ORIGINAL ARTICLE

A cadaveric study of thoracic paravertebral spaces from the point of view of paravertebral block

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ABSTRACT

Background: Paravertebral block (PVB) is a regional anesthetic technique, in which a local anesthetic is injected into the thoracic PVS, resulting in ipsilateral somatic and sympathetic nerve blockade. **Objectives:** The present study aimed at observing the extent of thoracic paravertebral space (TPVS) at the levels of $T_{1–2}$, $T_{6–7}$, and $T_{11–12}$ by measuring the horizontal and vertical spread of the dye in the Indian population. **Materials and Methods:** Methylene blue dye was injected into the TPVS at the levels of $T_{1–2}$, $T_{6–7}$, and $T_{11–12}$ and its spread observed. **Results:** A total of 25 cadavers were studied. The extent of horizontal the spread was average of 83.0 mm at the level of $T_{1–2}$, 103.0 mm at the level of $T_{6–7}$, and 88.2 mm at the $T_{11–12}$ level. The average vertical spread in the intercostal space at the level of $T_{1–2}$ was found to 48.1 mm, at the level of $T_{6–7}$ was found to be 44.6 mm, and at the level of $T_{11–12}$ was found to be 55.04 mm. The maximum vertical spread of dye was over three intercostal spaces. Sixty-four percent of the cadavers studied showed a spread of dye from TPVS to lumbar paravertebral space. In 20% of the cadavers, a contralateral spread of injected dye was observed. The average depth of the needle to reach the TPVS was observed to be 36.8, 35.7, and 36.1 mm for $T_{1–2}$, $T_{6–7}$, and $T_{11–12}$, respectively. **Conclusions:** A paravertebral block (PVB) has immense potential in regional anesthetic techniques involving thoracic and lumbar dermatomes. The present study will be helpful for surgeons and anesthesiologists to reduce uncertainties of the spread of anesthetic agents in thoracic PVB and its complications.

Keywords: Anaesthesia, paravertebral block, paravertebral space

INTRODUCTION

The paravertebral space (PVS) is a wedge-shaped space situated adjacent to the vertebral bodies. In the thoracic region, this space is bound anterolaterally by the parietal pleura, posteriorly by the superior costotransverse ligament, medially by the body of the vertebra and the intervertebral foramina and the heads of the ribs superiorly and inferiorly.[1] Here, the spinal root emerges through the intervertebral foramen, communicates with the sympathetic chain through the gray and white communicates and divides into the dorsal and ventral rami.[1] The PVS may extend laterally into the intercostal space, medially into the epidural space through the intervertebral foramen and above and below with adjacent PVS. It may also be continuous with contralateral PVS across the midline.[2]

The thoracic PVS begins at $T_{1–2}$. This space is continuous cranially with the cervical PVS.[1]

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Submitted: 06-Sep-2019 **Accepted:** 11-Feb-2020 **Published:** 13-Jul-2021

Access this article online	
Quick Response Code:	Website: www.smjonline.org
	DOI: 10.4103/smj.smj_44_19

Cite this article as: Dayer MJ, Bharambe VK. A cadaveric study of thoracic paravertebral spaces from the point of view of paravertebral block. Sahel Med J 2021;24:80-9.

The attachment of psoas major muscle is said to be the caudal limit of the thoracic PVS. However, there is a disagreement about the caudal extent of this space as there are reports of thoracolumbar anesthesia following low thoracic paravertebral injection of anesthetic.[2-4]

Paravertebral block (PVB) is a regional anesthetic technique, in which a local anesthetic is injected into the thoracic PVS, resulting in ipsilateral somatic and sympathetic nerve blockade. The somatic blockade is reported to extend over five dermatomes and sympathetic over eight dermatomes vertically, indicating the vertical spread of the injected anesthetic in the PVS.[5] Lateral spread along the intercostal spaces and contralateral spread in front of vertebrae has been reported.[6,7] However, there are conflicting reports about the spread of the anesthetic drug between the thoracic and lumbar PVS.[8]

