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Impact of preoperative pleural effusion on ultrasound- and pressure-guided thoracic paravertebral block: a prospective observational study

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Abstract

Objective To evaluate the impact of preoperative pleural effusion on the ultrasound visualization of the paravertebral space (PVS), thoracic paravertebral nerve block administered by anesthesiologists, and to investigate whether ultrasound combined with pressure guidance can assist in locating the paravertebral space in patients with pleural effusion.

Methods This prospective observational study enrolled patients undergoing thoracic surgery at Beijing Jishuitan Hospital between September 2021 and September 2022. Patients were categorized into two groups based on preoperative CT findings: the pleural effusion group ($n=40$) and the non-pleural effusion group ($n=40$). Prior to the induction of general anesthesia, all patients were placed in a lateral position. Thoracic paravertebral nerve block (TPVB) was administered using ultrasound guidance combined with pressure monitoring, with a 20 ml of 0.5% ropivacaine.

Results Parameters recorded included the duration of puncture and ultrasound pre-scan for TPVB, the ultrasound image definition score of the PVS, the pressure in the external intercostal muscle and PVS, and additional relevant indicators. Mean arterial pressure (MAP) and heart rate (HR) were measured before anesthesia induction, post-induction, and during skin incision. Compared to the non-pleural effusion group, the pleural effusion group demonstrated prolonged ultrasound pre-scan and puncture durations. The PVS definition score, the ventral displacement of the pleura, and the accuracy of resident anesthesiologists in identifying the PVS were all significantly lower in the pleural effusion group ($p<0.05$). Compared to non-pleural effusion group, the pleural effusion group had significantly higher pressure in PVS. In the pleural effusion group, the pressure in PVS was significantly lower than that in external intercostal muscle ($p<0.05$). No significant differences were observed in MAP and HR between the two groups before anesthesia induction, post-induction and during skin incision ($p>0.05$).

Conclusion Preoperative pleural effusion is associated with reduced clarity of ultrasound visualization of the PVS, and extended procedural durations for anesthesiologists, thereby increasing the complexity of TPVB. Pressure detection

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during TPVB implementation can assist in locating the position of the puncture needle. For anesthesiologists with less experience, TPVB should be carefully performed in patients with preoperative pleural effusion.

Trial registration The trial was prospectively registered with the Chinese Clinical Trial Registry under registration number ChiCTR2100050582, on August 30, 2021.

Keywords Paravertebral block, Pleural effusion, Pressure measurement, Regional block, Ultrasound-guided

Introduction

Thoracic paravertebral nerve block (TPVB) is a fundamental component of multimodal analgesia in trunk surgery and is widely used in clinical anesthesia settings [1, 2]. TPVB is recognized for its ability to provide effective unilateral analgesia of the chest wall, demonstrating analgesic efficacy that is comparable to epidural anesthesia [3, 4]. The mechanism of TPVB involves the administration of local anesthetics into the paravertebral space (PVS), effectively blocking the ventral and dorsal branches of the spinal nerves as well as the sympathetic trunk, thereby achieving significant analgesic outcomes [5]. Given that the PVS is the primary anatomical target in TPVB, its accurate identification is essential for successful implementation.

The PVS is situated bilaterally adjacent to the spine and is characterized by its wedge-shaped structure. The anterolateral boundary is formed by the parietal pleura, while the vertebral body, intervertebral foramen, and the contents of the spinal canal constitute the medial boundary. The posterior boundary is delineated by the superior costotransverse ligament or the internal intercostal membrane (IIM) [6]. Notably, the integration of ultrasound-guided techniques in TPVB has substantially enhanced the success rates compared to conventional body surface localization methods. Moreover, recent studies suggest that combining ultrasound guidance with pressure localization technology enhances the precision of PVS localization [7].

