

## Cadaveric Study



## Ultrasound-assisted Thoracic Intervertebral Foramen Block. A Cadaveric Study

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**Background:** A thoracic paravertebral block can be a useful opioid-sparing technique for controlling postoperative pain after thoracic and visceral abdominal surgery.

**Objectives:** Our aim was to assess dye spread into the ventral branch, connecting branch, sympathetic trunk, thoracic paravertebral space, and epidural space after performing a modified ultrasound-assisted thoracic paravertebral block via the intervertebral foramen.

**Study Design:** This was a nonrandomized cadaveric study.

**Setting:** The cadavers were kept at the Department of Anatomopathology of the San Salvatore Academic Hospital of L'Aquila (L'Aquila, Italy).

**Methods:** We performed a bilateral thoracic paravertebral block via the intervertebral foramen at the second, fifth, ninth, and twelfth thoracic vertebrae. A linear array ultrasound transducer was used. Then, cadaveric dissection was performed. A Tuohy needle was gently inserted in-plane with the ultrasound beam in a lateromedial direction to contact the spinous process. Subsequently, the needle tip was advanced 2 mm along the transverse process of the vertebra, and 5 mL of methylene blue 1% dye was injected at each level. Then, 2 continuous catheter sets were inserted.

**Results:** Forty intervertebral foramen blocks were performed in 5 cadavers. For 38 injection sites, we found dye on both sides of the thoracic paravertebral space and epidural space at each level of puncture. The retropleural organs were also stained. In 2 cases, methylene blue accumulated intramuscularly at the level of the twelfth thoracic vertebra.

**Results:** The spread of dye into the ventral rami, communicating rami, and sympathetic trunk in the thoracic paravertebral space and the epidural space was assessed. We also evaluated the position and the distance (mm) between the catheter tip and the thoracic intervertebral foramen content. Finally, puncturing of intervertebral blood vessels, nerve rootlet and root damage, lung and pleural injuries, and the extent of intramuscular dye accumulation were evaluated and recorded as iatrogenic complications related to the anesthetic procedure. Forty thoracic paravertebral blocks in 5 cadavers were performed. For 38 injection sites, we found dye on both sides of the thoracic paravertebral space and the epidural space at each level of puncture. The ventral rami, the communicating rami, and the sympathetic trunk were also stained. In 2 cases, methylene blue accumulated intramuscularly at the level of the twelfth thoracic vertebra.

**Limitations:** The first limitation of this study is its small sample size. In addition, the study design did not consider or measure the width of the transverse processes. Another limitation is that the ultrasound beam could not identify the thoracic intervertebral foramen content or the needle tip behind the acoustic shadow of the transverse and vertebral articular processes.

**Conclusion:** Paravertebral block via the thoracic intervertebral foramen achieved consistent dye spread into the thoracic paravertebral space and epidural space, capturing retropleural organs.

**Key words:** Dye spread, epidural space, ventral branch, connecting branch, sympathetic trunk, thoracic paravertebral space, ultrasound guidance, iatrogenic complications

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**W**ith the aging of the Italian population (1) and the increasing use of anticoagulation therapy, anesthesiologists and interventional pain management physicians often encounter the challenge of the potential risk of bleeding or thrombosis, especially in cases of discontinuation or interruption of anticoagulation drugs (2).

Epidural analgesia and thoracic paravertebral block (TPVB) are widely considered to be useful opioid-sparing procedures for controlling postoperative acute or chronic pain (3-5).

A wide range of patient and cadaver techniques using ultrasound-guided TPVB or ultrasound-assisted epidural analgesia have been described. Multiple guidelines for patients undergoing antithrombotic therapy prior to interventional techniques have been developed. They suggest a comprehensive assessment of each patient and a risk-benefit analysis before proceeding with the intervention (2). However, individual physician preferences, skills, and experience preclude making evidence-based recommendations for the choice of technique (6).

A wide range of patient and cadaver techniques have been described using an ultrasound-guided (USG) TPVB. In fact, individual physician preferences, skills, and experience preclude making evidence-based recommendations for which technique to choose (4).