The present research focuses on evaluating and attempting to overcome the gaps in the existing knowledge of thoracic PVS. The present study attempts to define the extent to which a fluid substance can spread vertically and transversely on being injected into the thoracic PVS. It also attempts to establish whether there is continuity between thoracic and lumbar PVS and if continuous, to define the path of continuity. The knowledge thus obtained would help in the procedure of thoracic PVBs. It also would provide a better understanding of the ipsilateral and contralateral spreads of analgesics and anesthetics which has a great clinical significance in surgeries and postoperative and miscellaneous analgesia. The spread method, depth measurement, and the failure rate determination would help in preventing complications such as pneumothorax and pleural puncture. Thus, this research is expected to help expand the current knowledge of the PVSs from an anatomical perspective along with its clinical significance.

Objectives

The objectives of the present study were:

i. To define the extent to which a fluid substance can spread vertically and transversely on being injected into the thoracic PVS
ii. To establish whether there is continuity between thoracic and lumbar PVS
iii. To measure the depth to which the needle has to be inserted to reach thoracic paravertebral space (TPVS) at the levels of $T_{1–2}$, $T_{6–7}$, and $T_{11–12}$.

MATERIALS AND METHODS

Institutional Ethical Committee clearance was obtained from the Ethical Approval body, i.e., Institutional Ethics Subcommittee (IESC) of Dr. D Y Patil Medical College, Hospital and Research Centre, protocol number was IESC/Short term studentship/2018/02 dated May 14, 2018. The study was commenced only after obtaining this clearance.

Adult formalin-fixed cadavers were used for the present study. The cadavers used in the present study were donated bodies. Written informed consent was obtained from each donor stating clearly that they were donating their bodies to the Anatomy Department, for the purpose of anatomical dissection and medical research the data from which could be used for research publications. All the procedures have been carried out as per the guidelines given in the Declaration of Helsinki 2013.

Study setting

The present study was conducted in the dissection hall of Dr. D Y Patil Medical College, Hospital and Research Centre. The study design was experimental type of analytical study. The duration of the study was 3 months extending from June 2018 to Sep 2018. The inclusion criteria for the selection of cadaver were that the formalin-fixed cadaver should be adult, with no obvious vertebral abnormalities. Exclusion criteria were those cadavers with visible vertebral abnormalities such as kyphosis, scoliosis which were, therefore, excluded from the study. Each cadaver was examined for any damage to the area to be studied or for any visible vertebral abnormalities. Twenty-five of these cadavers meeting all requirements were selected for the present study.

The method of selection of the number of cadavers was convenience sampling.

Each selected cadaver was labeled with numbers for identification. Initially, the cadaver was examined to note surface landmarks. The spines of the 12 thoracic vertebrae were palpated and marked. A line was drawn joining these in the midline. The superior level of T_1, T_6, and T_{11} spines were marked on this line. A parasagittal line was drawn parallel and 2.5 cm lateral to the midline. Horizontal lines from above-marked points were drawn to the parasagittal line. The points of crossing indicated the position of the transverse process of the vertebra immediately below.

The objectives of the present study were to measure the depth to which the needle is needed to be inserted to reach the thoracic PVS at $T_{1–2}$, $T_{6–7}$, and $T_{11–12}$ level, to delineate the spread of a substance injected into these PVSs (vertically and transversely) and to determine communications between thoracic and lumbar PVSs.

The needle (18G) was inserted at the above-marked points on the parasagittal plane, lateral to the most cephalic aspect of the spinous processes of T_1, T_6, and T_{11} vertebrae. It was then advanced perpendicular to the skin in all planes to contact the transverse process of the vertebrae below. If the bone was not encountered at this depth, it was possible that the needle tip could be lying between adjacent transverse processes. It was imperative to locate the transverse process before advancing the needle any further to prevent inadvertent deep insertion and possible pleural puncture. In case the transverse process was not encountered, the needle was then advanced a little further and the above process was repeated until the transverse process was contacted.

The needle was then pushed above the transverse process and gradually advanced until a subtle "pop" was felt, indicating that the needle had pierced the superior costotransverse ligament. The length of the needle inserted was measured using a Vernier caliper and noted. This procedure was repeated for all the cadavers. Thus, the depth to which a needle is to be inserted to reach the PVS was measured.