Most existing studies on TPVB focus on patients with normal thoracic anatomy. However, certain surgical candidates, including individuals with rib fractures, chronic empyema, liver cirrhosis, congestive heart failure, or malignancies, may present with preoperative pleural effusion [8, 9]. These conditions result in alterations to the typical thoracic anatomy, with pleural effusion notably causes separation between the visceral and parietal pleura. This disruption can impede the ultrasound visualization of the PVS, thereby complicating the execution of ultrasound-guided TPVB. Previous research has shown that approximately 80% of patients with multiple rib fractures exhibited indistinct PVS during ultrasound-guided TPVB due to the presence of pleural effusion [10]. For anesthesiologists with limited experience, such complications may increase the risk of adverse events, including inadvertent pleural puncture or injury to the intercostal nerves and vessels, particularly when multiple puncture attempts are required.

Currently, research on the application of TPVB in patients with pleural effusion is limited. It is hypothesized that pleural effusion may obscure the PVS on ultrasound imaging, thereby increasing the procedural difficulty for anesthesiologists. Therefore, in this study we aim to conduct a prospective, single-center observational study to evaluate the impact of preoperative pleural effusion on the ultrasound visualization of the PVS, thoracic paravertebral nerve block administered by anesthesiologists, and to investigate whether ultrasound combined with pressure guidance can assist in locating the paravertebral space in patients with pleural effusion.

Materials and methods

Study design and participants

The study protocol was approved by the Beijing Jishuitan Hospital Institutional Review Board (2021204-01) and subsequently registered in the Chinese Clinical Trials Registry (ChiCTR2100050582, https://www.chictr.org.cn/showproj.html?proj=132771). Written informed consent was obtained from all participants prior to enrollment. Participants were divided into two groups based on preoperative CT findings: The pleural effusion group ($n=40$) and the non-pleural effusion group ($n=40$). Exclusion criteria included refusal to participate, inability to cooperate during the TPVB procedure, presence of coagulation disorders, infection at the puncture site, chronic opioid use, allergy to local anesthetics, and severe cardiopulmonary diseases. The study flow chart is shown in Fig. 1.

Study protocol

Upon arrival in the operating room, standard monitoring was initiated, including electrocardiogram (ECG) and peripheral oxygen saturation (SpO2) monitoring. Radial artery catheterization was performed under local anesthesia to enable continuous invasive blood pressure monitoring. Ultrasound-guided TPVB with pressure guidance was performed in both groups prior to the induction of general anesthesia.

Participants were positioned in the lateral decubitus position, and the T4-5 intercostal space was identified. Portable ultrasound equipment with a 15 – 6 MHz linear probe was used. The TPVB procedure utilized a

