ORIGINAL ARTICLE

A Cadaveric Study Investigating the Mechanism of Action of Erector Spinae Blockade

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Background and Objectives: Erector spinae block is an ultrasound-guided interfascial plane block first described in 2016. The objectives of this cadaveric dye injection and dissection study were to simulate an erector spinae block to determine if dye would spread anteriorly to the involve origins of the ventral and dorsal branches of the spinal nerves.

Methods: In 10 unembalmed human cadavers, 20 mL of 0.25% methylene blue dye was injected bilaterally into the plane between the fifth thoracic transverse process and erector spinae muscle. An in-plane ultrasound-guided technique with the transducer orientated longitudinally was used. During dissection, superficial and deep muscles were identified, and extent of dye spread was documented in cephalocaudal and lateral directions. The ventral and dorsal rami of spinal nerves and dorsal root ganglion at each level were examined to determine if they were stained by dye.

Results: There was extensive cephalocaudad and lateral spread of dye deep and superficial to the erector spinae muscles. Except for 1 injection (from 20), the ventral rami were not stained by the dye. In only 2 injections did the dye track posteriorly through the costotransverse foramen to the dorsal root ganglion. In all other cases, the dorsal root ganglia were not involved in the dye injection. The dye stained the dorsal rami posterior to the costotransverse foramen.

Conclusions: There was no spread of dye anteriorly to the paravertebral space to involve origins of the ventral and dorsal branches of the thoracic spinal nerves. Dorsal ramus involvement was posterior to the costotransverse foramen.

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Erector spinae block (ESB) is an ultrasound-guided interfascial plane block first described in 2016 to successfully treat severe thoracic neuropathic pain.[1] In ESB, the local anesthetic is injected using ultrasound guidance superficial to a thoracic transverse process and deep to erector spinae muscle group. In 2017, ESB has been described in case reports in multiple clinical scenarios including to manage acute postoperative pain following elective laparoscopic ventral hernia repair,[2] thoracic surgery,[3,4] breast surgery with reconstruction,[5] and bariatric surgery.[6] Erector spinae block has also been used for management for rib fractures,[7] postthoracotomy pain syndrome,[8] and chronic shoulder pain.[9]

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In clinical reports, ESB resulted in extensive cutaneous sensory block indicating both ventral and dorsal spinal rami involvement.[1] Furthermore, a cadaveric dye injection and dissection in 1 cadaver reported spread of dye in the vicinity of the origins of the ventral and dorsal rami of the spinal nerves.[1] Hence, ESB has been described as a technically simpler alternative to ultrasound-guided paravertebral block with a similar mechanism of action. In addition, ESB is likely to be safer than paravertebral blockade because the injection is in a plane remote from critical structures such as the pleura, and thus there has been significant clinical interest in this block. Therefore, the objective of this current cadaveric experiment was to simulate an ESB to determine if dye would spread anteriorly to the paravertebral space to involve the origins of the ventral and dorsal branches of the thoracic spinal nerves. The extents of craniocaudal and medial-to-lateral spread of the dye were also documented.

METHODS

This project was approved by the Human Research Ethics Committee, University of Melbourne (Project within Program Ethics ID 1441811.3). Ten unembalmed human cadavers were obtained through the body donor program of the Department of Anatomy and Neuroscience. None of the specimens were frozen before the interventions were performed. Before commencement of the study, imaging of the cadavers confirmed that the relevant sonoanatomy was consistent with what is observed clinically, in the living patient. An M-Turbo (SonoSite, Inc, Bothell, Washington) ultrasound system with a 13- to 6-MHz linear array transducer covered with a protective plastic sheath was used in all procedures performed with the cadaver in the prone position. Before the procedure, the spinous processes were palpated and marked, and the fifth thoracic transverse process was identified using sonography counting up from the 12th rib and also down from the first rib. A preliminary ultrasound scan was performed with the transducer orientated both longitudinally and transversely to confirm position of the tip of the transverse process (Fig. 1, A and B). The procedure was performed with the transducer orientated longitudinally, so the transverse process was imaged in the sagittal plane approximately 3 cm away from the midline (Fig. 1C). A 100-mm, 21-gauge block needle (Pajunk Sonoplex, Geisingen, Germany) was directed cephalad-to-caudad in-plane with the ultrasound beam until the needle tip contacted the fifth transverse process (Fig. 1A). Twenty milliliters of 0.25% methylene blue dye was then injected over 1 to 2 minutes while observing for spread of dye in the plane between the erector spinae and the transverse processes (Fig. 1D).