Once the needle was inserted in the PVS, 10 ml of the methylene blue dye was injected into space. After removal of the abdominal and thoracic organs, the spread of the dye was carefully and precisely observed and the path of spread was noted. The transverse spread of the dye into the intercostal spaces as well as into the contralateral side, or into the epidural space was evaluated. The spread of the dye into adjacent TPVS was also looked for. Thus, an attempt was made to bring about a better understanding of all the communications of the PVSs.

Any anomaly was noted and also compared to the needle depth so that the possibility of incorrect injection could be eliminated.

Dye was also injected at the caudal and cranial ends of the thoracic PVS, i.e., at the level of $T_{1–2}$ and $T_{11–12,}$ respectively, to study the spread of the dye in the cervical and lumbar PVS. Thus, attempt was made to study communications between the thoracic PVS and cervical and lumbar PVS and understand the pathway of communication.

After carefully carrying out the said procedures, the observations were noted meticulously. The obtained data were fed into the excel sheet of MS office and were analyzed statistically.

RESULTS

The thoracic PVS at the level of $T_{1–2}$, $T_{6–7}$, and $T_{11–12}$ was studied in a total of 25 cadavers.

Depth to which the needle was inserted to reach the thoracic paravertebral space:

Here, the parameter being measured was the depth to which the needle has to be inserted to be able to enter the TPVS. The data were tabulated by using Microsoft Excel®. The excel program was used to calculate the mean, standard deviation, and standard error of the mean [Table 1].

At the level of $T_{1–2,}$ the range of depth of the TPVS, i.e., the distance to which the needle had to be inserted was between 18.1 and 54.1 mm. At the level of $T_{6–7}$, this range of depth was between 17.7 and 54.6 mm. At the level of $T_{11–12}$, this range of depth was between 15.1 and 54.0 mm. The average depth of the needle was observed to be 36.8, 35.7, and 36.1 mm for $T_{1–2}$, $T_{6–7}$, and $T_{11–12}$, respectively. The standard deviation was found to be 9.04, 8.17, and 7.29, respectively, and the standard error of the mean was found to be 1.84, 1.82, and 1.63, respectively.

The photograph shows the spread of dye at the levels of $T_{1–2}$, $T_{6–7}$, and $T_{11–12}$ [Figure 1].

Horizontal spread: [Table 1]

Here, the parameter being measured was the horizontal spread of dye once injected into the TPVS. The data

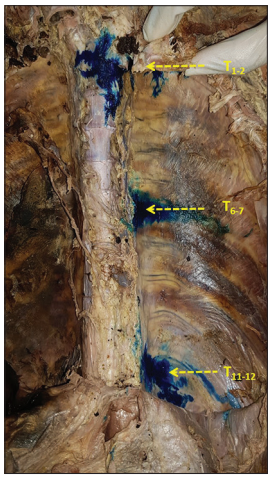

Figure 1: The photograph shows typical spread of dye at the levels of T_{1-2}, T_{6-7}, and T_{11-12}

Table 1: All the findings (in mm) related to horizontal, vertical spread, and depth to which the needle was inserted to inject the dye during the present study