Based on virtual dissections (Fig. 1) and clinical observations, we hypothesized an alternative method of performing TPVB, considering the related iatrogenic risks and damage (7,8). In this method, the aim was to medially direct the tip of the needle to the transverse process of the vertebra until it lost contact with the bone to clear the articular processes. Since the thoracic paravertebral space (TPVS), retropleural organs, and epidural space are reachable by dye via the thoracic intervertebral foramen (TIF), this injection site likely leads to effective injection spread (7).

Therefore, the aim of our study was to verify the dissemination of dye to nervous structures in the retropleural space (9) (ventral branch, connecting branch, and sympathetic trunk) and into the TPVS and epidural space in cadavers. Furthermore, we established a relationship between the position of the catheter tip

and the distribution of the dye injected into the TIF compartment via the catheter and recorded related iatrogenic complications.

## METHODS

The Institutional Review Board of the Ethics Committee of the cities of L'Aquila and Teramo, Abruzzo, Italy (Approval number: 133/22; ClinicalTrials.gov identifier: NCT05603442) approved the study for an exemption from formal review. At the time of the study, the cadavers were kept at the Department of Anatomopathology of the San Salvatore Academic Hospital of L'Aquila (L'Aquila, Italy).

Ten cadavers from the Department of Anatomopathology were considered for use in our study. Five cadavers were excluded because of custodial law; the remaining 5 cadavers were included in our study protocol. In 3 cases, the legal proxies of the deceased needed more time to provide consent to publish photos. Thus, the data from a total of 40 TIF blocks performed in 5 cadavers are reported, as shown in the flow diagram (Fig. 2). The time to perform the anesthetic procedure for each injection was 19.25 minutes on average (SD = 2.22), with a median of 19 minutes, a minimum of 17 minutes, and a maximum of 22 minutes.

The clinical characteristics of the deceased are shown in Table 1; cadaveric dissection findings and dye spread are summarized in Table 2.

Emergency medical interventions were performed in 2 cases before death. A postmortem examination revealed no signs of iatrogenic injuries from an emergency medical intervention, including intubation and chest compressions. Two of the deceased had spinal diseases (osteoarthritis of the spine involving the facet joints and osteoporosis-related vertebral fractures). One individual suffered from Grade III (70% slippage) spondylolisthesis of T12 on L1 as well as spinal stenosis. No signs of pathology within or near the TPVS were documented by the dissection.

We first performed an anesthetic procedure on the cadavers; this is required according to Italian law. Therefore, the cadavers were not embalmed, and autopsies were performed less than 24 hours postmortem. Cadavers in the custody of the law were excluded from our

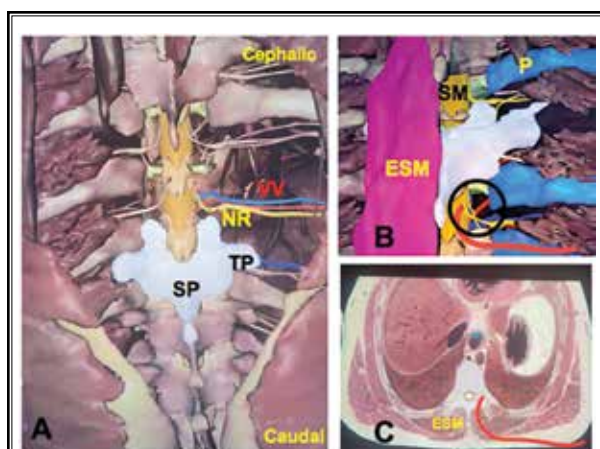


Fig. 1. Virtual dissection of the posterior thorax wall. A. Skin, subcutaneous tissue, and all muscle planes were dissected, identifying the spine. The eighth and ninth vertebrae were removed to identify the nerve root (NR) and intervertebral blood vessels (VVs). The tenth thoracic vertebra is represented in white. B. The red line identifies the catheter position inserted in the caudal-to-cephalic direction, close to the thoracic intervertebral foramen area (black circle). C. Transverse plane: the red line identifies the catheter position on the ESM plane. SP: spinous process; TP: transverse process; P: pleura; SM: spinal medulla; ESM: erector spinae muscle.

study. Our study was carried out while respecting the ethical guidelines of the Italian mortuary police regulation for investigations using human cadavers (mortuary police regulations, Presidential Decree 285/1990). Written informed consent was obtained from proxies or legal surrogates of the deceased. This article complies with the current guidelines for Transparent Reporting of Evaluations with Nonrandomized Designs (TREND).

