Prospective Study

The Novel Costotransverse Foramen Block Technique: Distribution Characteristics of Injectate Compared with Erector Spinae Plane Block

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Background: The costotransverse foramen (CTF) is a space continuous with the paravertebral space. We hypothesized that injections passing through the CTF will result in a successful injectate spread to the paravertebral space.

Objectives: We investigated patterns of dye spread to assess characteristics of neural blockade following ultrasound-guided CTF and erector spinae plane (ESP) injection in an anatomic and clinical study.

Study Design: Prospective cadaveric study, and case studies.

Setting: University hospital.

Methods: Six soft cadavers were studied. The boundaries of the CTF and the needle pathway of CTF injection were identified in the first cadaver. The CTF and ESP injections were performed on either the left or right sides of the T4 vertebral level in cadavers 2 to 6. Fifteen milliliters of 0.2% methylene blue was injected in each block, and the spread of dye was assessed by anatomic dissection. We also report 2 case studies of CTF and ESP blocks.

Results: Cadaver studies of CTF injection demonstrate that with injection to the inferior aspect of the base of the transverse process, the dye mainly passes anteriorly through the CTF into the paravertebral space, with minimal track-back to the deep back muscles. Consistent sensory blockade was achieved in 2 case studies. With the ESP injection, the spread of dye was observed cephalocaudad to the fascia of the erector spinae muscle, with no dye spreading within the paravertebral space in all cadavers.

Limitations: Prospective case series.

Conclusions: CTF block was consistently associated with a mainly anterior spread of injectate into the paravertebral space that involved the thoracic spinal nerves, and minimal posterior spread of injectate to the deep back muscles.

Key words: Thoracic vertebrae, rib cage, paraspinal muscle, nerve block, joints

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Thoracic paravertebral block (TPVB) and intercostal nerve block are well-described and recognized techniques for postoperative analgesia following thoracic surgeries, such as thoracotomy (1-3) and mastectomy (4,5). They are a valid alternative to epidural block that may offer comparable analgesic efficacy and fewer adverse effects. However, the boundaries of the injection site are still in close proximity to vital organs, and therefore they require more expertise to execute safely. The potential risks of pneumothorax, unintentional neurovascular injection, or local anesthetic systemic toxicity therefore remain, whether or not ultrasound guidance is utilized (6,7). Moreover, the view provided by ultrasound is rarely optimal, especially in patients with thick back fat or muscles, so superb dexterity is required to compensate.

Interest in ultrasound-guided fascial plane blocks has been steadily increasing in recent years. Several studies have reported on novel techniques of paraspinal fascial plane blocks, including retrolaminar block (8,9), erector spinae plane (ESP) block (10-12), and midpoint transverse process to pleura (MTP) block (13). These methods seem to provide a superficial block, which results in effective analgesia in the thoracic region, are easy to perform, and have minimal risk of pneumothorax. Although the injection point differs between these 3 techniques, the mechanism of action seems to be similar. The success of these techniques depends on the local anesthetic spreading through the gap between the superior costotransverse ligaments (SCTL) or through the costotransverse foramen (CTF), reaching the nerve root in the paravertebral space (13-16). The CTF is a space between the neck of the rib and the SCTL that is continuous with the paravertebral space, which is the opening for the dorsal ramus and intercostal nerve (17). Therefore it has been postulated that local anesthetic injected into the CTF may spread through the paravertebral space, whereas keeping the tip of the needle far from the pleura.

In this study, we describe a novel technique that provides an alternative to TPVB called CTF block, whereby the injected solution is distributed through the CTF. We hypothesized that an injection passing through the CTF under ultrasound guidance will result in a successful spread of injectate to the paravertebral space. We also investigated the pattern of dye spread in the paravertebral region and compared the characteristics of neural blockade following ultrasound-guided CTF and ESP injection in an anatomic and clinical study.

Methods

This study was approved by the institutional review board of Chulalongkorn University, Bangkok, Thailand, and was registered with Clinical trials.in.th (TCTR20190205004). Six soft-embalmed cadavers (3 women and 3 men) were selected from cadavers donated for scientific research at the Department of Anatomy, Chulalongkorn University. We chose one male soft cadaver to explore the boundary of the CTF on one side of the back. We performed a needle injection with minimal dye to the CTF under ultrasound guidance from the other side to assure the needle pathway. The remaining 5 soft cadavers were randomly allocated to receive the CTF injection on either the left or right side of the back, and the ESP injection on the opposite side.

First, we analyzed the CTF and its anatomic landmarks in one side of the back of the soft cadaver. In a prone position, the skin, subcutaneous tissue, muscle and fascia were removed until the boundary of the CTF was revealed. The CTF is defined medially by the lamina of the thoracic spine, laterally by the SCTL, superiorly to the base of the transverse process (TP), caudally to the neck and tubercle of the rib below, and anteriorly by the paravertebral space. The SCTL are strong fibrous bands that stretch from the upper border of the neck of the rib to the lower part of the TP of the vertebra superior to it (Fig. 1A) (18,19). Therefore we decided to choose the inferior aspect of the base of the TP medial to the attachment of a SCTL as a reference bony landmark for ultrasound-guidance, and determined the needle pathway and needle tip most appropriate for the technique of CTF block.