Cadaver number	TPVS	Horizontal spread	Vertical spread	Depth of needle
1	T_{1-2}	83.57	59.02	42.63
	T_{6-7}	117.21	54.15	41.87
	T_{11-12}	84.69	82.12	41.98
2	T_{1-2}	58.87	41.44	40.97
	T_{6-7}	94.32	73.19	39.44
	T_{11-12}	71.88	85.11	40.44
3	T_{1-2}	103.29	54.3	35.86
	T_{6-7}	89.29	33.85	34.97
	T_{11-12}	125.5	52.69	35.64
4	T_{1-2}	90.91	69.57	40.03
	T_{6-7}	152.5	101.56	39.32
	T_{11-12}	115.08	65.22	39.97
5	T_{1-2}	79.43	37.82	36.19
	T_{6-7}	117.39	34.16	34.17
	T_{11-12}	116.25	33.12	35.28
6	T_{1-2}	91.82	45.92	41.11
	T_{6-7}	146.23	30.59	40.9
	T_{11-12}	81.35	63.52	41.74
7	T_{1-2}	76.93	40.87	41.63
	T_{6-7}	97.32	35.05	42.21
	T_{11-12}	66.6	22.45	34.17
8	T_{1-2}	78.56	66.21	40.65
	T_{6-7}	100.37	68.48	40.08
	T_{11-12}	141.27	137.04	38.67
9	T_{1-2}	90.69	60.44	38.01
	T_{6-7}	74.87	37.87	36.93
	T_{11-12}	93.36	39.12	36.27
10	T_{1-2}	103.1	58.4	38.23
	T_{6-7}	112.48	27.36	37.79
	T_{11-12}	66.29	57.97	37.99
11	T_{1-2}	102.63	37.34	39.63
	T_{6-7}	82.73	45.22	37.28
	T_{11-12}	98.16	43.31	38.91
12	T_{1-2}	65.28	51.06	27.72
	T_{6-7}	93	13.36	37.47
	T_{11-12}	44.26	41.65	40.65
13	T_{1-2}	91.3	41.83	43.66
	T_{6-7}	103.49	53.77	43.01
	T_{11-12}	59.98	44.89	43.26
14	T_{1-2}	51.9	26.69	25.71
	T_{6-7}	89.3	55.67	24.55
	T_{11-12}	114.16	38.19	27.28
15	T_{1-2}	103.98	60.23	18.15
	T_{6-7}	118.64	41.84	19.57
	T_{11-12}	117.22	56.73	20.28
16	T_{1-2}	114.52	52.12	20.02
	T_{6-7}	97.43	44.16	19.54
	T_{11-12}	136.3	47.83	20.21
17	T_{1-2}	48.31	38.87	26.16
	T_{6-7}	87.97	27.78	17.78
	T_{11-12}	66.19	54.11	15.19
18	T_{1-2}	59.29	37.2	51.08
	T_{6-7}	69.58	41.17	54.62
	T_{11-12}	52.28	40.81	53.28
19	T_{1-2}	-	-	-
	T_{6-7}	152.55	47.58	28.18
	T_{11-12}	74.73	54.5	29.21
20	T_{1-2}	113.39	67.83	54.15
	T_{6-7}	109.79	65.87	53.31
	T_{11-12}	68.29	60.28	54.06
21	T_{1-2}	60.88	41.71	24.18
	T_{6-7}	85.22	55.57	19.15
	T_{11-12}	88.75	49.07	26.21
22	T_{1-2}	63.1	52.02	40.23
	T_{6-7}	92.02	43.27	39.68
	T_{11-12}	75.01	47.33	41.83
23	T_{1-2}	107.5	40.69	33.41
	T_{6-7}	153.56	21.85	24.75
	T_{11-12}	141.68	29.21	25.03
24	T_{1-2}	68.46	37.25	43.28
	T_{6-7}	73.89	19.68	42.9
	T_{11-12}	63.7	74.1	43.96
25	T_{1-2}	85.36	36.93	41.91
	T_{6-7}	64.11	43.54	43.91
	T_{11-12}	43.28	55.72	42.66

Sample number 19 did not have a suitable 1st TPVS. TPVS: Thoracic paravertebral space

were tabulated by using Microsoft Excel®. The excel program was used to calculate the mean, standard deviation, and standard error of the mean.

The horizontal spread in the intercostal space at the level of T_{1-2} was found to be ranging between 48.3 and 114.5 mm. In one case, the appropriate 1st TPVS was not available for carrying out the process. The average horizontal spread at the level of T_{1-2} was 83.04 mm, and the standard deviation from the mean was found to be 20.03 with the standard error of the mean being 4.08. The similar horizontal spread at the level of T_{6-7} was found to be ranging between 64.1 and 153.5 mm and the average was 98.3 mm, standard deviation from the mean was 32.09, and the standard error of the mean was found to be 6.69. The horizontal spread at the level of T_{11-12} was found to be ranging between 43.2 and 141.6 mm and the average was 82.46 mm, the standard deviation from the mean was 29.78 and the standard error of the mean was 6.34 [Figure 1].