Since the anesthetic procedure was bilaterally performed (Fig. 3), each cadaver was placed in the left lateral decubitus position and then in the right lateral decubitus position. Next, cadaveric dissection was performed. The anesthetic procedure was performed at the level of the second, (fifth, ninth, and twelfth thoracic vertebrae. An ultrasound countdown from the seventh cervical spinous process to the T12 spinous process was performed. The tips of the spinous processes from the T2 to the T12 vertebrae were identified using a transverse high-frequency linear array ultrasound (ULSD) transducer (EDAN, Acclarix AX4).

The location was marked on the skin with a marker pen. We began ULSD scanning in the transverse plane, and the tips of the spinous processes were visual-

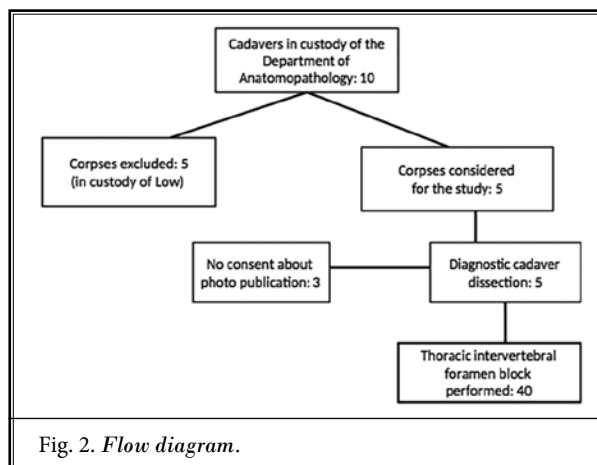


Fig. 2. Flow diagram.

Table 1. Clinical characteristics of the decedents. Values are number (percentage) and mean (SD).

	n (%) or mean (SD)
Age	76 (7.1)
Gender	
Men	4 (80)
Body Mass Index (kg/m <sup>2</sup> )	27.5 (2.7)
Diseases	
Cardiovascular	5 (100)
Respiratory	3 (60)
Neurological	2 (40)
Metabolic	3 (60)
Hepatic	2 (40)
Kidney	3 (60)
Spinal	2 (40)
Emergency medical intervention	2 (40)
Iatrogenic injuries from the emergency medical intervention	0 (100)
Pathology within or in the vicinity of the thoracic paravertebral space	0 (100)

ized as hyperechoic circles with acoustic shadowing underneath. A plastic sheath was used to protect the ULSD transducer. The probe was slightly moved in the mediolateral direction while maintaining a transverse orientation and controlling the angle between the spinous process and the transverse process. The transverse process was seen as a hyperechoic continuous line deep into the fascial plane of the erector spinae muscle.

A Tuohy needle (18G, 90 mm Contiplex, BBraun) was inserted in-plane with the ULSD beam and moved in a lateromedial direction through the angle with the

transverse process to gently contact the spinous process. Then, the needle tip was moved in a cephalocaudal direction, tilting the probe in the same direction.

Subsequently, we advanced the needle tip 2 mm along the inferior side of the transverse process until bone contact was lost in order to clear the inferior articular process of the vertebra. Herein, 5 mL of methylene blue 1% dye was injected. Similarly, the same

solution was injected in a caudocephalad direction, advancing the needle tip 2 mm along the superior side of the transverse process in order to clear the superior articular process of the vertebra. We used the half-the-air technique through a 3-way stopcock (10) to keep the injection pressure below 15 psi (11).