Second, an X-Porte (Sonosite, Inc, Bothell, WA) ultrasound system with an 8-3 MHz, C35xp, and curved array transducer with a protective plastic sheath was used for all ultrasound procedures. For the CTF injection technique, the T4-T5 thoracic spinal level was identified using ultrasonography counting down from the first thoracic TP to the first rib junction. The positions of the fourth and fifth ribs were identified and marked with the transducer orientated longitudinally. We began ultrasound scanning in the parasagittal plane of the fourth to fifth ribs (Fig. 2A), which could be visualized as a hyperechoic, round shape with acoustic shadowing below. The linear hyperechoic interface corresponding to the parietal and visceral pleura could be visualized deeper and located in-between the ribs (Fig. 2B). The transducer was then guided in a lateral to medial direction while maintaining a parasagittal orientation and observing for the transition from ribs to the TP (a change in shape and a slight step-up of a bony structure in the ultrasound image, Fig. 2C). This allowed the TP to be visualized as a square-shaped structure that lies more superficial to the skin compared with the ribs. The superior part of the ribs was visualized as a continuous hyperechoic line that appeared deeper (anteriorly) and slightly in front of (superiorly) the TP. The hyperechoic pleural line could still be seen between the TP in this ultrasound view, but deeper and less determined than in the rib view. In addition, the SCTL could be visualized above the paravertebral space in this view (Fig. 2D). The transducer was moved medially to identify the base of the TP, a slight step-down from the hyperechoic shape of the TP. The pleural structure was determined in this view by gradually moving deeper and away from the TP (Fig. 3A, B). The neck of the rib could be clearly visualized at this level. To confirm the position of the base of the TP, the transducer was slid medially until a flat hyperechoic area with acoustic shadowing beneath it, which was the vertebral laminae, came into ultrasound view (Fig. 3C, D). The transducer was then slid back until the base of the TP could be seen once again (Fig. 3E).

The injection procedure was performed using an in-plane technique under real-time ultrasound guidance. An 80-mm, 22-gauge block needle (Pajunk SonoTAP, Geisingen, Germany) was directed caudad-to-cephalad until the needle tip contacted the anteroinferior part of the base of the T4 TP (Fig. 3F). The correct needle tip position was confirmed by the injection of 0.5 to 2 mL of 0.9% normal saline solution to visualize the spreading from posterior to anterior. If bulging of the erector spinae muscle or distension of the fascial plane between the back muscle and the TP was observed following the injection, owing to more posterior than anterior spread of injectate, the needle was moved off the bone in an anterior direction and the injection incrementally adjusted until the anterior spreading of injectate fluid was adequately visualized in the ultrasound view. After that, 2 (first cadaver) or 15 mL (cadavers 2–6) of 0.2% methylene blue dye was injected over 1 to 2 minutes while the spreading of dye in an anterior direction was observed.

The ESP injection was performed by placing the ultrasound transducer in a similar longitudinal parasagittal orientation over the tip of the TP as previously described. The same needle type was inserted in a caudad-to-cephalad in-plane with the ultrasound beam contacting the tip of the T4. Correct needle tip position was confirmed by injection of 1 to 2 mL of 0.9% normal saline solution, and visualization of linear fluid spread that distended the fascial plane between the erector spinae muscle and the tip of the TP. Fifteen milliliters of the same dye solution was then injected. All injections for both techniques were performed by the same investigator (W.K.).

The anatomic dissections were performed 30 minutes after dye injection by a single anatomist (T.T.) who was blinded as to which side had received the CTF or the ESP injection. An incision was made along the skin over the midline of spinous processes from C7 to the lumbar

