}\) found that the spread of ropivacaine in the TTMP between the fourth and fifth ribs was larger than that between the third and fourth ribs. Therefore, the fourth and fifth ribs next to the sternum were used in all patients in our study for the TTMP block.

High-dose sufentanil was able to maintain hemodynamic stability; it is still widely used in many countries for bolus dosing or infusion regimes during cardiac anesthesia.\(^\text{21}\) However, high-dose opioid techniques cause postoperative nausea and vomiting, respiratory depression, pruritus, delayed recovery, prolonged ventilation, increased ICU stays, increased costs,\(^\text{22}\) and limited postoperative recovery after open cardiac surgery.\(^\text{23}\) Our study revealed that the use of bilateral TTMP blocks decreased the consumption of perioperative sufentanil without adverse events and that they may work via the following two aspects. On the one hand, the TTMP block was found to cover the T2–T6 intercostal nerves,\(^\text{11}\) and it had the potential to provide analgesia for surgery of the anterior chest wall. Therefore, it could greatly reduce the amount of intraoperative sufentanil used during open cardiac surgery before opening the sternum. On the other hand, this block reduced the dose of postoperative sufentanil consumption by providing effective postoperative analgesia.\(^\text{24}\) Therefore, reducing the perioperative dose of sufentanil was an important part of the enhanced recovery of cardiac surgery.

Open cardiac surgery results in severe and prolonged postoperative pain, especially at the median sternotomy site, and peaking during the first 2 days after the operation.\(^\text{25}\) Poorly controlled postoperative pain in open cardiac patients results in hemodynamic instability,
hypercoagulability, pulmonary complications, sympathetic activation, and increased rates of delirium. In our study, we demonstrated that bilateral TTMP blocks provide effective analgesia during open cardiac surgery both at rest and during mobilization. Moreover, sufentanil and flurbiprofen axetil consumption was still significantly lower in the TP group than in the CO group during the 48 h after surgery, and it could reduce the adverse effects of these two drugs. Neuraxial techniques and paravertebral nerve blocks can also provide effective postoperative analgesia for patients undergoing open cardiac surgery. However, they are not routinely performed in cardiac surgery due to concerns of hemorrhage and hematoma after coagulopathy and heparinization. Therefore, ultrasound-guided TTMP blocks represent a novel, effective, promising, and safe regional analgesic technique in cardiac surgery and should be widely used.

Sleep quality is critical for patients’ postoperative comfort and fatigue after cardiac surgery. Our results showed that the TP group had better sleep quality than the CO group, which may be associated with the enhanced recovery after cardiac surgery. Better pain relief and pain reduction after sufentanil consumption contributed to better sleep quality in the TP group because sufentanil is known to disrupt sleep quality. This study demonstrated that bilateral TTMP blocks led to

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**Figure 1** Patient flow diagram

**Figure 2** Transversus thoracic muscle plane block was performed. Pectoralis major internal muscle (PMM), internal intercostal muscle (IIM), and the transversus thoracis muscle (TTM) lie above the pleura (PL). Local anesthetic (LA) can be visualized in the transversus thoracic muscle plane after block.
early extubation and early time to the first bowel movement. Finally, decreased sufentanil consumption, improved pain control, early extubation and early time of the first flatus were responsible for the reduction in the length of stay in the ICU and the length of hospital stay.

This study has some limitations. The volume and concentration of the TTMP block used in our study were based on previous research. In further trials, the optimum capacity and concentration of the TTMP block in open cardiac surgery should be evaluated. Continuous TTMP block may provide optimal and long postoperative analgesia during median sternotomy, but our study did not use this technique. Therefore, randomized controlled studies are necessary to explore the utility of continuous TTMP block in different surgical patients. In addition, effective postoperative pain relief may prevent the development of chronic pain, but we did not observe the effect of this block on postoperative chronic pain.