Two epidural catheters (1000 mm Perifix Standard, Epidural catheter, BBraun) were inserted and threaded one cm from the needle tip in a caudocephalad direction. At the anesthetic block's conclusion, we performed a second control ULSD scan of the TPVS. The ULSD images were collected, recorded, stored, and revised interpreted by a radiologist. Subsequently, the cadaver was moved into a supine position, and cadaveric dissection began, allowing direct visualization of the methylene blue and the catheter tip position into the TPVS and epidural space from T2 to T12.

We performed an en bloc resection of the anterior body wall, removing the thoracic and abdominal contents. Beginning cranially, the para- and prevertebral organs were exposed. The retropleural space and its contents (the ventral rami, communicating rami, and sympathetic trunk) were opened to evaluate the dye spread by carefully removing the parietal pleura bilaterally. Subsequently, the spinal canal was opened to evaluate coloring within the epidural space from T1 to

Table 2. Cadaveric dissection findings and dye spread. Values are numbers (percentage).

	Right n (%)	Left n (%)
TIF area (T2)	5 (100)	5 (100)
TIF area (T5)	5 (100)	5 (100)
TIF area (T9)	5 (100)	5 (100)
TIF area (T12)	4 (80)	4 (100)
TPSV (T2)	5 (100)	5 (100)
TPSV (T5)	5 (100)	5 (100)
TPSV (T9)	5 (100)	5 (100)
TPSV (T12)	4 (80)	4 (80)
ES (T2)	5 (100)	4 (80)
ES (T5)	5 (100)	4 (80)
ES (T9)	5 (100)	4 (80)
ES (T12)	4 (80)	4 (80)
Ventral rami (T2)	5 (100)	5 (100)
Communicating rami (T2)	5 (100)	5 (100)
Sympathetic trunk (T2)	5 (100)	5 (100)
Meningeal sheaths of nerve roots (T2)	5 (100)	5 (100)
Iatrogenic injures (T2)	0	0
Ventral rami (T5)	5 (100)	5 (100)
Communicating rami (T5)	5 (100)	5 (100)
Sympathetic trunk (T5)	5 (100)	5 (100)
Meningeal sheaths of nerve roots (T5)	5 (100)	5 (100)
Iatrogenic injuries (T5)	0	0
Ventral rami (T9)	5 (100)	5 (100)
Communicating rami (T9)	5 (100)	5 (100)
Sympathetic trunk (T9)	5 (100)	5 (100)
Meningeal sheaths of nerve roots (T9)	5 (100)	5 (100)
Iatrogenic injuries (T9)	0	0
Ventral Rami (T12)	4 (80)	4 (80)
Communicating rami (T12)	4 (80)	4 (80)
Sympathetic trunk (T12)	4 (80)	4 (80)
Meningeal sheaths of nerve roots (T12)	4 (80)	4 (80)
Iatrogenic injuries (T12)	0	0

TIF: thoracic intervertebral foramen; TPSV: thoracic paravertebral space; ES: epidural space.

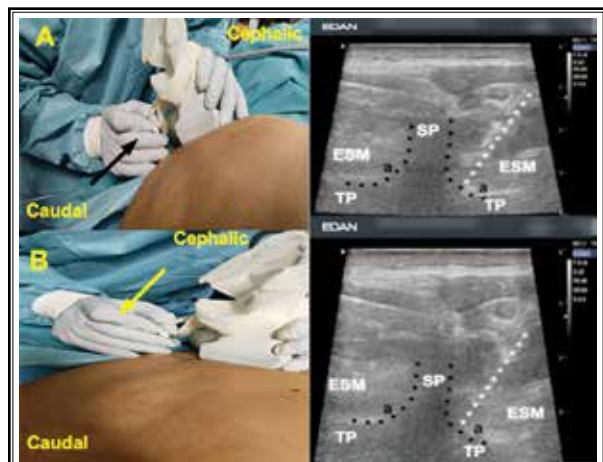


Fig. 3. Ultrasound-assisted thoracic intervertebral foramen block. The anesthesiologist injected the local anesthetic deeply into the erector spinae muscle plane by clearing the angle (a) between the spinous process (SP) and transverse process (TP) of the vertebra. A. The needle (white star) is moved upward (black arrow), directing the tip from the cephalocaudal position. B. The needle is moved down (yellow arrow), directing the tip from the caudal to cephalic position.