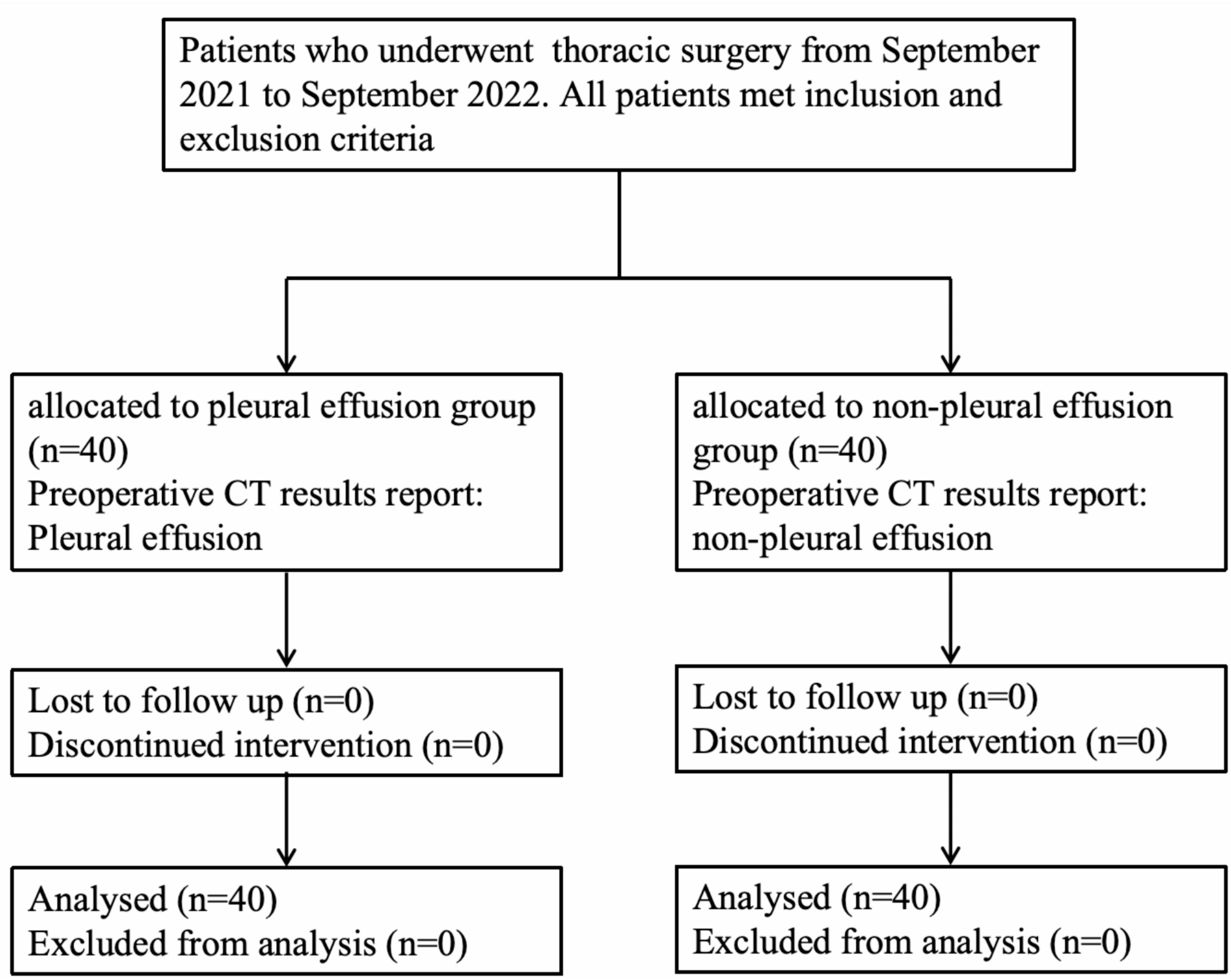

Fig. 1 The flow chart of the study

combination of ultrasound guidance and pressure guidance, involving scanning of the transversal technique at the transverse process and the in-plane puncture technique. The ultrasound probe was positioned lateral to the posterior midline, aligned along the intercostal space. Three key anatomical landmarks—the pleura, internal intercostal membrane (IIM), and transverse process—were visualized using ultrasound guidance (Fig. 2). During TPVB, paravertebral space pressure was measured using an arterial pressure transducer connected to a saline-filled line. A three-way stopcock at the terminus of the transducer was connected to a puncture needle and a syringe containing normal saline [11, 12](Fig. 3). The pressure transducer was zeroed at the level of the posterior midline (Supplemental Appendix 1 provides a video illustrating pressure changes in the external intercostal muscles and PVS). The puncture was performed laterally to medially. Needle tip localization was aided by the water separation technique with minimal saline infusion. Upon confirmation of ventral displacement of the pleura following saline infusion, 20 mL of 0.5% ropivacaine was administered. If ventral displacement of the pleura was absent or unclear, the anesthesiologist determined empirically whether the puncture needle had reached the PVS and administered ropivacaine.

Outcome measurements

The primary outcome measured in this study was the duration of puncture for TPVB. Secondary outcomes included the duration of ultrasound pre-scan for TPVB, the PVS definition score [13, 14], the degree of ventral displacement of the pleura, the proficiency of resident anesthesiologists in identifying the PVS, and the pressure in the external intercostal muscle and PVS. Mean arterial pressure (MAP) and heart rate (HR) were recorded before anesthesia induction, post-induction, and during the skin incision by a blinded observer. The duration of puncture for TPVB was defined as the time from the initiation of puncture to the completion of drug administration, excluding the time required for pressure