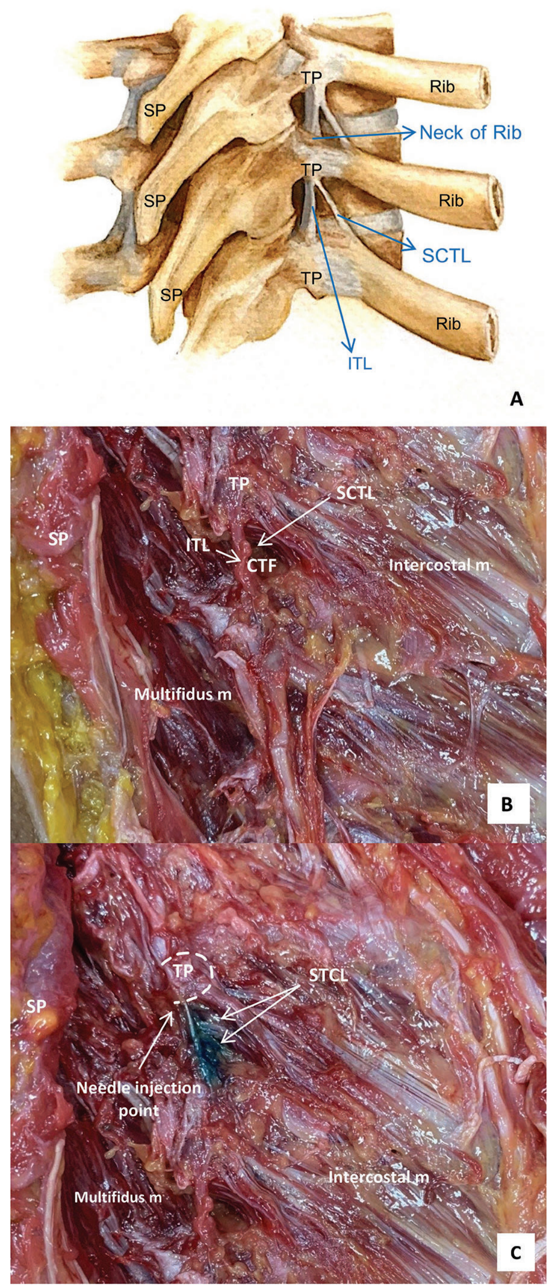

Fig. 1. *(A, B) Illustration and the image of the first cadaver dissection, showing the boundaries of the CTF: superior to the TP, inferior to the neck of next rib, medial to the lamina of the thoracic spine, lateral to the superior costotransverse ligament (was retracted and overlapped by the levator costarum muscle), and anterior to the paravertebral space. (C) The dye staining is present in the area of the CTF following CTF with minimal dye injection for confirmation of the needle pathway at the level of the base of TP. ITL, intertransverse ligament.*

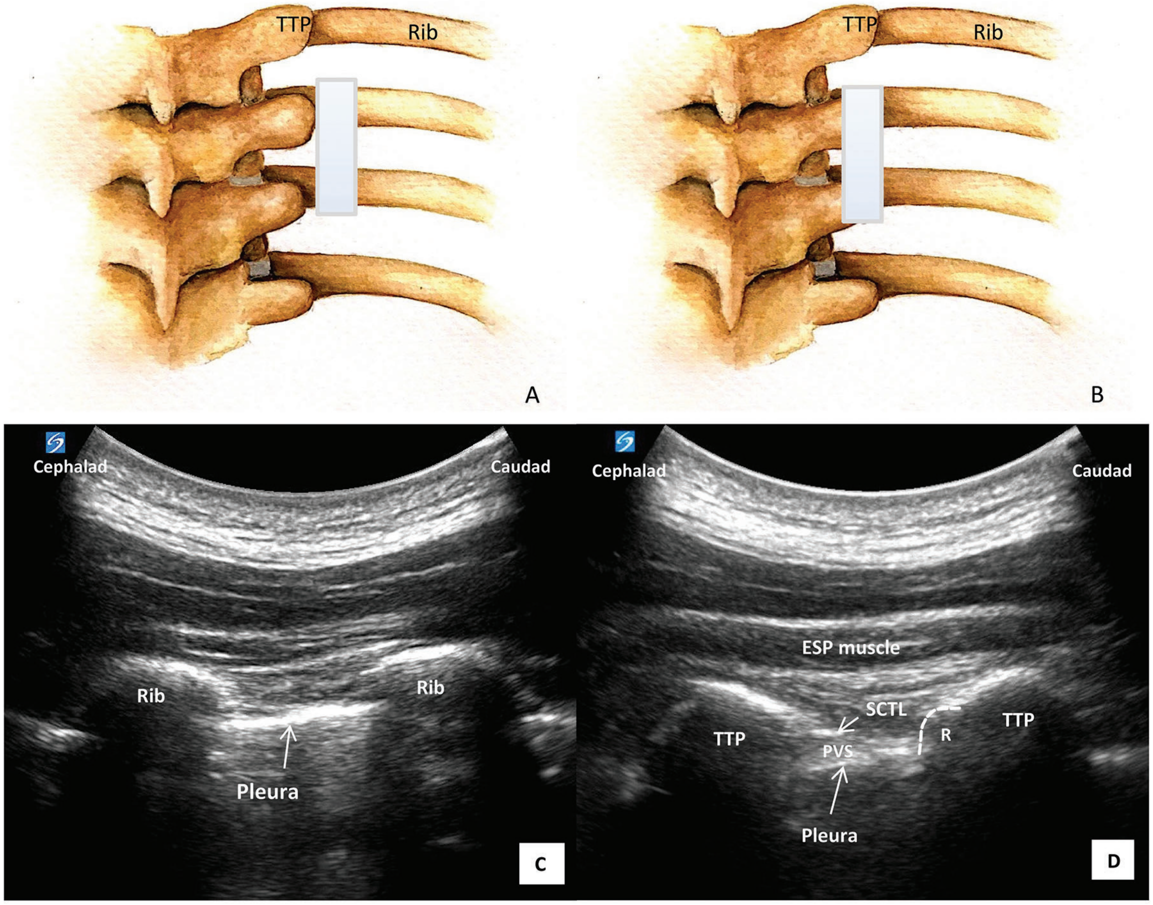

Fig. 2. *The illustrations demonstrate the posterior view of thoracic spines and ribs with ultrasound probe positions (white bar, A and B) and ultrasonographic visualization to identify the ribs and TP in the sagittal plane for the CTF block (C and D). (A, C) The ultrasound transducer was placed between 2 ribs (fourth to fifth), the ribs appear as convex structures, and the pleural line is the horizontal hyperechoic line between the ribs. (B, D) The ultrasound transducer was placed between the 2 TPs (fourth to fifth). The TP is visualized as a square structure, and the fifth rib appears as a step-down of the hyperechoic convex line superior to the fifth TP. The paravertebral space is located between the hyperechoic lines of the superior costotransverse ligament and the pleura. PVS, paravertebral space.*