T12.

The soma, transverse processes, lamina and pedicle of the vertebrae and the head and neck of the corresponding ribs were gently extricated from the spine to evaluate the dye spread within the erector spinae muscle plane, TIF compartment, and costovertebral foramina. Nerve rootlets and roots (“nerve root compartment”), the intervertebral blood vessels (“blood vessel compartment”) (128) and the foraminal ligaments (in particular, the superior corporopedicular, superior transforaminal, midtransforaminal, and inferior transforaminal ligaments) were carefully evaluated before opening the spinal canal. In addition, the 2 layers of spinal pia mater, arachnoid, the dura mater surrounding the rootlets, and the thin connective tissue sheath around the dorsal and ventral roots were assessed. The time in minutes to perform the anesthetic block and the position and distance in millimeters between the catheter tip and the TIF content were also evaluated.

Finally, intervertebral blood vessel punctures, nerve rootlet and root damage, lung and pleural injuries, and the extent of intramuscular dye accumulation were evaluated and recorded as iatrogenic complications related to the anesthetic procedure.

The spread of dye into the retropleural organs in the TPVS and epidural space was photographed and documented by the anatomist.

**Descriptive Statistics**

All data collected were recorded in a standardized spreadsheet and analyzed using Stata14 (StataCorp LLC). Descriptive statistics are reported as the mean and SD or median and range (minimum – maximum) for numerical variables and percentages for categorical variables.

**Data Availability**

The datasets generated and/or analyzed during the current study are not publicly available because the decedents’ proxies or legal surrogates have reserved all rights on the datasets. The datasets are, however, available from the corresponding author upon reasonable request.

**RESULTS**

At 38 injection sites (95%), the dissection revealed that the dye was predominantly found in the TPVS (Fig. 4), with scant dissemination deep into the erector spinae muscle plane or in the angle between the transverse process and spinous process of the vertebra along the lamina (Table 3). In the cadaver with spondylolisthesis, the dye injected at the T12 level was bilaterally

found along the lamina and deep into the erector spinae muscle plane (Table 2).

Similarly, the epidural spread (Fig. 4) of dye was bilateral in 38 injection sites (95%) (range from T2 to T12, in the cephalic and cephalocaudal direction, while in one cadaver (Table 3), the dye accumulated intramuscularly into the erector spinae muscle plane without epidural spread at the injection sites at the T12 level bilaterally. The ventral rami, the communicating rami, and the sympathetic trunk (ranging from T2 to T12) were bilaterally stained by the dye, except in one

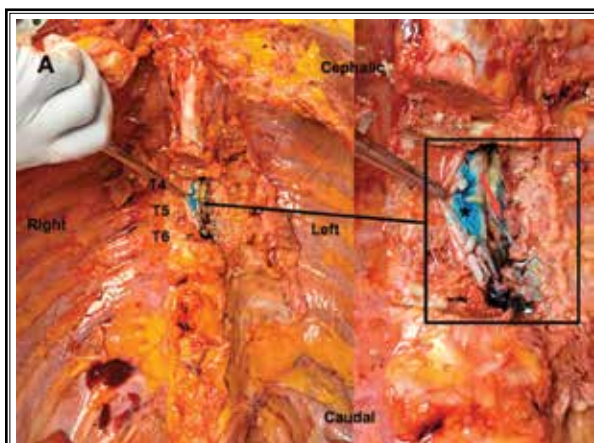


Fig. 4. Pathway of dye spread - spinal cord view. *En bloc* resection of the anterior body wall: thoracic and abdominal contents are removed. A. The spinal canal is opened: soma, transverse processes, lamina and pedicle of fourth, fifth and sixth vertebrae, and the head and neck of corresponding ribs are extricated from the spine on the left side. B. Black stars indicate the epidural spread of dye obtained at the T5 level, while the red arrow indicates the ventral rami, communicating rami, and sympathetic trunk staining.