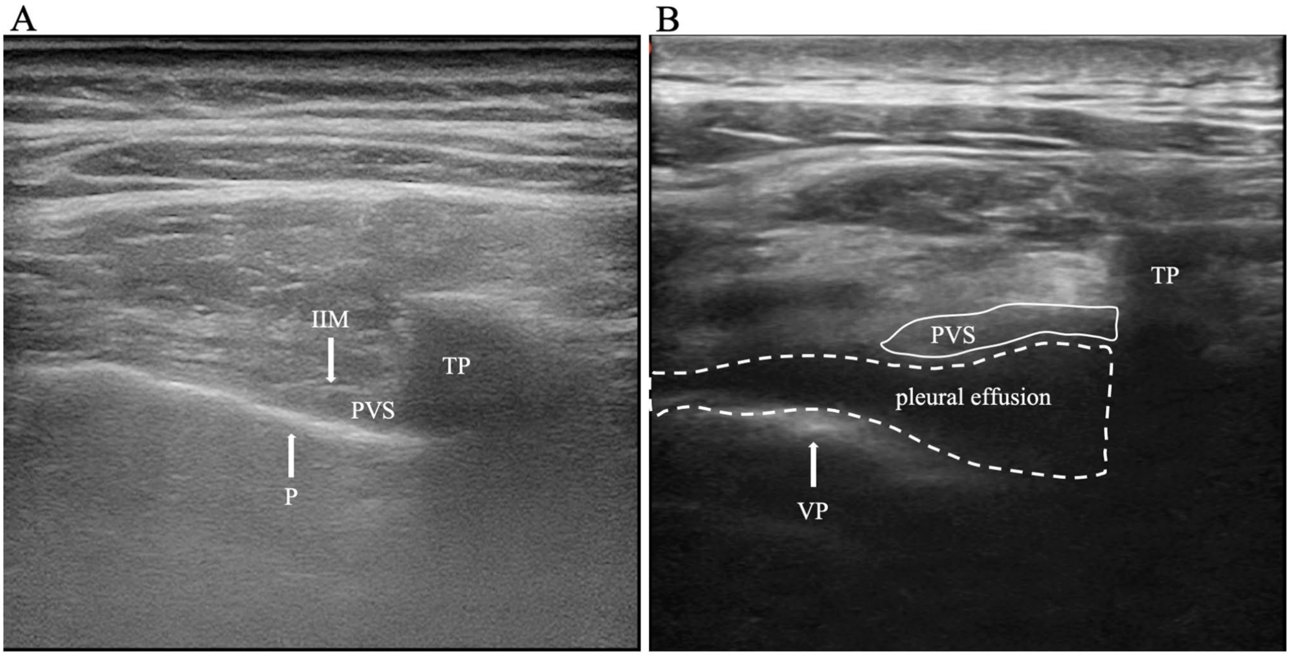

Fig. 2 Ultrasound images comparing the PVS in a patient without pleural effusion and in a patient with pleural effusion during TPVB. (**A**) TPVB ultrasound image of a patient without pleural effusion. (**B**) TPVB ultrasound image of a patient with pleural effusion. The dashed line outlines the pleural effusion located between the visceral and parietal pleura. The area enclosed by solid lines represents the PVS, as identified by the anesthesiologist. TPVB (thoracic paravertebral block), PVS (paravertebral space), TP (transverse process), IIM (internal intercostal membrane), P (pleura), and VP (visceral pleura)