In conclusion, this study showed that the use of ultrasound-guided TTMP block in open cardiac surgery reduced the length of hospital stay by providing effective postoperative pain, reducing sufentanil and flurbiprofen axetil consumption, decreasing

**TABLE 1**

|                        | CO group (n = 30) | TP group (n = 30) | p value |
|------------------------|------------------|------------------|---------|
| Age, year              | 56 ± 9           | 57 ± 10          | .508    |
| Height, cm             | 169 ± 11         | 170 ± 13         | .841    |
| Weight, kg             | 65 ± 14          | 61 ± 12          | .603    |
| ASA classification, II/III | 17/13          | 16/14            | .629    |
| Duration of surgery, min | 181 ± 24       | 185 ± 30         | .873    |
| Size of incision, cm   | 20 ± 3           | 20 ± 3           | .831    |
| Intraoperative urine output, ml | 870 ± 225 | 848 ± 250 | .673    |
| Intraoperative bleeding volume, ml | 767 ± 295 | 758 ± 300 | .805    |
| Intraoperative crystalloids, ml | 786 ± 175  | 788 ± 170        | .502    |
| Intraoperative colloids, ml | 1626 ± 119 | 1723 ± 107       | .804    |

**TABLE 2**

|                                | CO group (n = 30) | TP group (n = 30) | p value |
|--------------------------------|------------------|------------------|---------|
| Intraoperative sufentanil consumption, μg | 125 ± 30       | 74 ± 10          | <.01    |
| postoperative sufentanil consumption, μg | 98 ± 10        | 60 ± 10          | .02     |
| flurbiprofen axetil consumption, mg | 225 ± 100      | 125 ± 100        | <.01    |
| Time to extubation, h           | 8.6 ± 2.7        | 2.6 ± 1.1        | .03     |
| Time to drain removal, h        | 30 ± 7           | 28 ± 8           | .21     |
| Length of stay in the ICU, h    | 25 ± 10          | 15 ± 8           | .04     |
| Sleep quality during first night, cm | 6.8 ± 3.2     | 4.1 ± 2.8        | <.01    |
| Sleep quality during second night, cm | 6.7 ± 2.8     | 4.6 ± 2.3        | .03     |
| Time to first flatus, h          | 34 ± 16          | 26 ± 6           | <.01    |
| Time to first feces, h           | 42 ± 16          | 39 ± 11          | .43     |
| Length of hospital stay, h       | 195 ± 36         | 152 ± 28         | .04     |

Abbreviations: CO, group with no nerve block; ICU, intensive care unit; TTMP, transversus thoracis muscle plane; TP, group underwent bilateral TTMP blocks.

**FIGURE 3** Pain intensity at rest after extubation which was measured using the verbal numerical scale (NRS) score. *p < .05 considered statistically significant. Results are mean ± SD. CO, group with no nerve block; NRS, Numerical Rating Scale; TTMP, transversus thoracis muscle plane; TP, group underwent bilateral TTMP blocks; SD, standard deviation

**FIGURE 4** Pain intensity at movement after extubation which was measured using the verbal numerical scale (NRS) score. *p < .05 considered statistically significant. Results are mean ± SD. CO, group with no nerve block; NRS, Numerical Rating Scale; TTMP, transversus thoracis muscle plane; TP, group underwent bilateral TTMP blocks; SD, standard deviation

This study has some limitations. The volume and concentration of the TTMP block used in our study were based on previous research. In further trials, the optimum capacity and concentration of the TTMP block in open cardiac surgery should be evaluated. Continuous TTMP block may provide optimal and long postoperative analgesia during median sternotomy, but our study did not use this technique. Therefore, randomized controlled studies are necessary to explore the utility of continuous TTMP block in different surgical patients. In addition, effective postoperative pain relief may prevent the development of chronic pain, but we did not observe the effect of this block on postoperative chronic pain.

In conclusion, this study showed that the use of ultrasound-guided TTMP block in open cardiac surgery reduced the length of hospital stay by providing effective postoperative pain, reducing sufentanil and flurbiprofen axetil consumption, decreasing
the mechanical ventilation time and the time to the first flatus, improving sleep quality, and reducing the length of stay in the ICU.

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CONFLICT OF INTERESTS
The authors declare that there are no conflict of interests.

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