Table 3. Distance between the catheter tip and the nerve roots. Values are mean (SD) and median (range).

Distance	Side of injection	
	Right Mean (SD) Median (range)	Left Mean (SD) Median (range)
T2	4.40 (0.55) 4 (4-5)	5.40 (0.89) 5 (5-7)
T5	5.80 (0.84) 6 (5-7)	6.20 (1.30) 6 (5-8)
T9	6 (1.58) 6 (4-8)	5.20 (0.837) 5 (4-6)
T12	5.50 (1.29) 5.50 (4-7)	6.50 (1.29) 6.50 (5-8)

cadaver at the T12 level.

All 40 dissected TIF compartments were considered useful for assessing dye spread (Table 2). Nerve roots and the intervertebral blood vessels of 38 TIF compartments were saturated with methylene blue, as well as the foraminal ligaments (superior corporopedicular, superior transforaminal, midtransforaminal, and inferior transforaminal ligaments). In addition, the dorsal rootlets were reached by the dye at each spinal segment involved in the block. The dye spread involved the 2 layers of spinal pia mater, the arachnoid, and the dura mater surrounding the rootlets that advanced toward the intervertebral foramen. The thin connective tissue sheath surrounding the dorsal and ventral roots exiting through the separate perforations in the dura was also saturated with dye. Two TIF compartments in one cadaver were not filled by dye.

Thirty-eight catheter tips (95%) were placed into the TIF area between the superior transforaminal ligament and the midtransforaminal ligament. Table 3 shows the distances between the catheter tip and the nerve roots.

No iatrogenic injuries were documented during the dissection.

In 38 cases, the second ULSD scan of the TPVS (Fig. 5) documented anechoic fluid into the bilateral TPVS ranging from the T2 to T12 levels, indicating dye

spread. In one cadaver at the T12 level, the methylene blue spread was not bilaterally documented by a ULSD scan.

## DISCUSSION

In the present study, we evaluated the injection spread of 40 TIF blocks performed by placing the needle tip and catheter medially to the vertebral transverse processes via TIF. The results demonstrate that this injection point achieved a consistent dye spread dye into the TPVS and epidural space with extensive coloring of the retropleural organs.

Shibata, et al (13) described the costotransverse foramen block. They aimed to posteriorly reach the TPVS via the costotransverse foramen. The ULSD beam was focused to identify the superior costotransverse ligament above the TPVS. The superior costotransverse ligament forms the posterior boundary of the TPVS together with the transverse processes of the vertebrae and the head and neck of the ribs (14); it is a part of the interconnecting muscular-aponeurotic system.

We injected dye medially into the transverse process of the vertebra by inserting the needle tip so that it cleared the superior and inferior sides of the transverse process until contact with the bone was lost. We obtained an extent of coloring predominantly in the TPVS and epidural space at 38 injection sites, with a success rate of 95%. In one cadaver, the bilateral injection site at the T12 level was found outside the anesthetic target. Similarly, the dye stained the ventral rami, communicating rami, and sympathetic trunk (ranging from T4 to T12) in 38 cases.

Erector spinae plane block, midpoint transverse process to pleura block, and intercostal/paraspinal block have been utilized as alternatives to conventional thoracic paravertebral blocks, but sympathetic ganglion involvement has been inconsistently observed (15). In a retrolaminar block, the goal is to insert the needle until it contacts the vertebral lamina, confirming the location both by ULSD imaging and by feel (16). Considering the bony boundary of the TIF and the speculations of Yan, et al (17), we endeavored to place the needle tip close to the TIF without contacting the lamina. In the first step of our anesthetic procedure, the needle tip reached the anesthetic target, clearing the inferior side of the transverse process along the inferior articular process of the vertebra; it was then advanced along the superior side of the transverse process, clearing the superior articular process of the vertebra.