vertebrae, and the skin was reflected laterally to expose the posterior thoracic wall. The trapezius, latissimus dorsi, rhomboid, and serratus posterior were revealed and reflected superiorly. The thoracolumbar fascia and the erector spinae muscle group, consisting of iliocostalis, longissimus, and spinalis muscles, were revealed and removed at their attachments. The extent of the spread of the dye superficially and deep to these muscles was explored. These muscles were cut at the cephalad end and reflected inferiorly to visualize the thoracic cage, including the costotransverse ligament and the transversospinalis group, consisting of the semispinalis, multifidus, and rotatores muscles. The external intercostal muscle, internal intercostal membrane, SCTL, and ribs were removed for dissection and identification of the spinal nerves. The paravertebral space was also revealed by removing the TP and neck of the rib. At each stage of the dissection, the extent and pattern of the spread of the dye were photographed and noted.

Results

A total of 6 soft cadavers (3 women and 3 men, mean age of 77.8 years) were included in this study. Ultrasound landmarks were determined without dif-

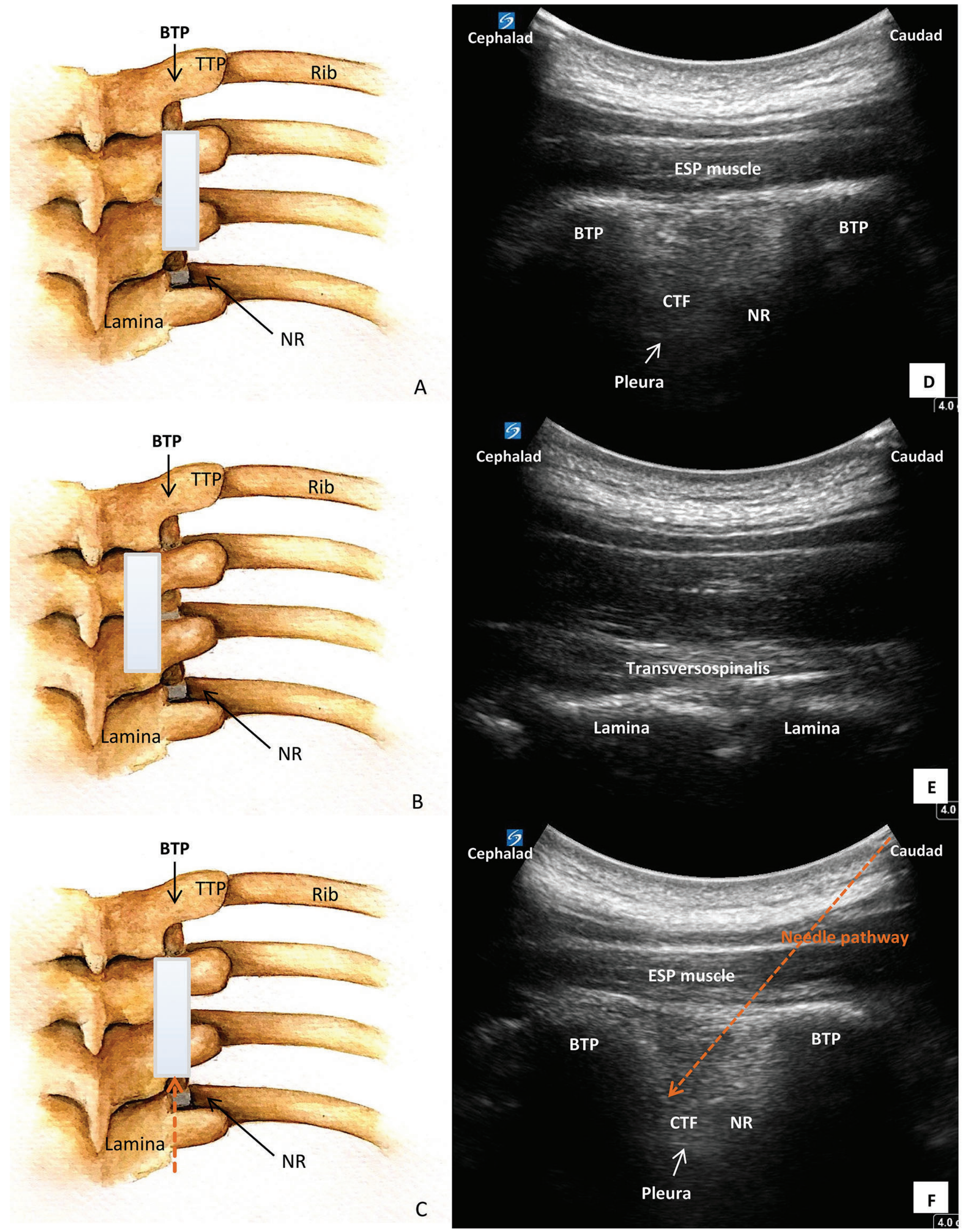

Fig. 3. *The illustrations demonstrate the posterior view of the thoracic spines and ribs from the ultrasound probe position (white bar, A–C) and ultrasonographic visualizations showing the base of the TPs and lamina in the sagittal plane for the CTF block (D–F). (A, D) The ultrasound transducer was placed between the bases of TPs (fourth to fifth). The bases of TPs appear more squared-off than the tip of the TP, which is deeper and close to the more obscure pleural line. The neck of fifth rib appears as a step-down of the hyperechoic convex line anterosuperiorly to the fifth TP. (B, E) The ultrasound transducer was placed between laminas 4-5. (D, F) The ultrasound transducer was located at the level of the base of TP (fourth to fifth) using the in-plane needle approach where the needle was inserted from the caudad to cephalad direction into the anteroinferior part of the base of the fourth TP. BTP, base of TP; NR, neck of rib.*