Vertical spread: [Table 1]

Here, the parameter being measured was the vertical spread of dye once injected into the TPVS. The data was tabulated by using Microsoft Excel®. The excel program was used to calculate the mean, standard deviation, and standard error of the mean.

The vertical spread in the intercostal space at the level of T_{1-2} was found to be ranging between 26.6 and 69.5 mm. The average was 48.1 mm. One cadaver showed the spread of dye in upward direction, indicating that the spread of dye entered into the cervical PVS.

The similar vertical spread at the level of $T_{6–7}$ was found to be ranging between 13.3 and 101.5 mm. The average was 44.6 mm.

The vertical spread at the level of $T_{11–12}$ was found to be ranging between 22.4 and 137.0 mm. The average was 55.04 mm. The vertical spread was observed both superiorly as well as inferiorly.

Table 2 depicts the vertical spread of dye when injected at the level of $T_{1–2}$ in terms of the number of adjacent PVSs the dye was able to spread.

Table 3 depicts the vertical spread of dye when injected at the level of $T_{6–7}$ in terms of the number of adjacent PVS the dye was able to spread.

Table 4 depicts the vertical spread of dye when injected at the level of $T_{11–12}$ in terms of the number of adjacent PVS the dye was able to spread. Sixteen cadavers showed the spread of dye in downward direction indicating that the spread of dye entered into the Lumbar PVS. Thus 64% of the cadavers studied showed a spread of dye from TPVS to lumbar PVS. The photograph depicts the inferior spread of dye below the level of the diaphragm [Figure 2].

Table 2: The vertical spread of dye when injected at T_{1-2} level in terms of number of adjacent paravertebral space the dye was able to spread into

Number of PVS into which the spread of dye was observed and direction of spread in relation to the PVS injected (T_{1-2})	Number of cadavers showing the type of spread
1 PVS inferior	19
2 PVS inferior	2
1 PVS superior as well as inferior	1
No vertical spread	2
Total	24

One cadaver did not have the appropriate 1st PVS in the thoracic region.
PVS: Paravertebral space

Table 3: The vertical spread of dye when injected at T_{6-7} level in terms of number of adjacent paravertebral space the dye was able to spread into

Number of PVS into which the spread of dye was observed and direction of spread in relation to the PVS injected (T_{6-7})	Number of cadavers showing the type of spread
1 PVS superior	8
1 PVS inferior	6
2 PVS inferior	2
1 PVS superior as well as inferior	2
1 PVS superior, 2 PVS inferior	1
No vertical spread	6
Total	25

PVS: Paravertebral space

Medial spread of the dye

In most cases, the dye injected was able to spread medially along the lateral and anterior surfaces of the vertebra, just as it spread laterally in the intercostal space and vertically into the adjacent TPVS. However, only in five cadavers, the dye was able to spread to the contralateral side across the midline. After crossing the midline, the dye spread on to the contralateral side vertically as well as horizontally.

In three cases, this contralateral spread was observed at the level of $T_{6–7}$ and in two cases at the level of $T_{11–12}$. Table 5 gives the details of the vertical and horizontal spread of dye on the contralateral side.

The given figures show the spread of dye to the opposite side, passing anterior to the vertebral bodies at the $T_{6–7}$ level [Figures 3 and 4].

In one cadaver, the dye was injected on the left side in the $T_{11–12}$ PVS and its spread could be seen in the $T_{11–12}$ PVS of the contralateral (right) side. However, no sign of the dye crossing anterior to the vertebra was observed [Figure 5]. On elevation of the diaphragm, the spread of the dye could also be seen below it.