Dissections were performed 30 minutes following dye injection. A skin incision was made along the midline over the spinous processes from above C7 to the lower lumbar vertebrae, and the skin reflected laterally to expose the posterior thoracic wall and scapula. Superficial muscles (trapezius, latissimus dorsi, and rhomboids) were individually identified and reflected. The erector spinae muscles were identified and removed at their attachments, and the extent of dye spread deep and superficial to the muscles was explored and documented. The extent of cephalocaudal spread of

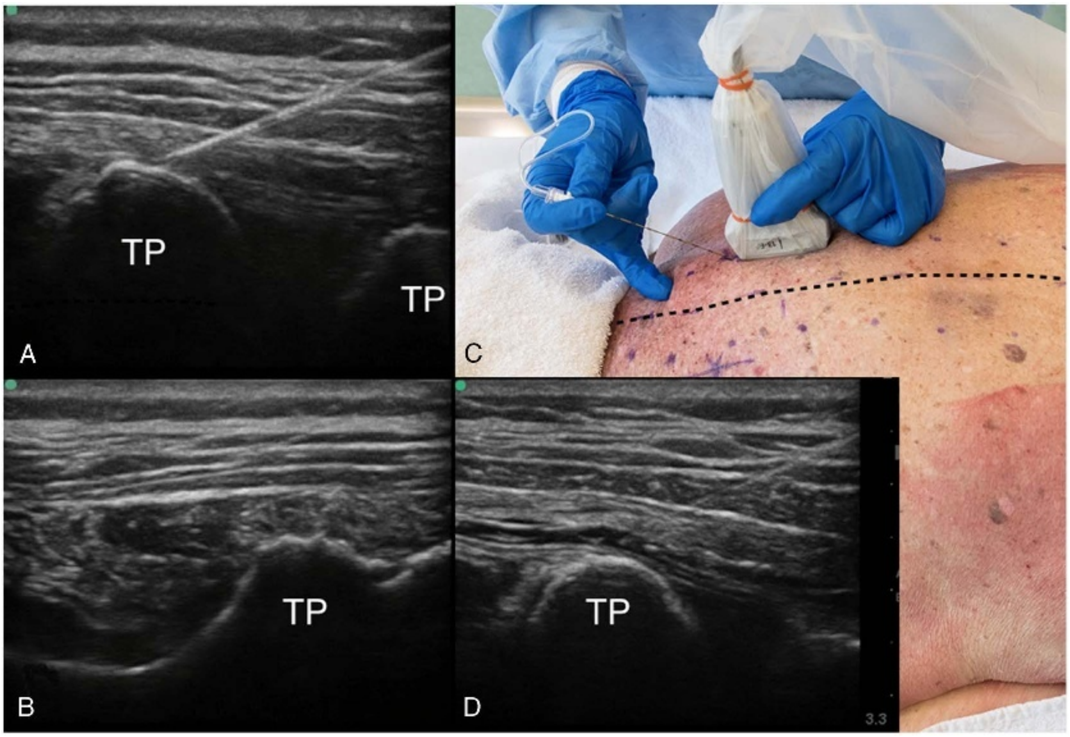

FIGURE 1. A and B with transducer orientated longitudinally and transversely, respectively, were used to confirm the position of the tip of the transverse process (TP). The procedure was performed with the transducer orientated longitudinally approximately 3 cm away from the midline (external image C), resulting in the TP being imaged in the sagittal plane (A, D). Block needle was directed cephalad-to-caudad (C) in-plane with the ultrasound beam until the needle tip contacted the fifth transverse process (A). Example of spread of dye in the plane between the erector spinae and the transverse process (D).