The mean body mass index (BMI) of the cadavers

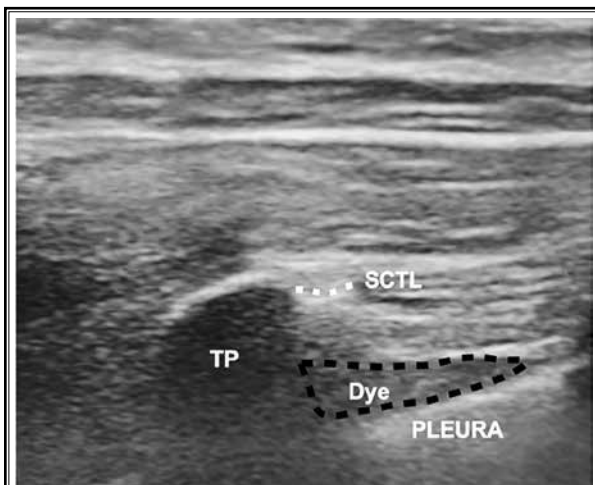


Fig. 5. Second ultrasound scan. Anechoic fluid in the thoracic paravertebral space (TPVS, black points), indicating dye spread. The TPVS is located between the hyperechoic line of the costotransverse ligament (SCTL [superior costotransverse ligament], white points) and the pleura. TP: transverse process.

was 27.5, indicating Class I obesity – overweight (18). We believe that this characteristic did not influence the procedure. In the cases that the anesthetic target was not reached (5%), the failure may have been due to the clinical characteristics of the deceased. In one case, the cadaver had spondylolisthesis of T12 on L1, along with spinal stenosis; this presumably influenced dye spread. However, we are confident that none of the deceased's other phenotypic characteristics influenced the block's success.

Karmakar, et al (19) injected an anesthetic solution into the TPVS, using a ULSD beam to visualize the needle tip at the apex of the paravertebral space and the anterior displacement of the parietal pleura after injecting the anesthetic solution. The TP and the superior costotransverse ligament were used as key sonoanatomical landmarks for ULSD-guided TPVB using a sagittal approach, while the transverse process and internal intercostal membrane were used as key sonoanatomical landmarks for TPVB using transverse transducer guidance (20).

The muscular-aponeurotic system of the posterior TPVS boundary is formed by the aponeurosis of the internal intercostal muscle and the internal intercostal membrane, which protects the pleura from iatrogenic injuries (21). Inadvertent pleural puncture and pneumothorax or vascular puncture with paraspinous intramuscular hematoma can be avoided if the anesthetic procedure is performed or supervised by a single experienced operator, as suggested by Pangthipampai et al (22). We believe that the TPVS and its contents can be reached by dye if the TIF area is used as the medial TPVS boundary. The anatomy and the anatomical boundaries of the TPVS have previously been meticulously described, but the injection site for local anesthetic remains controversial due to the thoracic paravertebral anatomy's complexity. Thus, misinterpretation of previous studies and inter- and intraindividual variability (especially regarding the ligaments) are responsible for inappropriate as well as confusing new anesthetic procedures.

The TPVS is a triangular area located bilaterally alongside the length of the thoracic vertebral column. The communicating branches, dorsal branches and ventral branches of spinal nerves, intercostal nerves and blood vessels, hemiazygos vein, thoracic duct and sympathetic trunk are found in this area (23).

The TIF is an oval area that laterally faces the spinal medulla. Medially, it contains the dural sleeve with its emerging nerve root, and laterally, it contains the

fascial sheet, which is part of the anterior layer of the thoracolumbar fascia. Gkasdaris, et al (12) described 2 separate oval perforations in this fascia: the posterior perforation contains the nerve roots ("nerve root compartment"), while the smaller anterior perforation contains the intervertebral blood vessels ("blood vessel compartment"). The posterior compartment of the fascia is closely related to the exiting nerve root; it is limited by various foraminal ligaments. Anteriorly, the superior corporopedicular ligament traverses to the posterolateral vertebral body from the superior pedicle. Superiorly, the superior transforaminal ligament runs from the arches of the superior and inferior vertebral notches to the articular capsule of the superior pedicle. Inferiorly, the midtransforaminal ligament extends from the annulus fibrosus and superior and inferior corporopedicular ligaments to the articular capsule. The inferior transforaminal ligament limits the nerve to the vascular compartment, running from the junction of the annulus fibrosus and the posterior vertebral body to the superior articular facet (7).