Table 4: The vertical spread of dye when injected at T_{11-12} level in terms of number of adjacent paravertebral space the dye was able to spread into

Number of PVS into which the spread of dye was observed and direction of spread in relation to the PVS injected (T_{11-12})	Number of cadavers showing the type of spread
1 PVS superior	6
2 PVS superior	1
1 PVS inferior	8
1 PVS superior as well as inferior	5
2 PVS inferior	2
3 PVS inferior	1
No vertical spread	2
Total	25

PVS: Paravertebral space

Table 5: Details of the vertical and horizontal spread of dye on the contralateral side

Cadaver number	PVS injected	Measurement of spread of dye on the contralateral side	
		Horizontal (mm)	Vertical (mm)
3	T_{6-7}	47.3	45.5
6	T_{11-12}	51.5	31.1
10	T_{6-7}	101.6	10.8
11	T_{6-7}	34.7	14.2
12	T_{11-12}	50.2	28.7

PVS: Paravertebral space

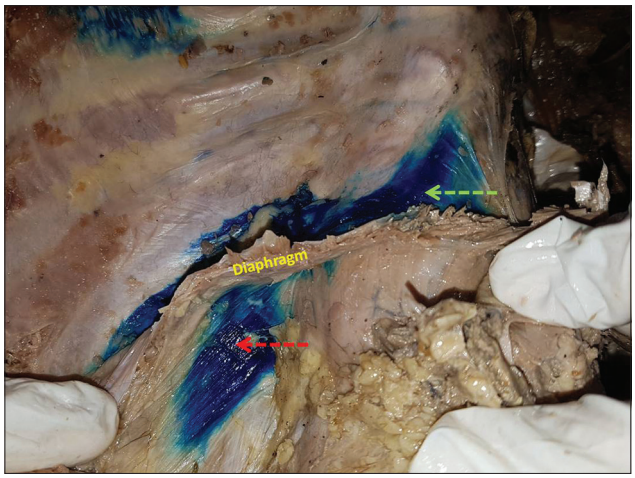

Figure 2: The photograph shows a spread of dye above (green arrow) and below (red arrow) the diaphragm

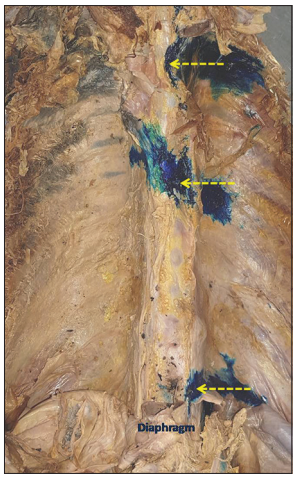

Figure 3: This picture shows the spread of dye anterior to the vertebral bodies

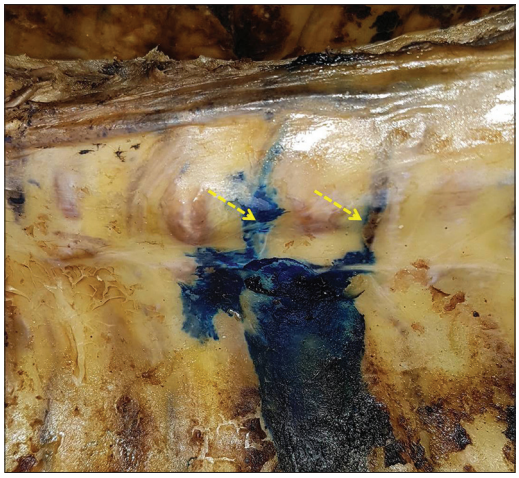

Figure 4: This picture shows the spread of dye anterior to the vertebral bodies. The spread of dye between the vertebral bodies and the prevertebral fascia is well visualized here

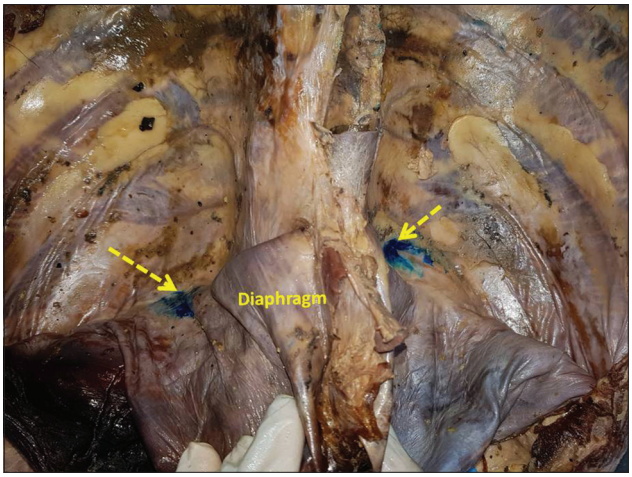

Figure 5: This picture shows the spread of dye (indicated by arrows) from paravertebral space into which it was injected (left) to the contralateral side (right)