dye was described in relation to the vertebral levels and their associated ribs, and this was explored from 1st to 12th thoracic vertebrae. Lateral spread was described relative to each of the erector spinae muscles/attachments (spinalis, longissimus, and iliocostalis; Fig. 2). In the thoracic region where the injections were made, spinalis occupied the space between the spinous process and the costotransverse joint, longissimus occupied the space lateral to the costotransverse joint and extended to the medial border of the iliocostalis (typically located at the angle of the ribs), and iliocostalis was located lateral to the angle of the ribs. Dye spread beyond the lateral border of iliocostalis and onto the lateral surface of the thoracic cage and serratus anterior was also noted. The posterior part of each intercostal space was dissected by removing the external and internal intercostal muscle layers to identify the plane in which the intercostal nerves (ventral rami of spinal nerves) were located. These nerves were identified and isolated at each intercostal space and were carefully examined to determine if they were stained by the dye. The nerve at each space was followed medially to identify it in the paravertebral space and entering the intervertebral foramen. The dorsal rami of the spinal nerves and the dorsal root ganglion at each level were also identified and examined to determine if they were stained by the dye. This was facilitated by removing the transverse processes of the vertebrae and performing a laminectomy.

RESULTS

Twenty sides from 10 cadavers were injected mocking a clinical ESB and subsequently dissected. Sonographic landmarks were identified without difficulty in all specimens, which were considered to be in good condition. There was extensive dye spread observed in planes both superficial and deep to the erector spinae muscles and in some cases laterally as far as the attachments of serratus anterior (Figs. 2, 3A, and 4B). The deep muscles of the vertebral column (semispinalis, multifidus, rotatores, and interspinales) were not stained by the dye. Cephalocaudad spread of the dye was usually over many segments and differed slightly when planes superficial versus deep to the erector spinae muscles were explored. Table 1 documents the full extent of dye spread in the plane deep to the erector spinae muscles, within the intercostal spaces for ventral ramus involvement, and within the intervertebral foramen for dorsal root ganglion involvement.

In the region of the first to sixth vertebrae, there were high proportions of injections in which the deep surface of erector spinae was stained by dye (Figs. 2, 3A, and 4B). For example, in 75% to 100% of injections in the region of the third to sixth thoracic vertebrae, we noted dye at or around the level of injection deep to the longissimus muscle (Table 1 and Figs. 3A and 4A). In the region of the third to sixth thoracic vertebrae, there was also spread of dye superficial to longissimus in 60% to 75% of injections. At these levels, the dye was always located over the posterior aspect of the transverse processes and in close proximity to the costotransverse foramen (Fig. 4A). In the region of the third to sixth thoracic vertebrae, the dorsal ramus was stained in 25% to 70% of sides as it emerged from the foramen posteriorly to innervate the medial skin and musculature of the back (Table 1). Deep to longissimus, the dye extended up to (and beyond) the first thoracic vertebrae (in 85% of injections) and down to (but not beyond) the 12th thoracic vertebrae in only 2 injections (10% of cases) (Table 1). At or above the injection level, the dye often spread laterally, beyond the angle of the rib and deep to iliocostalis muscle (Figs. 2, 3A, and 4B).

