Original Article

Pathways of dye spread after injections in the paraspinal spaces—A cadaveric study

ABSTRACT

Background: The erector spinae plane (ESP) block is the most sought-after block since its inception. However, it is more of dorsal rami block with unpredictable ventral diffusion to the paravertebral area. We injected dye in ESP and other paraspinal spaces to study and compare the dye diffusion pattern along the neuroaxis and paraspinal region in human cadavers.

Methods: In six soft-embalmed cadavers (12 specimens), 20 mL methylene blue dye (erector spinae plane and paravertebral space) or indocyanine green dye (inter-ligament space) was injected bilaterally using an in-plane ultrasound-guided technique at the level of the costotransverse junction of fourth thoracic vertebrae. Dye spread was evaluated bilaterally in the coronal plane in the paravertebral and intercostal spaces from the 1st and the 12th rib. Axial and sagittal sections were performed at the level of the 4th thoracic vertebrae. After cross sections, the extent of dye spread was investigated in ESP, inter-ligament, and paravertebral spaces. The staining of the ventral and dorsal rami and spread into the intercostal spaces was evaluated.

Results: ESP injection was mainly restricted dorsal to the costotransverse foramen and did not spread anteriorly to the paravertebral space. The paravertebral injection involved the origin of the spinal nerve and spread laterally to the intercostal space. The inter-ligament space injection showed an extensive anterior and posterior dye spread involving the ventral and dorsal rami.

Conclusions: Following ESP injection, there was no spread of the dye anteriorly to the paravertebral space and it only involved the dorsal rami. Inter-ligamentous space injection appears to be the most promising block as dye spread both anteriorly to paravertebral space and posteriorly toward ESP.

Key words: Cadaver, dye, injections, paraspinal space

Introduction

The erector spinae block has gained huge popularity among regional anesthesiologists ever since it was first described by Forero *et al*.[1] for the management of thoracic neuropathic pain. It was seen as a "surrogate" block to paravertebral block as it was found to have similar effects. However, despite a sea of literature currently attesting to its effectiveness for a range of indications for surgeries across the trunk, the exact

Access this article online	
Website: https://journals.lww.com/sjan	Quick Response Code
DOI: 10.4103/sja.sja_582_23	

How to cite this article: Diwan S, Shivamallappa S, Timane R, Pai P, Gupta A. Pathways of dye spread after injections in the paraspinal spaces—A cadaveric study. Saudi J Anaesth 2024;18:181-6.

Sandeep Diwan, Shivprakash Shivamallappa[1], Rasika Timane[2], Pallavi Pai[3], Anju Gupta[4]

Department of Anaesthesiology, Sancheti Hospital, Pune, Maharashtra, [1]Department of Anatomy, JSS Medical College, Mysuru, Karnataka, [2]Department of Anaesthesia and Critical Care, KRIMS Hospital, Nagpur, Maharashtra, [3]Department of Anaesthesiology, Dinanath Mangeshkar Hospital, Pune, Maharashtra, [4]Department of Anaesthesiology, Pain Medicine and Critical Care, AIIMS, New Delhi, India

Address for correspondence: Dr. Anju Gupta, Department of Anaesthesiology, Pain Medicine and Critical Care, No. 6, 4th Floor, Porta Cabin, Teaching Block, All India Institute of Medical Sciences, New Delhi - 110 029, India.
E-mail: dranjugupta2009@rediffmail.com

Submitted: 29-Jan-2023, **Revised:** 11-Jul-2023 **Accepted:** 13-Jul-2023, **Published:** 14-Mar-2024

mechanism of action of this block remains poorly understood. Controversies reign regarding the distribution of injectate following the deposition of local anesthetic in the erector spinae plane. Studies in animals and humans suggest that the erector spinae plane block is a "dorsal rami block,"[2-5] while others claim that it acts by spreading into the para-neuraxial and neuraxial space.[6-8] A cadaveric study described the "anatomical barriers in the paraspinal spaces" and concluded that there are only three points at which injections can be performed; the deep erector spinae plane, the inter-ligament plane, and the paravertebral space.[9] A microscopic histology study demonstrated a disparity between the macroscopic analysis of dye spread and histological results. This pilot study approves that the pathway from the dorsal to the ventral is through the costotransverse foramen, and presumed it to be a paravertebral spread.[10] However, dissection and sampling of tissues can lead to inadvertent spread and can lead to misinterpretation of results. Hence, we aimed to assess the injectate spread following injection into the above-mentioned spaces, performed sections at various levels, and hypothesized that injection in each of these planes and spaces would restrict a ventral diffusion into the paravertebral space.