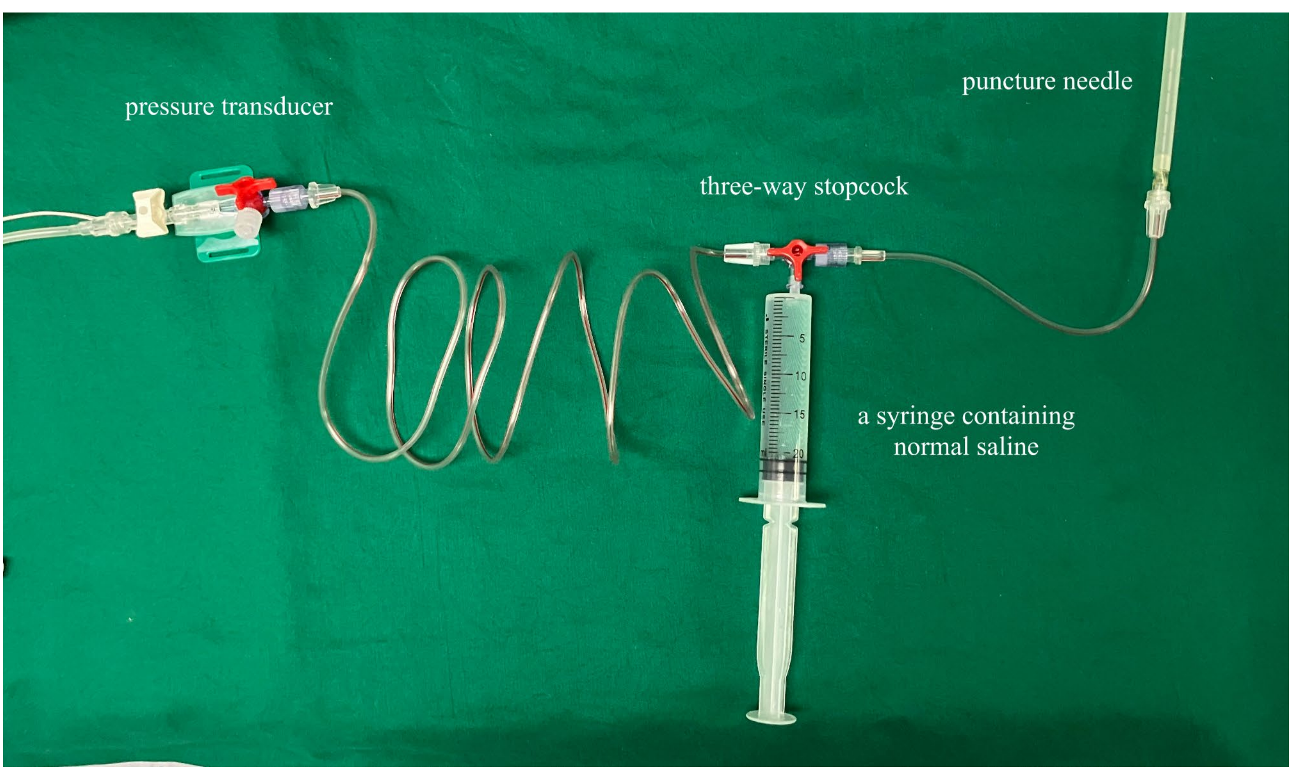

Fig. 3 An illustration of the pressure localization technique

Table 1 Demographic and clinical characteristics

	Pleural effusion group (*n* = 40)	Non-pleural effusion group (*n* = 40)	*P* Value
Gender, (men/women, n[%])[c]	25(62.5)/15(37.5)	23(57.5)/17(42.5)	0.648
ASA physical status, (II/III, n[%])[c]	29(72.5)/11(27.5)	34(85%)/6(15%)	0.172
Preoperative diagnosis, n(%)[c]			0.073
Cancer	17(42.5)	25(57.5)	
Rib fracture	23(57.5)	15(37.5)	
Age(y), median (IQR)[b]	47(31.5, 57.75)	55.5(36, 65)	0.087
Height(cm), mean (± SD)[a]	168.1 ± 8.4	166.8 ± 9.8	0.535
Weight(kg), mean (± SD)[a]	69.2 ± 14.0	66.5 ± 13.1	0.361
Distance between visceral pleura and parietal pleura in ultrasound image (cm), mean (± SD)	2.57 ± 1.35	-	-

a independent sample t test used

b Mann-Whitney U test used

c chi-square test used

ASA: American Society of Anesthesiologists

Table 2 Effect of pleural effusion on TPVB implementation

	Pleural effusion group (*n* = 40)	Non-pleural effusion group (*n* = 40)	*P* Value
Duration of ultrasound prescan for TPVB (sec), mean (± SD)[a]	74.6 ± 30.7	44.8 ± 8.2	0.001
Duration of puncture for TPVB (sec), mean (± SD) [a]	87.0 ± 34.4	60.7 ± 17.2	0.001
Definition score of PVS, median (IQR)[b]	4(2,6)	9(8,10)	0.001
Ventral displacement of pleura, (Yes/No, n[%])[c]	17/23(42.5%)	40/0(100%)	0.001
Accuracy of resident anesthesiologists in identifying PVS, (n%)[c]	25(25%)	73(73%)	0.001

a independent sample t test used

b Mann-Whitney U test used

c chi-square test used

TPVB: thoracic paravertebral block; PVS: paravertebral space; IQR: interquartile ranges

measurement. The PVS definition score was evaluated by experienced anesthesiologists using an 11-point Numerical Rating Scale, with scores ranging from 0 (very unclear) to 10 (very clear). The accuracy of resident anesthesiologists in identifying the PVS was assessed by randomly saving 10 TPVB ultrasound images, which were later reviewed by two third-year residents for PVS identification. The results were subsequently evaluated by two blinded anesthesiologists.

