A single paravertebral injection via a needle vs. a catheter for the spreading to multiple intercostal levels: A randomized controlled trial

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Keywords

catheter; needle; paravertebral injection; regional anesthesia; thoracic paravertebral block

Abstract

Purpose

Thoracic paravertebral block (TPVB) provides a unilateral nerve block at multiple intercostal levels allowing injection of a local anesthetic into paravertebral space (PVS) via a needle or catheter. However, the most effective injection method remains unclear. This study compared the real-time spread of ropivacaine between two paravertebral injection methods using thoracoscopy.

Methods

Thirty-four patients scheduled for thoracoscopic surgery were randomly allocated into the Needle or Catheter groups, and performed transverse in-plane ultrasound-guided TPVB. The Needle group received 20 ml of 0.5% ropivacaine via a needle placed into the lateral edge of PVS; the Catheter group received the same dose of ropivacaine via a catheter inserted 5cm into PVS. The primary outcome was the spreading pattern of ropivacaine in each group. The secondary outcome was intraoperative vasopressors requirement after paravertebral injection.

Results

In the Needle group, all cases showed ropivacaine spread to multiple intercostal levels, mainly across the ribs. Contrastingly, the Catheter group showed variable spreading patterns; multiple intercostal levels (n = 10) [across the ribs (n = 4), anterolateral aspect of the vertebral bodies (n = 6)] or unobservable spreading (no change; n = 7) (P = 0.007). Vasopressors were required in two and ten cases in the Needle and Catheter groups, respectively (P = 0.010).

Conclusion

Paravertebral injection via a needle typically resulted in spreading to multiple intercostal levels, especially across the ribs on the peripheral side of injection site, whereas injection via a catheter resulted in variable spreading patterns. Therefore, injections via needles are more stable.

Introduction

Thoracic paravertebral block (TPVB) is a technique in which a local anesthetic is injected into the thoracic paravertebral space (TPVS) via a needle or a catheter. TPVB provides a unilateral somatic and sympathetic nerve block at multiple intercostal levels [1–5]. Although several studies have shown spreading patterns into TPVS using radiocontrast agents [4–8], magnetic resonance imaging contrast agent [2] or colored dyes [3, 9], these studies were performed using various paravertebral injection methods and did not include any real-time observations. Our recent study reported the real-time paravertebral spread of local anesthetic injected via a needle using thoracoscopy [10]. To date, it is unclear how the local anesthetic spreads into the TPVS at multiple intercostal levels depending on the paravertebral injection methods, i.e., via a needle or a catheter.

The needle tip can be properly placed into TPVS under ultrasound-assisted visualization [4–5]. In contrast, it is difficult to place the catheter in an ideal position. The paravertebral catheter location is highly variable [3–6]. Therefore, this study was based on the assumption that paravertebral injection via a needle is a better TPVB method than via a catheter.

This study compared the real-time spreading pattern of a local anesthetic to multiple intercostal levels between the two paravertebral injection methods via a needle or a catheter under direct vision using thoracoscopy.

Methods

Trial design and participants

This study was designed as a single-center, randomized-controlled, single-blind trial. The trial was registered at the UMIN - Clinical Trials Registry (https://www.umin.ac.jp/ctr) (ref: UMIN000016472) on February 8, 2015. Ethical approval for this study was provided by the Tosei General Hospital ethics committee, Seto, Japan on May 22, 2015 (ref: 489). The written informed consent was obtained from patients scheduled for a lung biopsy by video-assisted thoracic surgery due to a diagnosis of interstitial pneumonia. This study was conducted at the Tosei General Hospital between June 2015 and March 2016. This study included patients aged ≥ 20 years with an ASA physical status class 1–2. Exclusion criteria were as follows: renal dysfunction (estimated glomerular filtration rate (eGFR) < 30 mL/min/1.73 m^2), liver dysfunction (Child-Pugh score ≥ B), or allergy to ropivacaine.