Methods

The Institutional Ethics committee, JSS Medical College, Mysore, approved an observational study [JSSMC/IEC 1t3042022/46NCT/2021-22] to be conducted on six soft embalmed cadavers [four male and two female], bilaterally (total 12 specimens), all aged above 50 years. None of the cadavers suffered from any lung infection or malignancy. None of the cadavers had previously undergone dorsal spine surgery or a thoracotomy.

Our primary aim was to inject in three compartments as defined in a previous study[9], i.e., deep erector spinae plane, inter-ligament space, and paravertebral space, and after obtaining sections to look if there are specific barriers [ligaments] which would hamper the spread into other spaces.

The secondary aim was:

1. Injection in the deep erector spinae plane and visualize dye in inter-ligament space and epidural/paravertebral space.
2. Injection in inter-ligament space and visualize anterior paravertebral and epidural spread and posterior deep erector spinae plane.
3. Injection in paravertebral space and visualization of spread in epidural, intercostal space, and posteriorly in the inter-ligament space and deep erector spinae plane.

Following injections, the cadavers underwent axial, sagittal, and coronal sections. Subsequently, a macroscopic examination of the dye diffusion was performed. This, thus avoided the unnecessary spread of the injectate with open dissection.

Two cadavers each underwent the following interventions:

1] Erector spinae plane injection (cadavers 1 and 2);
2] Inter-ligament space injection (cadavers 3 and 4) and
3] Paravertebral injection (cadavers 5 and 6), in the prone position.

A linear probe [5–12 mHz, M-turbo Sonosite-Fuji] was used to insonate and identify designated planes and spaces, needle tip, and injectate diffusion. All injections were performed with a 22-gauge, 50-mm needle (Pajunk Sonoplex, PAJUNK Medizintechnologie GmbH, Geisingen, Germany).

Description of technique

Erector spinae plane injection

In cadavers 1 and 2, the probe was deployed longitudinal [para-sagittal] at the level of the 1st rib, and with caudal shift bilateral 4th rib was identified. Shifting medial the 4th costotransverse junction was identified. The needle was inserted in a caudal–cephalad direction into the posterior thoracic wall at the 4th costotransverse junction. An initial injection of 1 ml of normal saline visualized the spread in the appropriate plane, deep to the erector spinae muscle and superficial to the costotransverse junction. A subsequent 20 ml injection of methylene blue dye was completed while visualizing spread in the erector spinae plane.

Inter-ligament space injection

In cadavers 3 and 4, a similar imaging and needling technique as mentioned in the erector spinae plane injection was performed at the level of the 4th costotransverse junction. However, the needle tip was positioned in the space bounded superiorly by the inter-transverse ligament and inferiorly by the costotransverse ligament, underlying rib. An initial injection of 1 ml of normal saline was visualized to spread in the inter-ligament space and was followed by a 20 ml injection of indocyanine green dye. This block is equivalent/akin to the "costotransverse foramen" block.[9]

Paravertebral space injection

In cadavers 5 and 6, the probe was made oblique from the parasagittal position to identify the paravertebral space in front of the costotransverse ligament at the level of the 4th costotransverse junction. The needle was inserted from medial to lateral and a loss of resistance was appreciated as the needle tip was being advanced through the costotransverse junction. After 1 ml of saline injection

confirmed the correct needle tip position in the paravertebral space, 20 ml methylene blue dye was injected.

Dissections

Post injection, evisceration of the thorax was performed. Dye spread was evaluated bilaterally in the coronal plane in the paravertebral and intercostal spaces. Subsequently, each cadaver was subjected to an axial section at the level of the 4th costotransverse junction and a sagittal section through the costotransverse junctions.

Results

Needle positioning and injections were successful in all specimens. The evisceration of thoracic organs identified the injected methylene blue dye beneath the parietal pleura in the coronal plane staining the paravertebral space and the intercostal spaces in cadavers 5 and 6 [Figure 1a and b], but not in cadavers 1, 2, 3 and 4. In the sagittal section, the dye heavily stained the connective tissue in the paravertebral area and engulfed the ventral nerve. The costotransverse ligament was stained moderate to light; however, a strip of inter-ligament was stained heavy blue along with the dorsal nerve root. Dye spilled from the paravertebral area in two intercostal areas [Figure 2a] In Figure 2b, the dye was visualized tracking the ventral nerve root from the paravertebral space into the intercostal nerve staining the intercostal nerves. Further dissection revealed all components of the intercostal groove stained moderate to light from medial to lateral.