Statistical analysis

All data were analyzed using SPSS 25.0 software. The normality of continuous variables was assessed using the Shapiro–Wilk test. Normally distributed data are presented as mean ± standard deviation (SD), while non-normally distributed data are expressed as median (interquartile range). Comparisons between groups were conducted using the Student's t-test for normally distributed data and the Mann–Whitney U test for non-parametric distributions. Categorical data are presented as n (%), and differences between the two groups were evaluated using the chi-squared test or Fisher's exact test.The two-way repeated measures analysis of variance (ANOVA) was used to compare groups over time for variables with repeated measurements.A p-value of < 0.05 was considered statistically significant.

Sample size calculation

The sample size calculation was based on the primary outcome of this study. An initial pilot study including 10 patients revealed that the TPVB puncture time was 96.9 ± 37 s in the pleural effusion group and 73.7 ± 16.7 s in the non-pleural effusion group. Using PASS software, a minimum of 34 participants per group was determined to be necessary to achieve 90% power with an α of 0.05. Ultimately, 40 patients were enrolled in each group to account for an anticipated 10% dropout rate.

Results

Initially, 104 patients were enrolled in the study; however, 24 patients diagnosed with rib fractures were subsequently excluded due to their inability to cooperate with the completion of TPVB prior to anesthesia induction because of severe preoperative pain. Consequently, the final study group consisted of 80 patients, evenly divided into two groups, with 40 patients in each group. TPVB procedures were successfully completed in all patients, with no TPVB-related complications were observed. Patient demographics and surgical characteristics, including gender, ASA physical status, preoperative diagnosis, age, height, and weight, are summarized in Table 1. In ultrasound images of patients with pleural effusion, the distance between visceral pleura and parietal pleura on the lateral transverse process is recorded in Table 1. No statistically significant differences were observed between the two groups across these parameters ($p > 0.05$).

The ultrasound pre-scan time and puncture time for TPVB were significantly longer in the pleural effusion group compared to the non-pleural effusion group ($p < 0.05$) (Table 2). The PVS definition score, the extent of ventral displacement of the pleura, and the accuracy of resident physicians in identifying the thoracic paravertebral space were significantly lower in the pleural effusion group compared to the non-pleural effusion group ($p<0.05$) (Table 2).

There was no significant difference MAP and HR between the two groups prior to the induction of anesthesia, post-anesthesia induction, and during skin incision ($p>0.05$) (Table 3). No substantial difference in pressure was observed between the two groups when the needle tip was positioned in the external intercostal muscle ($p>0.05$). However, the pressure in the PVS was significantly higher in the pleural effusion group compared to the non-pleural effusion group ($p<0.05$). Additionally, in both groups, the pressure in PVS was significantly lower compared to the pressure in the external intercostal muscle ($p<0.05$) (Fig. 4).

Table 3 Comparison of MAP and HR at various time points between the two groups

	Pleural effusion group (*n*=40)	Non-pleural effusion group (*n*=40)	*P* Value
MAP before induction of anesthesia, mean (±SD) [a]	94.1±13.7	88.8±11.5	0.064
HR before induction of anesthesia, mean (±SD) [a]	80.1±18.9	75.7±12.0	0.217
MAP after induction of anesthesia, mean (±SD) [a]	77.2±13.2	75.0±14.1	0.477
HR after induction of anesthesia, mean (±SD) [a]	75.9±11.8	73.6±11.6	0.371
MAP during skin incision, mean (±SD) [a]	87.0±14.3	85.6±11.1	0.608
HR during skin incision, mean (±SD) [a]	82.3±19.3	79.6±12.9	0.456

a independent sample t test used

MAP: mean arterial pressure; HR: heart rate

Discussion

The results of this study found that PVS may not be clear when TPVB ultrasound scans are performed in patients with pleural effusion. Among them, 57.5% of patients with pleural effusion did not show significant ventral displacement of pleura when local anesthesia was administered, resulting in a significant increase duration of puncture for TPVB. Measuring the pressure of different tissues during TPVB puncture with puncture needles and pressure transducers can assist the anesthesiologist in locating PVS.