Randomization

The patients were randomly allocated to two groups based on the injection method of ropivacaine into TPVS via a needle (Needle group) or via a catheter (Catheter group). Block randomization with block sizes of four or six was applied and similar numbers were given to each group using a computer-generated randomization software (http://www.randomization.com). Participants were blind to the study allocation. The anesthesiologist who performed TPVB (TF) and the surgeon were informed of the allocation just before the patient arrived in the operation room. During the video-assisted thoracic surgery, the allocated paravertebral injection method was performed under general anesthesia.

General anesthesia and interventions

None of the patients received any premedication. General anesthesia was induced with propofol 1.5–2 mg/kg and remifentanil 0.3 μg/kg/min. Rocuronium 0.8–1.0 mg/kg was administered to facilitate orotracheal intubation with a double-lumen endotracheal tube. Anesthesia was maintained with propofol 4–5 mg/kg/h and remifentanil 0.1–0.3 μg/kg/min, with positive pressure ventilation in a circle system. Another anesthesiologist, who did not perform TPVB, maintained anesthesia and hemodynamics.

During the thoracoscopic surgery, transverse in-plane ultrasound-guided TPVB was performed using an intercostal approach and in-plane needling [11]. The paravertebral injection site was the intercostal space at the largest surgical incision. First, the transverse image of TPVS was visualized with a portable ultrasound machine (S-Nerve; FUJIFILM SonoSite Inc., Bothell, WA, USA), and an 18-gauge Tuohy needle (Hakko Epidural Anesthesia Set; Hakko Co. Ltd., Nagano, Japan) was inserted from the outer end of a 15–6 MHz ultrasonic linear array transducer in a lateral-to-medial direction (Fig. 1). After the needle tip reached the lateral edge of TPVS between the internal intercostal membrane and the parietal pleura, the parietal pleura was pressed down ventrally and the TPVS was expanded on the ultrasound image by injecting 10 ml of saline via the Tuohy needle.

In the Needle group, 20 ml of 0.5% ropivacaine was injected into the TPVS via a Tuohy needle inserted at the lateral edge of TPVS. For postoperative analgesia, the paravertebral catheter was placed into TPVS after a single paravertebral injection via a needle. In contrast, in the Catheter group, 20 ml of 0.5% ropivacaine was injected into the TPVS via the catheter after the catheter (radiopaque polytetrafluoroethylene catheter; Hakko Co. Ltd., Nagano, Japan) was inserted to a depth of 5 cm into the TPVS through the Tuohy needle. These procedures were observed and recorded using thoracoscopy. All patients were extubated in the operation room.

Outcome measures

For the primary outcome, the spreading pattern of ropivacaine was evaluated as follows: (1) ropivacaine spread to multiple intercostal levels mainly across the ribs or anterolateral aspect of the vertebral bodies around the sympathetic trunk; (2) other spreading patterns such as spreading of ropivacaine to only one intercostal space (single intercostal space) or an unobservable spreading pattern of ropivacaine (no change). This primary outcome was assessed by an independent anesthesiologist (YS) who was blinded to the group allocation and did not perform the allocated procedure. As a secondary outcome, intraoperative vasopressor requirements after paravertebral injection of 20 ml of 0.5% ropivacaine was assessed retrospectively between the two groups. The use of vasopressor types and doses were left to the discretion of individual anesthesiologists who did not perform TPVB. These data were collected from the anesthesia records.

Statistical analysis

Sample size calculation was performed using the proportion of paravertebral spreading pattern reported in a previous study [4]. Based on this study, the proportion of paravertebral and intercostal spread across multiple intercostal levels with an injection of local anesthetic via a paravertebral catheter was 0.55. In accordance with our previous report [10] and an unpublished pilot study on paravertebral injection via a needle, the spread of local anesthetic to multiple intercostal levels was observed in all cases. Therefore, a sample size of 17 participants in each group was calculated to provide 80% power (two-sided α of 0.05) to test for an expected 0.4 improvement in the proportion of the paravertebral spreading pattern.