The central and dorsal rootlets converge in the TIF, forming the segmental spinal nerve. The rootlets are surrounded by 2 layers of pia mater, arachnoid, and dura mater. Then, the pial and arachnoid layers fuse with the dura mater of the thecal sac until the rootlets advance toward the intervertebral foramen (7).

The mean foraminal width has been estimated to be 0.8 cm, while the width of the thoracic transverse process is between 1.2 and 1.3 cm (24,25). On this basis, we believe that the "nerve root compartment" of the TIF is 1.5 cm from the anterior side of the transverse process of the vertebra. Thus, this area can be filled with dye by gently advancing the needle 2 mm beyond the transverse process, providing an effective block without the risk of damaging the pleura and the epidural space's content. Similarly, catheter placement should not exceed 1.5 cm from the tip of the needle to avoid iatrogenic injuries to the vulnerable structures of the TIF.

According to these premises and Shaw's hypothesis (26), the epidural space extends laterally through the TIF to communicate with the paravertebral spaces on each side because it is partially delineated by the vertebral pedicles. Thus, although the sections of the dura abutting the ligamentum flavum, vertebral lamina, and other borders of the vertebral canal compartmentalize the epidural space, it is possible to argue that this anatomic compartment includes a potential space within the TPVS and TIF (27,28).

In addition, the spinal nerve root with its sheaths

and spinal arteries and the internal and external venous plexuses that fill the foramen can be considered the “lacuna nervorum” and “lacuna vasorum” of the TIF, respectively. We speculate that these compartmentalized spaces allow the injected solution to spread to the TPVS and epidural space via the TIF.

The superior transforaminal and midtransforaminal ligaments and connective tissue sheath protect the anterior “blood vessel compartment” of the TIF from iatrogenic injuries. The use of ultrasonography and the restriction of a depth of no more than 2 mm after losing bone contact may have prevented dural sleeve puncturing, nerve root injury, and epidural hematoma. Thus, we hypothesized that our technique (that had a 95% success rate) can be considered as an option for not only TPVB but also epidural analgesia under ULSD assistance because the needle and catheter tips do not reach the TPVS or epidural space. In fact, we aimed to direct the tip of the needle medially to the transverse process until it lost bone contact to clear the articular processes.

### Limitations

Several limitations affect our research. The first limitation the small sample size. In addition, we did not consider or measure the width of the transverse process during the dissections. Another limitation is that the ULSD beam could not identify the TIF content or the needle tip because of the acoustic shadow from the transverse process and the vertebral articular processes (Fig. 3). Nevertheless, it is possible to avoid iatrogenic injuries if the needle tip is carefully advanced along the transverse process no further than 2 mm until bone contact is lost given the compartmentalization of the

TIF by ligaments and the connective tissue sheath. In addition, the ULSD beam allows quick identification of the needle in the angle between the spinous process and transverse process into the plane of the erector spinae muscle by maintaining contact with the bone. Then, the catheters can be placed.

We are confident that virtual dissection is a potentially useful option to simulate the possible path for the needle and catheter tip to reach the anesthetic target. It was useful to evaluate the safety of our approach before performing it in the cadavers. Nevertheless, concerns about iatrogenic injuries to the nerve root or blood vessels remain. The safety of our procedure, even for patients receiving anticoagulation therapy, should be demonstrated with ad hoc studies. Finally, understanding whether musculoskeletal pathologies can influence dye spread should be considered.

### CONCLUSIONS

In summary, based on these findings and on clinical observations, we are confident that the TIF block achieves a consistent spread of the injectate into the TPVS and epidural space with extensive coloring of the retropleural organs at the level of injection. The findings from our study provide an important basis for our or others' further clinical trials on procedure safety and effectiveness.

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