ficulty in all soft cadavers, which were considered to be in suitable condition. For the first cadaver, the anatomic boundary of the CTF and the dye staining at the area of the tip of needle for the CTF injection are shown in Fig. 1B, C.

For cadavers 2 to 6, all CTF and ESP dye injections were successfully performed on each side, including 5 CTF and 5 ESP injections. After the extrinsic muscles of the back (the trapezius, rhomboid, and serratus posterior) were revealed, staining of the dye was observed beneath the posterior layer of the thoracolumbar fascia that covered the erector spinae muscle with the ESP injection, but slight leakage of dye along the injection pathway was shown with CTF injections. When the erector spinae muscle was explored, intense cephalocaudad dye staining was found in the superficial and deep planes of the erector spinae muscle with ESP injections (5–6 levels). Only minimal cephalocaudad staining was observed in deep planes of the erector spinae muscle with CTF injections (2–3 levels in 3 cadavers). Furthermore, no spread of dye in the plane of the erector spinae muscle was observed in 2 cadavers with the CTF injection.

There was minimal spread of the dye within the transversospinalis group (semispinalis, multifidus, and rotatores) at the level of injection with CTF injections, but no spread of the dye was observed with any of the ESP injections. With CTF injections, the dye spread was more medial, toward the intertransverse ligament. Spreading of the dye on the external fascia of the external intercostal muscle was observed in all ESP and CTF (3 cadavers) injections (Fig. 4). However, after the neck of the rib was removed, it was revealed that the dye did not penetrate the external intercostal muscles or internal intercostal membrane, and the dye spread did not involve the ventral rami in all ESP injections (Fig. 5A, B). However, in all CTF injections, the dye was observed to have spread into the paravertebral space via the CTF, and dye staining deep into the internal intercostal membrane and pleura was also observed (Fig. 5A, C). The ventral rami or spinal nerve involvement was observed mostly at the T3-T6 levels only with CTF injections. The dye spreading patterns deep to the erector spinae muscle and spinal nerves between CTF and ESP injections in cadavers 2 to 6 are shown in Table 1.