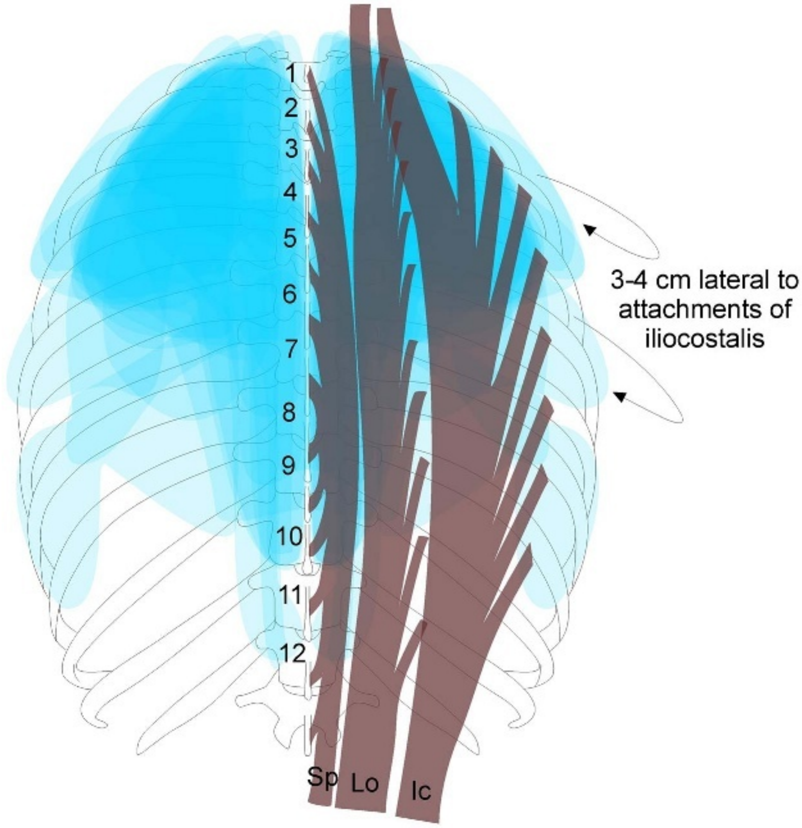

FIGURE 2. Schematic representation of the extent of dye spread on the posterior and lateral thoracic wall. The extent of dye spread for each injection deep to the erector spinae muscles is represented by blue shading. Each injection was made partly transparent and superimposed on all others. Thus, areas on the thoracic wall that were consistently involved in the spread of the dye appear a darker shade of blue. On the right, the image shows the same series of injections but with the erector spinae muscles (Ic indicates iliocostalis; Lo, longissimus; Sp, spinalis) superimposed, providing reference for the spread of dye relative to and beyond the attachments to these muscles.

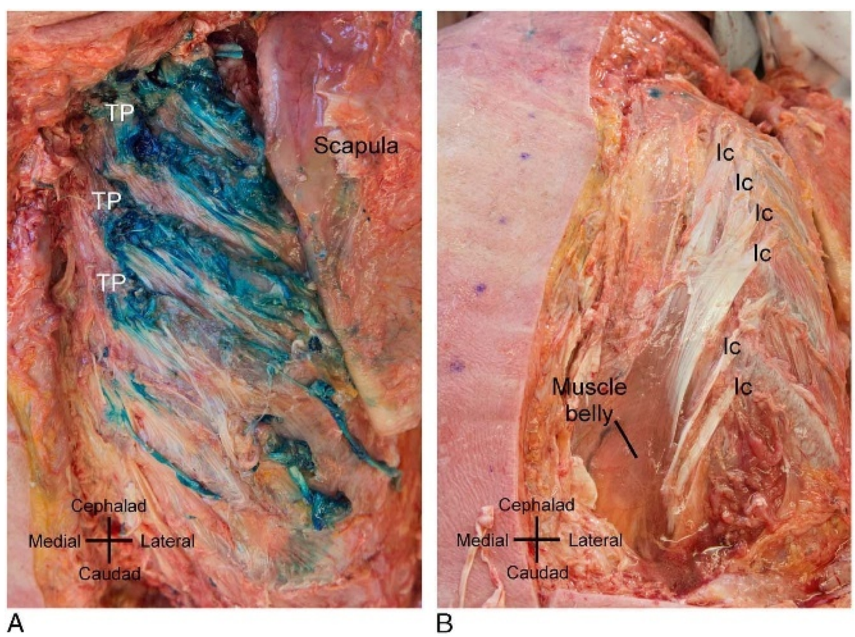

FIGURE 3. A, Lateral spread of dye in plane deep to the erector spinae muscles (TP indicates transverse process). B, Dissection demonstrating belly and the costal attachments of iliocostalis (Ic) muscle.