Previous studies have reported that rib fractures can lead to changes in lung anatomy such as pneumothoraces, subcutaneous emphysema, etc., making ultrasound imaging of TPVB challenging [15]. In our study, pleural effusion changes the thoracic anatomy and affects the ultrasound scanning, resulting in unclear visualization of the PVS on ultrasound images. The accuracy of our hospital residents in identifying PVS in patients with pleural effusion was significantly lower than that in normal patients.This is demonstrated by the supplemental scanning video of the PVS in patients with pleural effusion

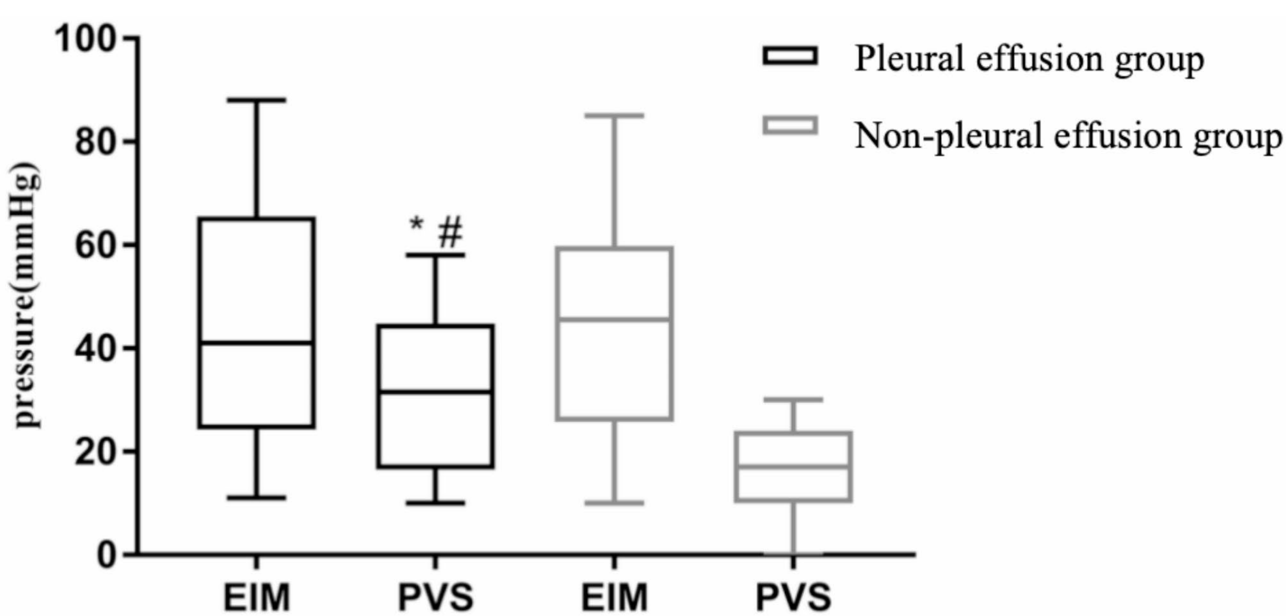

Fig. 4 Comparison of needle-induced pressure in the external intercostal muscles and PVS with and without pleural effusion. The needle exerts pressure on both the external intercostal muscles and the paravertebral space. The external intercostal muscles (EIM), paravertebral space (PVS), and the presence or absence of pleural effusion are considered in this context. *indicates statistically significant differences in external intercostal muscle pressure compared to PVS pressure. # indicates the statistical significance of the comparison between the two groups

provided in Online Supplementary Appendix 2. Misidentification of the PVS can result in complications associated with TPVB [16]. The reported incidence of pleural puncture and vascular puncture is as high as 1.1% and 3.8%, respectively [17].