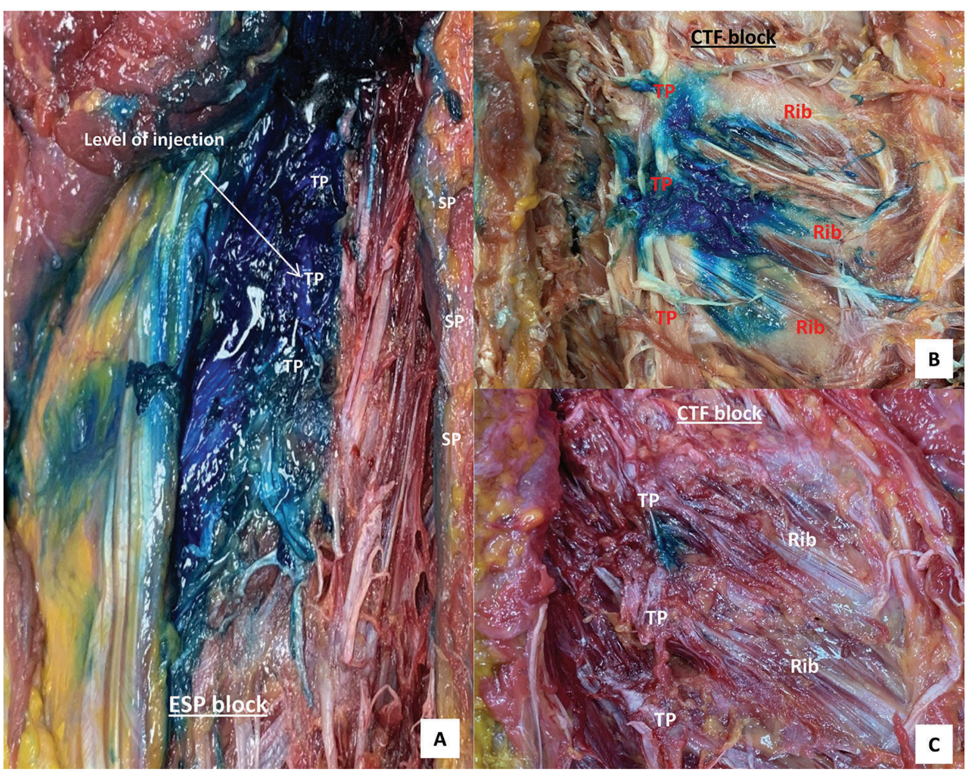

Fig. 4. *Anatomic dissection following ESP (A) and CTF (B and C) injection. After the erector spinae muscle was revealed, (A) intense cephalocaudad staining and lateral spreading of the dye in the plane of the intercostal muscle, with limited spread to the transversospinalis group. (B) Minimal cephalocaudad of the dye in plane of intercostal muscle, with partial spread to the transversospinalis group. (C) Spread of dye was only stained at the area of the CTF. SP, spinous process.*

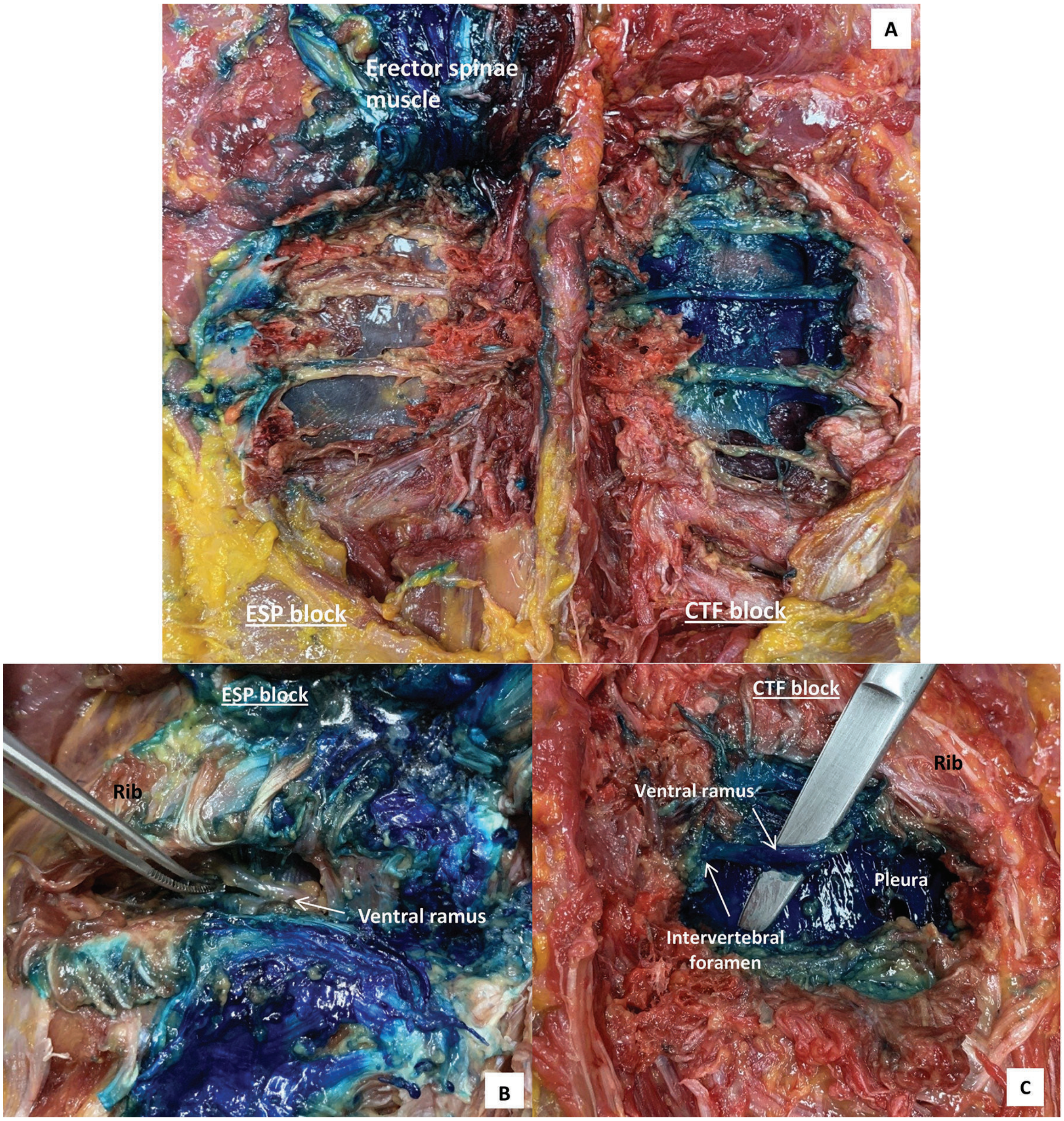

Fig. 5. *Anatomic dissection following ESP (A [left side] and B) and CTF (A [right side] and C) injection. After the ribs were removed, A (left side) and B, the surface of the ribs and the intercostal muscles were partially stained, but the intercostal nerves and the pleura were not stained with dye. (A) (right side) and (C), the intercostal nerves and the pleura were stained with dye.*