Dye injected in the inter-ligament space highlighted the costotransverse ligament [heavy green stain] as a green vertical shadow/structure in the sagittal section [Figure 3a]. Moreover, the section demonstrates a continuity of the paravertebral space ventral to the costotransverse ligament and soaking two ventral nerve roots in the paravertebral space and spilling into the intercostal spaces at multiple levels [Figure 3a]. At one point depicted as [* in yellow] was a possible needle tip target area, evident by a heavy green stain in the inter-ligament space Figure 3a. The green dye diminishes in

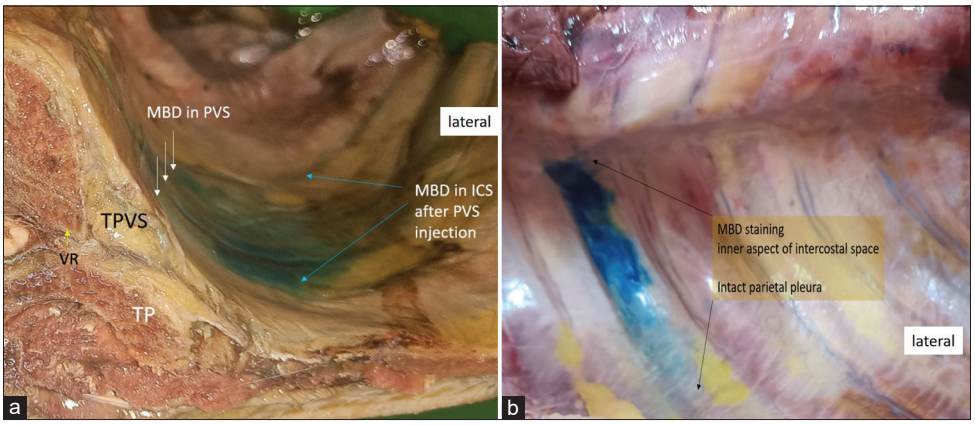

Figure 1: Dye staining the intercostal space after injection in paravertebral space (a). Coronal section; (b). Closer look of dye spread in intercostal space outside pleura

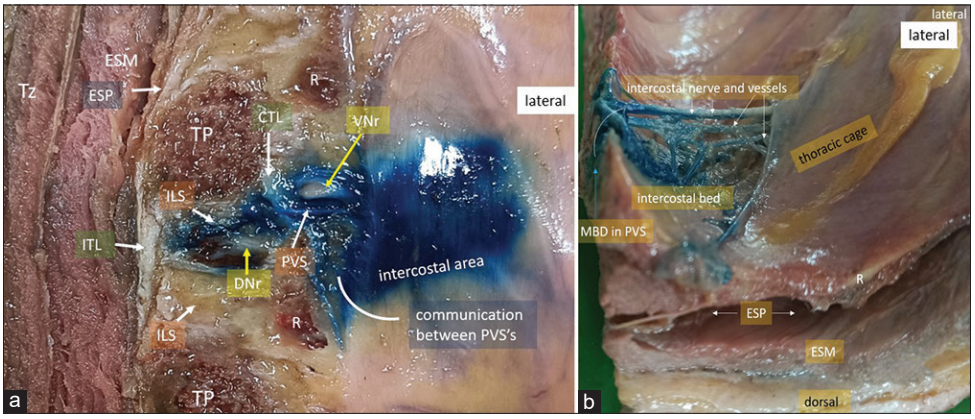

Figure 2: Dye spread following injection in the paravertebral space (a). Sagittal section showing the dye staining ventral and dorsal rami, adjacent paravertebral spaces, costotransverse ligament, inter-ligamentous space, intercostal spaces; (b). The transverse section shows the intercostal space dissected to show the intercostal neurovascular bundle stained by the dye. VNr - Ventral nerve root; ICS - Intercostal root; CTL - Costotransverse ligament; ESM- Erector spinae muscle; ESP - Erector spinae plane; IVF- Intervertebral foramen; ILS- Inter-ligamentous space; TPVS - Thoracic paravertebral space

intensity cephalad. However, spillage of dye is visualized in some parts of the erector spinae plane [Figure 3a]. A further section through the intervertebral foramen demonstrates the light green dye encircling the nerve root in the intervertebral foramen [Figure 3b] In another cadaver, a cross section at the level of injection revealed a spread of the green dye from the inter-ligament space to the paravertebral and erector spinae areas [Figure 3c].