The baseline characteristics of the two groups were compared using the Student's t-test, the Wilcoxon rank-sum test, or Fisher's exact test. The primary and secondary outcomes were evaluated using Fisher's exact test. Data are expressed as mean ± standard deviation (SD) or number of samples (proportion, %). *P* values < 0.05 were considered statistically significant. All statistical analyses were performed using the statistical software SAS, version 9.4 (SAS Institute Inc., Cary, NC, USA).

Results

Patient flow and baseline characteristics

Recruitment and enrolment of the patients are shown in a CONSORT flow diagram (Fig. 2). Thirty-four consecutive patients were randomly allocated to either the Needle group (*n* = 17) or the Catheter group (*n* = 17). No patients were excluded during the follow-up and analysis periods. There were no significant differences in patient characteristics between the two groups (Table 1).

Spreading pattern of ropivacaine to multiple intercostal levels

The primary spreading pattern of ropivacaine in the Needle group was observed as follows: (1) ropivacaine spread to multiple intercostal levels (*n* = 17) [mainly across the ribs as shown in Fig. 3a and the video (Online Resource 1)).

All of the cases showed similar spreading patterns.

In contrast, the observed findings for the Catheter group were as follows: (1) ropivacaine spread to multiple intercostal levels (*n* = 10) [mainly across the ribs (*n* = 2) as shown in Fig. 3b and the video (Online Resource 2)), mainly an anterolateral aspect of the vertebral bodies (*n* = 8) as shown in Fig. 3c and the video (Online Resource 3)] or (2) other spreading patterns (*n* = 7) [single intercostal space (*n* = 0), unobservable spreading pattern (no change) (*n* = 7) as shown in Fig. 3d and the video (Online Resource 4)]. The incidence of the spread of ropivacaine to multiple intercostal levels showed significant intergroup differences (*P* = 0.007; Table 2).

Requirement of intraoperative vasopressor

Intraoperative vasopressors were used in two cases (12%) in the Needle group and in ten cases (59%) in the Catheter group. Significant intergroup differences were observed in the use of intraoperative vasopressors (*P* = 0.010) (Table 3).

Discussion

Our study is the first to demonstrate that a local anesthetic injected via a Tuohy needle placed into the lateral edge of TPVS spreads to multiple intercostal levels in all cases, especially across the ribs at the peripheral side of the paravertebral injection site, as shown in the video. In contrast, a local anesthetic injected via a paravertebral catheter resulted in highly variable spreading patterns of a local anesthetic and involved either multiple intercostal spaces across the ribs or an anterolateral aspect of the vertebral bodies, or exhibited unobservable spreading patterns. In addition, the paravertebral injection of local anesthetic via a needle required less intraoperative vasopressor compared to via a catheter because the latter approach may lead to hypotension induced by the paravertebral injection of the high-dose ropivacaine.

For paravertebral injections via a needle, Naja et al. have described the paravertebral spreading patterns of a radiocontrast dye within a living body using a nerve-stimulator [7]. They showed that the injection point in the TPVS influenced the distribution pattern of a TPVB. A paravertebral injection at the ventral side of the endothoracic fascia led to a longitudinal spreading pattern close to the vertebral bodies, whereas injections at the dorsal side of the endothoracic fascia led to an unpredictable spreading pattern. Thus, they recommended performing paravertebral injections at the ventral side of the endothoracic fascia using a nerve stimulator. However, advancing a needle into the TPVS close to the intervertebral foramen or ventral to the endothoracic fascia is associated with an increased risk of penetrating the parietal pleura, thereby causing vascular or nerve injury. In addition to these risks, the high-dose local anesthetic may cause hypotension by significantly affecting the sympathetic trunk and the epidural space. Therefore, it is not recommended to advance the needle deeply. Our study showed that a local anesthetic injected via a needle placed into the lateral edge of TPVS could yield a stable spread to multiple intercostal levels, especially across the ribs at the peripheral side of a single paravertebral injection site.