Case 1

A 38-year-old, 50 kg woman with gender dysphoria and no other underlying diseases presented for bilateral breast amputation. She had extensive psychological evaluation and assessment. The interventions were performed in the block room, with pulse oximetry, electrocardiogram, and noninvasive blood pressure monitoring. The patient was placed in a prone position and received 1 mg of intravenous midazolam and 25 µg of fentanyl for sedation. Ultrasound-guided CTF and ESP blocks under aseptic conditions were performed at the T4 level on the left and right sides, respectively, with 20

Table 1. *Distribution characteristics of spread of dye between CTF and ESP injections in 5 cadavers.*

Thoracic Level	Erector Spinae		Serratus Anterior		Intercostal		Transversospinalis		Dorsal Rami (Posterior cutaneous branch)		Ventral Rami	
	CTF (n)	ESP (n)	CTF (n)	ESP (n)	CTF (n)	ESP (n)	CTF (n)	ESP (n)	CTF (n)	ESP (n)	CTF (n)	ESP (n)
1	0	4	0	4	0	2	0	0	0	4	0	0
2	0	5	0	5	0	3	0	0	0	5	4	0
3	3	5	0	5	3	5	3	0	3	5	5	0
4	3	5	0	5	3	5	3	0	5	5	5	0
5	2	5	0	5	3	4	0	0	2	5	5	0
6	0	5	0	4	0	3	0	0	0	5	4	0

mL 0.25% bupivacaine and epinephrine 1:200,000 injected in each block. Sensation was tested by a blinded resident anesthetist every 5 minutes after the blocks, until decreased sensation was noted. A sensory assessment with the patient in the supine position revealed diminished perception of pinprick sensation in the T3-T5 dermatomes from the left parasternal border to the axillary area on the left side (CTF block) at 20 minutes. Diminished perception of pinprick sensation was also seen in the T4-T5 dermatomes on the right side (ESP block) at 30 minutes after blocks, but this did not extend to the axillary area. The patient received an uneventful general anesthetic for the surgery, during which they were administered a total of 100 µg of intravenous fentanyl. The patient reported a pain score of 0/10 on a Numeric Rating Scale (NRS-11) at rest and 2/10 with activity after surgery in both sides, and required no further intravenous rescue analgesia until discharge. The sensory assessment was also reassessed in the postanesthesia care unit (PACU), in which the patient revealed diminished perception of pinprick sensation in the T3-T8 dermatomes from the left parasternal border to the axillary area on the left side (CTF block), and the T3-T8 dermatomes on the right side (ESP block) not extend to the axillary area. The duration of the blockade was an average of 8 hours for both blocks.

Case 2

A 44-year-old, 48 kg woman with a past medical history of breast cancer and no other underlying diseases presented for bilateral breast augmentation with prostheses. She had a history of bilateral mastectomy and sentinel lymph node biopsy 5 years prior, with general anesthesia.

The procedures were performed in the block room before the operation started, with pulse oximetry, electrocardiogram, and noninvasive blood pressure monitoring. The patient was placed in a prone position and under ultrasound-guidance, the CTF and ESP blocks were performed at T4 on the right and left sides, respectively, with 20 mL 0.25% bupivacaine and epinephrine 1:200,000 injected in each block. Sensation to pinprick was tested by a blinded nurse anesthetist every 5 minutes after the blocks, until decreased sensation was noted. A sensory assessment revealed diminished perception of pinprick sensation in the T3-T6 dermatomes from the right parasternal border to the axillary area on the right side (CTF block) at 15 minutes, and the T3-T4 dermatomes on the left side (ESP block) not extended to the axillary area at 30 minutes after blocks. The patient received an uneventful general anesthetic for the surgery, during which they were administered a total of 4 mg of intravenous morphine. The patient reported an NRS-11 score of 0/10 at rest and 1-2/10 with activity for the right side (CTF block), and 3/10 at rest and 5-7/10 with activity for the left side (ESP block) after surgery. The sensory assessment was also reassessed in the PACU until the patient revealed normal perception of pinprick sensation. The results of the loss of sensation were revealed as the same as the preoperative assessment, and the duration of the blockades was an average 6 hours for both blocks.