According to Huili Li et al. study [18], the pressure of PVS and external intercostal muscle in patients with non-metastatic lung cancer is similar to that in patients without pleural effusion in our study. However, in this study, PVS pressure was higher in patients with pleural effusion than in patients without pleural effusion.This increase may be attributed to the accumulation of pleural effusion between the visceral and parietal pleura, which exerts additional pressure on the parietal pleura, leading to a significant rise in pressure. In addition, 57.5% of patients in this study did not exhibit significant ventral displacement of the pleura. Several factors may contribute to this lack of displacement. First, the presence of pleural effusion may elevate intrathoracic pressure, thereby influencing the pressure dynamics within the PVS. Despite a significant pressure drop upon needle entry into the PVS from the external intercostal muscle in both groups, patients with pleural effusion demonstrated markedly higher intrapleural pressures within the PVS compared to those without pleural effusion. Second, inflammatory adhesions and rib fractures in patients with pleural effusion may lead to complications such as chest wall injury and pulmonary herniation, which could obscure ventral pleural displacement [19, 20]. Finally, pleural effusion may render the PVS less distinct on ultrasound images, prompting a cautious approach during TPVB and potentially resulting in instances where the needle tip did not penetrate the PVS, yet local anesthetic was still administered.

There were no significant changes in hemodynamics in both groups during skin incision. It is possible to accurately locate PVS due to ultrasound combined with pressure guidance.It may also be due to the porosity of the superior costotransverse ligament that local anesthesia can spread to the PVS [21–23].

It has previously been reported that TPVB can provide effective analgesia in patients with lung surgery and rib fractures when administered at T4-5 [24, 25]. Moreover, TPVB was assessed by Infrared thermography, and T2-T10 segments are blocked by injection of a local anesthetic at T4-5, which may provide thoracic surgical analgesia [26]. In order to avoid the influence of different puncture position on the pressure measurement, TPVB was selected to be implemented at the T4-5 level.

This study has several limitations: (1) The study population was restricted to patients with pleural effusion, but the volume of pleural effusion was not quantified or categorized into different groups. Variations in pleural effusion volume may have influenced the study outcomes. (2) The included patients had a range of preoperative diagnoses, including empyema, cancer, and rib fractures, resulting in a variety of surgical procedures. There was considerable heterogeneity in postoperative pain between the different types of surgery. Consequently, the study focused exclusively on the analgesic efficacy related to skin incisions in surgical patients. (3) Patients with rib fractures are often associated with pain, causing respiratory changes that may affect the measurement of PVS pressure. In future studies, we plan to establish a multicenter research framework to expand the sample size and further refine the classification of patients with pleural effusion, thereby conducting more rigorous validation.

Conclusion

Preoperative pleural effusion significantly impacts the implementation of ultrasound guidance TPVB. Pressure combined with ultrasound guidance can assist in locating PVS in patients with pleural effusion Inexperienced anesthesiologists should exercise caution in administering TPVB in patients with pleural effusion to avoid associated complications.

Abbreviations

PVS	Paravertebral space
TPVB	Thoracic paravertebral nerve block
MAP	Mean arterial pressure
HR	Heart rate
IIM	Internal intercostal membrane
ECG	Electrocardiogram
SpO2	Peripheral oxygen saturation
SD	Standard deviation.
MTP	Mid-point transverse process to pleura block

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13019-025-03437-3.

Supplementary Material 1

Supplementary Material 2

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Author contributions

Conception and design of the research: Yaoping Zhao, Qiang Zhang, Geng Wang. Acquisition of data: Dong Zhang, Shaoqiang Zheng, Nan Cai. Analysis and interpretation of the data: Shaoqiang Zheng. Statistical analysis: Dong Zhang, Shuang Yu. Writing of the manuscript: Yaoping Zhao, Nan Cai. Critical revision of the manuscript for intellectual content: Shuang Yu, Qiang Zhang, Geng Wang. All authors read and approved the final draft.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
This study was conducted with approval from the Beijing Jishuitan Hospital Institutional Review Board (202104-01). This study was conducted in accordance with the declaration of Helsinki. Written informed consent was obtained from all participants.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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