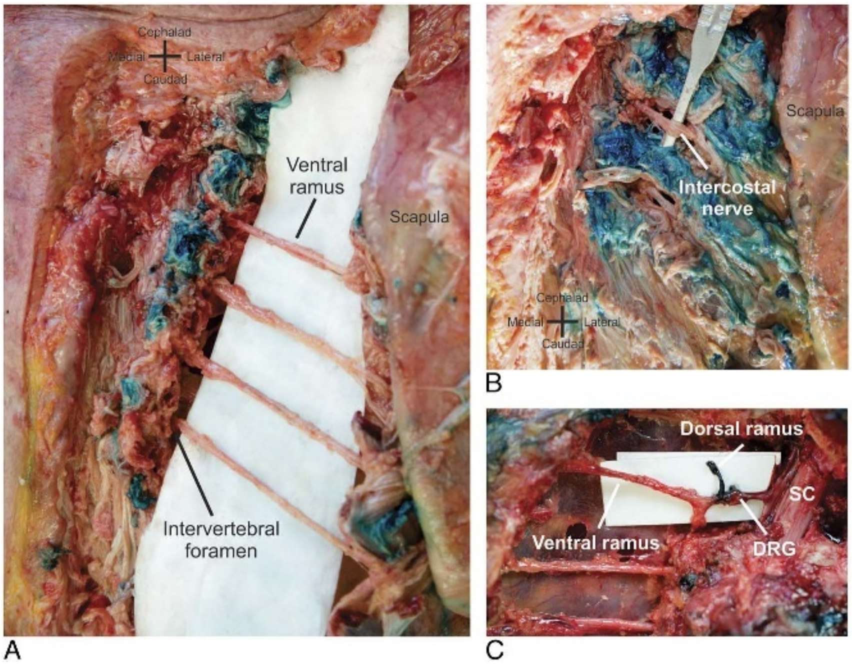

FIGURE 4. Photographic images at various stages of the dissection. A, Right side, ribs removed. Intercostal nerves were not stained with dye. B, Right side, ribs intact. The surface of ribs was stained, but intercostal spaces and intercostal nerves were not involved. C, Left side, an example of the involvement of the dorsal root ganglion and dorsal ramus. DRG indicates dorsal root ganglion; SC, spinal cord.

For example, in 70% to 85% of injections, there was spread of dye deep to the iliocostalis between the first and fifth vertebrae (Table 1). The costal attachments of iliocostalis (Fig. 3B) created an apparent boundary that often limited further spread of the dye laterally. However, in 15% to 25% of injections, the dye spread beyond this boundary, in the region of the first to fourth thoracic vertebrae, for 3 to 4 cm lateral to the attachments of the iliocostalis muscle and to the attachments of serratus anterior (Fig. 2).

Dye did not penetrate the external intercostal muscles (Fig. 4B), and there was (with the exception of 1 injection at 2 levels) no involvement of the ventral rami in the dye spread (Table 1 and Fig. 4, A–C). In only 2 injections (at 2 levels each) the dye appeared to track back along the dorsal rami, through the costotransverse foramen and onto the dorsal root ganglion (Table 1, Fig. 4C). In all other cases, the dorsal root ganglia were not involved in the dye injection.

DISCUSSION

This is the first study to investigate the mechanism of action of ESB with a dye injection and dissection study using multiple nonembalmed cadavers. These findings indicate that 20 mL of dye injected into the plane between erector spinae and the fifth thoracic transverse process results in extensive spread deep and superficial to the erector spinae muscles involving several segmental levels and lateral spread often to the lateral attachments of iliocostalis. The majority of the dye spread was cephalad to T6 and lateral into the plane deep to erector spinae muscle. In

TABLE 1. Spread of Dye Deep to Erector Spinae Muscles and Nerves From 20 Injections in 10 Cadavers