For paravertebral injections via a catheter, Luyet et al. showed various spreading patterns of a contrast dye in human cadavers using ultrasound [4–5]. They suggested that the catheter migrates out of the targeted area despite the accurate placement of the needle into the TPVS. As previous reports demonstrated, it is difficult to control the position of the paravertebral catheter tip [3–6], implying that the tip position may have affected the paravertebral spreading patterns. Our study also showed that the spreading patterns of a local anesthetic were highly variable by paravertebral injection via a catheter.

This study had several limitations. First, the field-of-view range with thoracoscopy was limited. The catheter probably advanced to regions away from the thoracic cavity, such as into an intervertebral foramen, an intercostal muscle or a back muscle. Therefore, the spread of local anesthetic could not be observed using thoracoscopy. However, thoracoscopy provides real-time and direct vision which improves evaluation of observed events. Secondly, the extent of sensory block after injecting the local anesthetic or during surgery was not evaluated in this study. In a past report, the extent of the sensory block at multiple intercostal levels was larger compared with the local anesthetic spread [2]. Thirdly, this study was based on observations for the non-ventilated side under one-lung ventilation. The changes in the pressure of the thoracic cavity with non-ventilation may affect the spread of local anesthetic. One-lung ventilation may also have a small influence on the paravertebral spreading of local anesthetic. Moreover, there were no definitions of hypotension and no criteria for the use of intraoperative vasopressors in this study. The use of intraoperative vasopressor types and doses were left to the discretion of individual anesthesiologists. In addition, the independent anesthesiologist could not be blinded to the study allocation. Finally, in this study, a paravertebral catheter was inserted to a depth of 5 cm into TPVS; however, the optimal depth to which a paravertebral catheter should be inserted is unknown. Future studies are required to determine the optimal insertion distance of a paravertebral catheter.

Conclusions

During ultrasound-guided TPVB, a single paravertebral injection via a needle typically resulted in spreading of a local anesthetic to multiple intercostal levels, especially across the ribs at the peripheral side of the injection site. In contrast, the paravertebral injection via a catheter resulted in variable spreading patterns of local anesthetic. Therefore, a more stable spreading of local anesthetic to multiple intercostal levels can be achieved by a single paravertebral injection via a needle rather than via a catheter.

Acknowledgments

The authors would like to express their profound gratitude to M. Nishimura (Department of Thoracic Surgery, Tosei General Hospital, Seto, Japan) for assistance with the thoracoscopy procedures for all the cases. The authors also thank Editage (http://www.editage.jp/) for providing professional editing services.

Compliance with ethical standards

Conflict of interest

The authors declare that they have no conflicts of interest.

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Tables

Table 1 Baseline and perioperative characteristics of the patients.

	Needle group (n = 17)	**Catheter group (n = 17)**
Age (years)	57.9 ± 12.1	52.5 ± 14.7
Sex (Male / Female)	8 (47%) / 9 (53%)	13 (76%) / 4 (24%)
BMI (kg/m^2)	23.3 ± 3.8	23.7 ± 4.3
%VC (%)	87.3 ± 18.3	80.9 ± 19.1
FEV1.0% (%)	82.3 ± 5.9	85.8 ± 6.2
eGFR (mL/min/1.73 m^2)	83.1 ± 22.7	87.5 ± 14.8
Operation time (min)	51.9 ± 7.9	49.7 ± 6.6
Anesthesia time (min)	102.6 ± 10.5	99.9 ± 11.1
In-out balance (mL)	508.5 ± 110.5	590.9 ± 133.8
Intra-operative remifentanil average dose (μg/kg/min)	0.13 ± 0.07	0.13 ± 0.04

Values are mean ± standard deviation or number (proportion). %VC, vital capacity as a percent of predicted; FEV1.0%, forced expiratory volume in 1 second as a percent of forced vital capacity; eGFR, estimated glomerular filtration rate.