Noticeably, in the erector spinae plane block, in both the cross section and a sagittal section the dye was visualized in the erector spinae plane [Figures 4a and 4b]. The dye was deep to the erector spinae muscle and superficial to the transverse process, transgressed lateral toward the intercostal area but dorsal to the rib, and, medially the dye was envisaged in the retrolaminar area and encircling a part of the medial erector spinae muscle [Figure 4a] No dye was seen in the paravertebral and epidural areas [Figure 4a]. In the sagittal section, the costotransverse ligament could be clearly visualized forming an important anatomical barrier between the inter-ligament space and the costotransverse spaces [Figure 4b]. However, one cadaver cross section revealed dye in the erector spinae plane and the epidural space highlighting the posterior and lateral epidural areas, without soaking the paravertebral region [Figure 4c]. Probably the dye must have percolated at the site of injection and the cross section was cephalad to the point of injection in the erector spinae plane [Figure 4c]. Following the axial and sagittal section, the details of dye visualization are summarized in Table 1.

Discussion

The diffusion of injectate from the erector spinae plane to the paravertebral space has to overcome three important anatomic barriers; the inter-transverse ligament, the inter-ligament space, and the costotransverse ligament.[9] The complex bony-musculo-tendinous structure would greatly impede the translocation of the dye from the dorsal (erector spinae plane) to the ventral (paravertebral) area.[9] However, with injection in the inter-ligament space, the anatomic barrier would be only the costotransverse ligament. We illustrated the movement of injectate from the erector

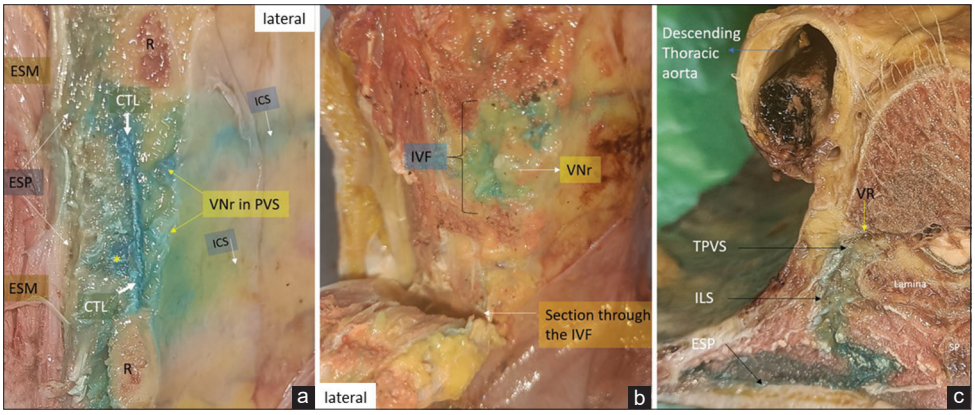

Figure 3: Dye spread within inter-ligamentous space (a). Parasagittal section showing staining of ventral rami, intercostal space, ESP; (b). Spread toward intervertebral foramen; (c). The transverse section shows anterior spread to paravertebral space and posterior spread to erector spinae plane. CTL – Costotransverse ligament; ICS – Intercostal space; ESM – Erector spinae muscle; ESP- Erector spinae plane; IVF – intervertebral foramen; VNr – ventral nerve root; ILS – Inter-ligamentous space; TPVS – Thoracic paravertebral space

Table 1: Summary of dye spread on dissection in coronal, sagittal, and axial sections

	Injection	Cadaver injection side	Axial			Coronal			Sagittal			ICS
			ESP	CTS	PVS	ESP	CTS	PVS	ESP	CTS	PVS	
CAD1	ESP	R	Y	Y	Y	Y	Y	Y	Y	Y	Y	N
		L	Y	N	N	N	N	N	N	N	N	N
CAD2	ESP	R	Y	N	N	Y	N	N	Y	N	N	N
		L	Y	N	N	Y	N	N	Y	N	N	N
CAD3	CTS	R	Y	Y	Y	N	Y	N	N	Y	Y	N
		L	N	Y	Y	N	Y	Y	N	Y	Y	Y
CAD4	CTS	R	N	Y	Y	Y	Y	Y	N	Y	N	Y
		L	N	Y	Y	Y	Y	Y	N	Y	Y	N
CAD5	PVS	R	N	N	Y	N	N	Y	N	Y	Y	Y
		L	N	N	Y	N	N	N	N	N	Y	Y
CAD6	PVS	R	N	N	Y	N	N	Y	N	Y	Y	Y
		L	N	Y	Y	N	Y	Y	N	Y	Y	Y