	Spinalis		Longissimus		Iliocostalis		Serratus Anterior		Dorsal Rami		Ventral Rami		Dorsal Root Ganglion	
Thoracic Level	n	%	n	%	n	%	n	%	n	%	n	%	n	%
1	7	35	17	85	14	70	3	15	0	0	0	0	0	0.0
2	7	35	18	90	16	80	4	20	2	10	0	0	0	0.0
3	9	45	20	100	16	80	5	25	11	55	0	0	2	10.0
4	12	60	20	100	17	85	5	25	14	70	0	0	0	0.0
5	12	60	19	95	15	75	1	5	12	60	1	5	2	10.0
6	10	50	15	75	9	45	0	0	5	25	1	5	0	0.0
7	9	45	6	30	3	15	0	0	3	15	0	0	0	0.0
8	8	40	5	25	0	0	0	0	0	0	0	0	0	0.0
9	6	30	4	20	0	0	0	0	0	0	0	0	0	0.0
10	4	20	4	20	0	0	0	0	0	0	0	0	0	0.0
11	2	10	3	15	0	0	0	0	0	0	0	0	0	0.0
12	1	5	2	10	0	0	0	0	0	0	0	0	0	0.0

contrast, anterior spread of dye into the paravertebral or intercostal spaces to consistently involve the origin of the ventral or dorsal rami in the paravertebral space did not occur. For example, except for 1 injection (from 20), the ventral rami were not stained by the dye (Table 1). Dorsal ramus involvement was posterior to the costotransverse foramen, and the dorsal ramus was frequently stained by dye as it exited the costotransverse foramen. This finding was likely because of the close proximity of the injection point to the costotransverse foramen. Because of this and the wide spread (lateral and cephalad) of dye deep to the erector spinae, this cadaveric model indicates that the dorsal rami are likely to be blocked with an ESB, either close to the costotransverse foramen or involving its more distal branches. Because the spread of dye in this current study did not involve the ventral rami or the paravertebral space, an ESB may not be an alternative or simpler version of paravertebral blockade.

In the original description of ESB, the dye was noted to be in the vicinity of the costotransverse foramen, but there was no definitive description of dye spreading to involve the ventral ramus.[1] Given the case reports that indicate ventral ramus blockade following an ESB, we were surprised with the consistent lack of anterior spread of dye to involve the ventral ramus noted in the present study. This result is different from what we anticipated given the effectiveness of ESB in case reports. Potentially, it is the deep muscles of the vertebral column (semispinalis, multifidus, rotatores, and interspinales) and their complex attachment to the transverse processes that prevented dye spread anteriorly. Because of the extensive lateral spread of dye that we noted here, an alternative mechanism to explain clinical blockade is the involvement of lateral cutaneous branches of the intercostal nerves after they pierce the intercostal muscles and leave the intercostal space to innervate the more superficial skin. This typically occurs at or lateral to the angle of the ribs, where most of the dye in this study was located.

There are limitations in using a cadaveric model to represent spread of local anesthetic in the living. For example, following ESB in the living, there may be more anterior or lateral spread of local anesthetic related to intrathoracic pressure changes, and the absence of tissue tension in a cadaver may limit spread of dye. Positioning of the patient and gravitational effect may potentially influence spread of local anesthetic. Using spread of dye to estimate local anesthetic spread is only an estimate, and clinical studies are required. However, we evaluated the spread of dye using a similar dye injection cadaveric model of paravertebral blockade[10] and transabdominis plane block[11–13] and noted it to be consistent with clinical effect. Thus, the spread of dye in between the extensive aponeuroses and attachments of the muscles of the cadaveric vertebral column may be consistent with what occurs in a living patient.

In conclusion, this cadaveric experiment designed to simulate a clinical ESB documented extensive craniocaudal and medial-to-lateral spread of the dye deep and superficial to the erector spinae muscles. There was no spread of dye anteriorly to the paravertebral space to involve origins of the ventral and dorsal branches of the thoracic spinal nerves. Dorsal ramus involvement was largely posterior to the costotransverse foramen. There was potential involvement of the lateral cutaneous branches of the intercostal nerves lateral to the angle of the ribs.

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