In two cadavers, the contralateral spread of the dye was observed without the dye passing anterior to the vertebral bodies. However, no spread below the diaphragm was observed on reflection of the diaphragm [Figures 6 and 7a]. On reflecting the fascia, no spread of dye was seen on the deeper aspect [Figure 7b].

DISCUSSION

The PVS is a space that lies lateral to the vertebral bodies. It is wedge shaped. While it is bound anterolaterally by parietal pleura, it is bound posteriorly by the superior costotransverse ligament. Medially, it is related to the vertebral bodies and the intervertebral foramina. Above and below it is related to the adjacent ribs. This space is traversed by the spinal nerve of that level, its dorsal and ventral rami and its communication with the sympathetic chain.[1]

The TPVS is continuous with the intercostal space laterally, epidural space medially and the contralateral PVS either by passing through the prevertebral space in front of the vertebral column or through the epidural space.[1,5] Space could have a vertical extension superiorly into the cervical region and inferiorly into the lumbar region. However, because of the origin of the psoas major muscle from the caudal boundary of the TPVS, the inferior spread of the space is thought to be unlikely.[8]

The procedure of PVB is a method, wherein the local anesthetic is injected into this PVS.[9] This method of anesthesia was pioneered by Sellheim in 1905.[1] The technique was not much used till it underwent a reappraisal by Eason and Wyatt, who presented a thoracic paravertebral block (TPVB). As the PVS is traversed by intercostal nerves and its rami communicantes, the PVB can provide sensory, motor, and sympathetic blockade,

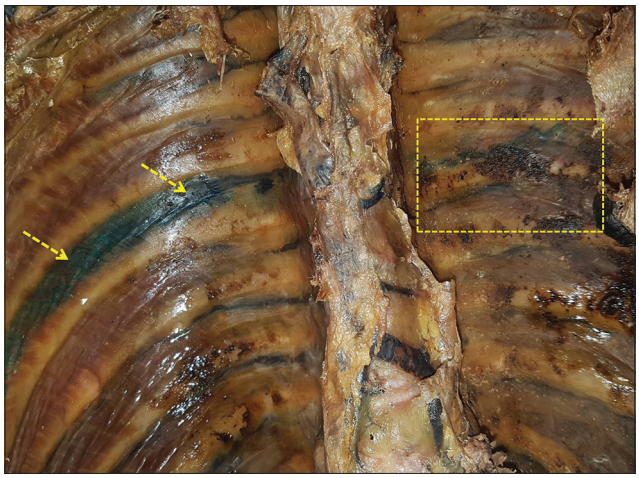

Figure 6: The picture shows spread of injected dye to corresponding integrated chemical system on the opposite side of the side of injection of dye at the level of T_{6-7}. However, this spread wasn't via the prevertebral space as no sign of dye passing anterior to the vertebral bodies was observed

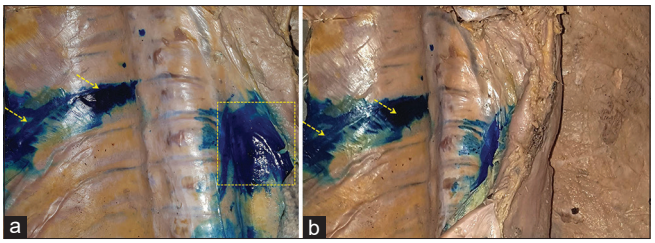

Figure 7: (a) The photograph shows the spread of dye in the sixth integrated chemical system on the side (left) on which it was injected (T_{6-7}). It also shows contralateral spread to the opposite side which spreads to the lower integrated chemical system too (yellow rectangle). (b) When the prevertebral fascia and the fascia covering the great vessels was reflected, no spread of dye to the deeper aspect was observed

extending over varying dermatomes as per the extent of the PVS.[2,3]

The present study was an attempt to understand the extent of this TPVS and its communications to understand the spread of a fluid agent when injected in it. This research aimed to bring about a better understanding of the vertical, horizontal, medial, and contralateral spread of TPVS.