Discussion

We have described an alternative technique for ultrasound-guided TPVB using a parasagittal in-plane approach, and injection through the CTF at the level of the base of the TP. Our cadaveric and case studies demonstrate that an injection through the CTF consistently results in a spread of dye anteriorly to the paravertebral space, involving the thoracic nerve at the level of the injection, and also adjacent levels, with minimal spread of dye posteriorly to the deep back muscles. The results of our ultrasound technique have many advantages that challenge traditional ultrasound-guided TPVB and the other paraspinal fascial plane blocks. First, the CTF block does not require clear identification of the SCTL in the ultrasound image and does not require the needle advancement to penetrate this ligament to place the injectate behind the pleura. Second, the pleura were not superficial or close to bony structures at the level of our ultrasound technique (the base of TP). Therefore there could be a lower incidence of pleural puncture because the position of the needle tip remains in a bony area (the inferior aspect of the base of the TP) and remains distant from the pleura. Third, the CTF block can reduce the potential risk of injury to the intercostal nerve and vessels that run in the paravertebral space. Forth, the CTF block can avoid injury to the dorsal ramus that exits via the CTF because the needle tip contacts the inferior aspect of the base of the TP, which lies superoposterior to the course of the dorsal ramus. Fifth, no patient in the case studies complained of a heaviness or uncomfortable pressure sensation in the chest when the CTF block was performed, which commonly occurs with TPVB injections. This result is probably because of the injectate gradually flowing through the CTF into the paravertebral space, which causes the opening pressure to be less than that caused by direct injection to the paravertebral space by the TPVB.

The intercostal spaces near the spine are limited by the costotransverse joints and intertransverse spaces, the latter being obturated by the superior costotransverse and intertransverse ligaments. The intertransverse ligaments are fibrous bands connecting the TPs of vertebrae. The SCTL blends laterally with the internal intercostal membrane, whereas the medial part is not blended and does not contact any structures (18,19). In our technique, the position of the needle tip was between the medial border of the SCTL and the lateral margin of the lamina, which was anterior to the intertransverse ligament. Therefore the injectate easily penetrates into the gap in the paravertebral space without barriers.

The results of dye spreading after the CTF injection in our cadaveric studies were consistent with the results of sensory blockade after the CTF block in the case studies. However, incongruous results between the cadaveric and case study occurred with the ESP block. An incompatibility results of the previous anatomic studies that investigate the mechanism of action of the ESP block may result from the use of different dissection techniques (14-16,20). The ESP blocks in our study found the cephalocaudad spread of dye into the fascial plane of the erector spinae muscle but found no anterior spread into the paravertebral or intercostal spaces, which would involve the spinal nerves, similar to previous studies (14,20). However, our case studies show that ESP blocks still produce sensory blockade at the level of the injection and adjacent levels, even though the blockade was equivocal and encompassed less dermatome levels in the second case. Moreover, slower onset of sensory blockade in the ESP blocks was determined when compared with the CTF blocks. These causes are likely because of the complex structures of the back, such as bones, muscles, or ligaments, and especially around the area of the TP, causing obstacles to the distribution of the injectate. Therefore the total amount of injectate cannot fully penetrate into the paravertebral space, and higher volumes would be required to achieve effective blockade in clinical practice. Furthermore, there are many factors that may affect the distribution of the local anesthetic after the ESP block is performed in a clinical setting, including the effects of gravity and the patients' position, introducing uncertainty and inconsistency into this method. The mechanism of action of the retrolaminar block may also be similar. However, the efficacy of cephalocaudad spread and the dorsal ramus blockade in the ESP and retrolaminar blocks may be used to relieve pain in multiple rib fractures, especially as a catheter technique for continuous analgesia (9,12,21).

The MTP block has been previously described as an alternative technique to the paravertebral block (13). However, the injection point and mechanism of action are different from our technique. The target point of MTP block is midway between the posterior border of the tip of the TP and the pleura, and posteriorly to the SCTL. Therefore the needle injection of this technique is into the muscular layer, behind the SCTL. The mechanism of action is through the spread of solution throughout the porous structure of the SCTL into the paravertebral space. Although our needle target is more medial (the base of the TP) than the MTP block, the solution will directly pass through the CTF. Moreover, the pleura are deeper to the level of our injection site, which could reduce the incidence of pneumothorax and do not need to identify the pleura during the injection was performed. The CTF block is also a superficial block, and no skilled hands are required during the ultrasound-guided technique. However, further clinical studies are necessary to explore the efficacy between CTF and MTP blocks.

This study has several limitations. In our cadaveric study, changes in integrity of tissue and temperature could have affected permeability of diffusion of the injectate, and the absence of tissue tension may also limit the spread of injectate. Finally, small sizes of case study were used. Therefore large sizes of further clinical studies are needed to focus on determining the extent of analgesia, volume of injectate, and duration of action when compared with the other paraspinal fascial plane blocks.

Conclusions

Our cadaveric and clinical studies suggest that by using an alternative technique of ultrasound-guided paravertebral block, the injected solution can pass through the CTF (CTF block) at the level of the base of the TP. This was consistently associated with a mainly anterior spread of injectate into the paravertebral space, which involved the thoracic spinal nerves, and minimal posterior spread of injectate to the deep back muscles. We found inconsistency in the spread of the injectate and sensory blockade using the ESP block.

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