Table 2 Comparison of the spreading patterns of ropivacaine to multiple intercostal levels.

Spreading pattern	**Needle group (*n* = 17)**	**Catheter group (*n* = 17)**	***P*-value**
Multiple intercostal levels [across the ribs, anterolateral aspect of the VBs]	17 (100%) [17, 0]	10 (59%) [4, 6]	0.007**
Others [single intercostal space, no change]	0 (0%) [0, 0]	7 (41%) [0, 7]	
Odds ratio [95% confidence interval]	25.0 [1.29–483.99] †		

Values are number (proportion) of patients. VBs, vertebral bodies; **significant difference (*P* < 0.01),

† The odds ratio was calculated with Haldane-Anscombe 1/2 correction (i.e., the addition of 0.5 to all cells).

Table 3 Comparison of the use of an intraoperative vasopressor.

Requirement of vasopressor	**Needle group (*n* = 17)**	**Catheter group (*n* = 17)**	***P*-value**
Yes	2 (12%)	10 (59%)	0.010*
No	15 (88%)	7 (41%)	
Odds ratio [95% confidence interval]	0.09 [0.02–0.54]		

Values are number (proportion) of patients. *significant difference ($P < 0.05$).

Figure captions

Fig. 1 Ultrasound-guided thoracic paravertebral block techniques used in this study.

(a) The patient is positioned in a lateral decubitus position with the surgical site on the upper surface. (b) A ultrasonic probe (linear array transducer) is placed just lateral to the spinous process and (c) the transverse plane ultrasound view is obtained. A Tuohy needle is inserted in a lateral-to-medial direction from the outer edge of ultrasonic probe and advanced until the needle tip reached the lateral edge of the thoracic paravertebral space. The Tuohy needle is indicated by the triangle mark. TP, transverse process; IIM, internal intercostal membrane; PP, parietal pleura; VB, vertebral body.

Fig. 2 CONSORT flow diagram.

Fig. 3 Various spreading patterns of ropivacaine injected via a needle or a catheter.

First, 10 ml saline is injected via the Touhy needle placed into the lateral edge of paravertebral space (left image to middle image). Next, 20 ml of 0.5%

ropivacaine is injected via a needle as shown in (a), or a paravertebral catheter as shown in (b), (c), and (d) (middle to right images).The ropivacaine is spread to multiple intercostal levels: involved mainly across the ribs as shown in (a) and (b), or an anterolateral aspect of the vertebral bodies as shown in (c). An unobservable spreading pattern is shown in (d).

The gray arrows show the injection point of saline via a Tuohy needle and the black arrows show the spreading of ropivacaine.

Video captions

Online Resource 1: Video 1

Injection via a Tuohy needle with spread across the ribs.

A local anesthetic is injected into a thoracic paravertebral space via a Tuohy needle placed into the lateral edge of the paravertebral space. The local anesthetic mainly spreads into the multiple intercostal levels, especially across the ribs at the peripheral side of injection site.

Online Resource 2: Video 2

Injection via a catheter and spreading at the anterolateral aspect of vertebral bodies.

A local anesthetic is injected into a thoracic paravertebral space via a paravertebral catheter. The local anesthetic mainly spreads into the anterolateral aspect of vertebral bodies around the sympathetic trunk at multiple intercostal levels.

Online Resource 3: Video 3

Injection via a catheter and spreading across the ribs.

A local anesthetic is injected into a thoracic paravertebral space via a paravertebral catheter. The local anesthetic mainly spreads into the multiple intercostal spaces across the ribs.

Online Resource 4: Video 4

Injection via a catheter and an unobservable spreading pattern.

A local anesthetic is injected into a thoracic paravertebral space via a paravertebral catheter. The spreading of the local anesthetic is not identified under thoracoscopy.