ESP - Erector spinae plane; CTS - Costotransverse space; PVS - Paravertebral space; ICS - Intercostal space; R - Right; L - Left

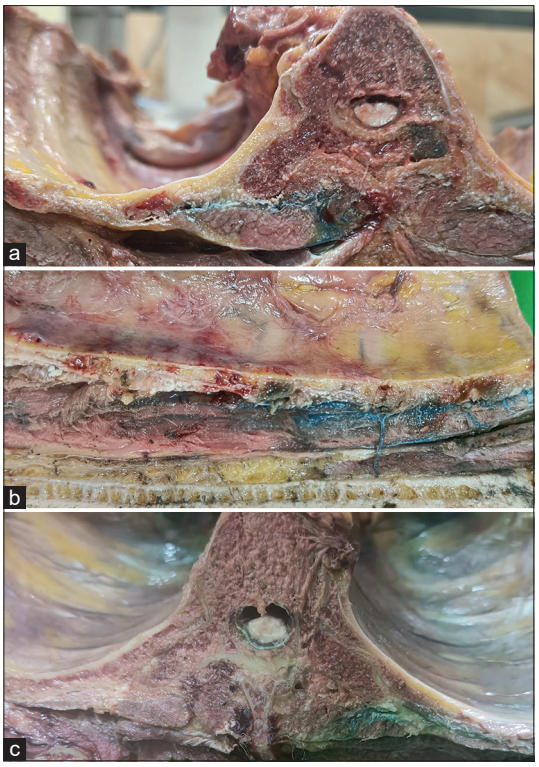

Figure 4: Erector spinae plane injection (a). Transverse section showing dye confined to ESP with no spread anteriorly to ILS or PVS (b). The sagittal section shows vertical dye spread along the erector spinae plane and staining the erector spinae muscle while the inter-ligamentous space and paravertebral spaces are spared (c). The transverse section shows dye spread toward the intercostal space following ESP injection. ILS: inter-ligamentous space, PVS: paravertebral space, ESP: erector spinae plane

spinae plane to the paravertebral space diffusing through the inter-ligament space. Moreover, with injections in the inter-ligament space, the dye moved both dorsal and ventral toward the erector spinae plane and the paravertebral space. An unpredictable minor ventral spread occurred with injection in the erector spinae plane. Lateral spread toward the intercostal space has been proposed as one of the mechanisms of action of erector spinae block;[2] however, no dye spread occurred toward the intercostal space with erector spinae deposition in the present study.

The ventral diffusion of erector spinae plane block has been demonstrated in a previous cadaveric and clinical study.[11,12] However, the subsequent cadaveric and clinical study illustrated an unpredictable diffusion and a dorsal rami block.[13,14] This could be the reason for the highly variable clinical efficacy of erector spinae plane block. In the present study also, the spread from erector spinae plane injections was primarily dorsal and the ventral rami were unstained.

There is recent evidence of a possible pathway of injectate spread from costotransverse foramen and ligaments toward the paravertebral space.[1,2,15,16] The costotransverse foramen block which is performed between the two ligaments (inter-transverse ligament and costotransverse ligament) was introduced as a simpler and safer paraspinal injection compared to the paravertebral injections.[17]

With the dorsal rami emerging through the costotransverse foramen, the medial portion of intercostal tissue in an approximation of the costotransverse foramen and the dorsal rami are in close relation to the blood vessels, this can be a plausible mechanism of injectate transfer from erector spinae plane or the inter-ligament space to the paravertebral and intercostal region.[18]

Interestingly, the dye injected in the inter-ligament space traveled both ventral and dorsal and more reliably blocked the ventral and dorsal rami. With the injection in the erector spinae plane, the dye diffused in the inter-ligament space and paravertebral space in only 25% of cadaveric specimens while the spread from injection in the paravertebral space occurred toward intercostal and inter-ligament spaces.

Extrapolating the spread of injection in a restricted number of cadavers to clinical scenarios is a major limitation. The integrity and tissue permeability are affected after death. Further, soft embalming and frozen cadavers might affect differently. In the living, there may be a more extensive diffusion of local anesthetic related to breathing, muscle tone, and contractions.

Conclusion

Based on this study, the inter-ligament space injection seems to hold promise as a future block due to its favorable dye spread pattern, with the injectate traveling ventral and lateral as well as dorsal and safe position of the needle away from pleura. However, erector spinae plane injection appeared to be only a dorsal rami block.

Financial support and sponsorship
Nil.

Conflicts of interest
There are no conflicts of interest.

References

1. Forero M, Adhikary SD, Lopez H, Tsui C, Chin KJ. The erector spinae plane block: A novel analgesic technique in thoracic neuropathic pain. Reg Anesth Pain Med 2016;41:621-7.
2. Ivanusic J, Konishi Y, Barrington MJ. A cadaveric study investigating the mechanism of action of erector spinae blockade. Reg Anesth Pain Med 2018;43:567-71.

3. Aponte A, Sala-Blanch X, Prats-Galino A, Masdeu J, Moreno LA, Sermeus LA. Anatomical evaluation of the extent of spread in the erector spinae plane block: A cadaveric study. Can J Anesth 2019;66:886-93.
4. Elsharkawy H, Bajracharya GR, El-Boghdadly K, Drake RL, Mariano ER. Comparing two posterior quadratus lumborum block approaches with low thoracic erector spinae plane block: An anatomic study. Reg Anesth Pain Med 2019;44:549-55.
5. Otero PE, Fuensalida SE, Russo PC, Verdier N, Blanco C, Portela DA. Mechanism of action of the erector spinae plane block: Distribution of dye in a porcine model. Reg Anesth Pain Med 2020;45:198-203.
6. Adhikary SD, Bernard S, Lopez H, Chin KJ. Erector spinae plane block versus retrolaminar block: A magnetic resonance imaging and anatomical study. Reg Anesth Pain Med 2018;43:756-62.
7. Yang HM, Choi YJ, Kwon HJ, O J, Cho TH, Kim SH. Comparison of injectate spread and nerve involvement between retrolaminar and erector spinae plane blocks in the thoracic region: A cadaveric study. Anaesthesia 2018;73:1244-50.
8. Choi YJ, Kwon HJ, Jehoon O, Cho TH, Won JY, Yang HM, *et al*. Influence of injectate volume on paravertebral spread in erector spinae plane block: An endoscopic and anatomical evaluation. PLoS One 2019;14:1-10. doi: 10.1371/journal.pone. 0224487.
9. Diwan S, Sala-Blanch X, Nair A. Anatomic barriers to paraspinal blocks: A cadaver case series. Braz J Anesthesiol 2021;S0104-0014(21) 00411-5. doi: 10.1016/j.bjane. 2021.10.011.
10. Bonvicini D, Boscolo-Berto R, De Cassai A, Negrello M, Macchi V, Tiberio I, *et al*. Anatomical basis of erector spinae plane block: A dissection and histotopographic pilot study. J Anesth 2021;35:102-11.
11. Diwan S, Garud R, Nair A. Thoracic paravertebral and erector spinae plane block: A cadaveric study demonstrating different site of injections and similar destinations. Saudi J Anaesth 2019;13:399-401.
12. Diwan S, Nair A. Is paravertebral-epidural spread the underlying mechanism of action of erector spinae plane block? Turk J Anaesthesiol Reanim 2020;48:86-7.
13. Dautzenberg KHW, Zegers MJ, Bleeker CP, Tan ECTH, Vissers KCP, van Geffen GJ, *et al*. Unpredictable injectate spread of the erector spinae plane block in human cadavers. Anesth Analg 2019;129:e163-6.
14. Zhang J, He Y, Wang S, Chen Z, Zhang Y, Gao Y, *et al*. The erector spinae plane block causes only cutaneous sensory loss on ipsilateral posterior thorax: A prospective observational volunteer study. BMC Anesthesiol 2020;20:88. doi: 10.1186/s12871-020-01002-0.
15. Adhikary SD, Bernard S, Lopez H, Chin KJ. Erector spinae plane block versus retrolaminar block: A magnetic resonance imaging and anatomical study. Reg Anesth Pain Med 2018;43:756-62.
16. Vidal E, Giménez H, Forero M, Fajardo M. Erector spinae plane block: A cadaver study to determine its mechanism of action. Rev Esp Anestesiol Reanim 2018;65:514-9.
17. Shibata Y, Kampitak W, Tansatit T. The novel costotransverse foramen block technique: Distribution characteristics of injectate compared with erector spinae plane block. Pain Physician 2020;23:E305-14.
18. Nielsen MV, Moriggl B, Hoermann R, Nielsen TD, Bendtsen TF, Børglum J. Are single-injection erector spinae plane block and multiple-injection costotransverse block equivalent to thoracic paravertebral block? Acta Anaesthesiol Scand 2019;63:1231-8.