Several authors have studied the TPVS using variable methods to define the extent of this space vertically, laterally, medially, anteriorly, and contralaterally.

The methodology followed in the present study is slightly different than the one, followed by Tighe. In the study conducted by Tighe, the caudal movement of the needle was advised after hitting the bone.[10] However, due to more chances of dye injecting in the lower integrated chemical system in this method, the method of cranial angulation was used, as was suggested later in Tighe's study and which corresponds to the method used in the study performed by Eason.[3,10] This method though having a slightly higher risk of piercing the pleural fascia leads to accurate insertion of the needle in the intended TPVS.

TPVB provides excellent intraoperative analgesia. However, pleural puncture by the needle is a possible complication. To avoid this, accurate placement of the needle in the PVS is essential. Hence prior knowledge of depth to which the needle needs to be inserted during TPVB is essential.[9] In the present study, the average depth to which the needle was inserted to enter the TPVS was found to be 36.8, 35.7, and 36.1 mm for T_{1-2}, T_{6-7}, and T_{11-12}, respectively. The standard deviation was found to be 9.04, 8.17, and 7.29, respectively, and the standard error of the mean was found to be 1.84, 1.82, and 1.63, respectively. The bodies in the department which were used for the dissection consisted of both donated as well as unclaimed cadavers. Accordingly, the thickness of the body wall varied as per the nutritional status of the individual at the time of death. Pusch *et al*. reported a mean distance of 40 mm as the distance from the skin to the point of "loss of resistance." The authors stated that this distance can also be measured using the method of ultrasonographic measurement.[9] Hara *et al*. reported a skin to "loss of resistance" measurement of 4.6 cm.[11] The findings by both the above authors are more than those reported by the present study. This could be because the present study was conducted in the Indian population, which is a different population group compared to the other two studies. Knowledge of such measurements will help to reduce the chances of pleural puncture during TPVB. Pace *et al*. suggested that the use of single injection, transverse, in-plane ultrasound-guided technique for TPVB in surgeries such as mastectomy, is associated with lesser complications.[12]

In the present study, the horizontal spread at T_{1-2} level was found to be ranging between 48.3 and 114.5 mm, and the average was 83.0 mm. The similar horizontal spread at the level of T_{6-7} was found to be ranging between 64.1 and 153.5 mm and the average was 103.0 mm. The horizontal spread at the level of T_{11-12} was found to be ranging between 43.2 and 141.6 mm and the average was 88.2 mm. While in some cadavers, the horizontal spread of dye was observed till the costal angle, in some, it extended beyond that too. In the study by Conacher, wherein the 10 ml of resin was injected in the midthoracic PVS in six cadavers, the resin delineated the space, in which the anesthetic agent could spread in case of PVB in this region. The resin was observed to

have spread horizontally into the adjacent intercostal space for a variable distance. In all cases studied, the spread was over two intercostal spaces. In one case, the resin injected spread till the midaxillary line.[7] In the study conducted by Bouman *et al*. the horizontal spread of injectate stopped at the costal angle.[13] A study similar to the present study was conducted by Cowie *et al*. on ten cadavers. The horizontal spread was reported in all cadavers, but the extent of horizontal spread was not reported.[14] Thus, many authors have studied the horizontal spread of injectate in the TPVS, and in most cases, the spread of the dye has been mentioned in relation to landmarks reached by the injectate such as costal angle or midaxillary line. The present study gives the actual measurements of the extent of horizontal spread.

In the present study, the vertical spread in the intercostal space at the level of $T_{1–2}$ was found to be ranging between 26.6 and 69.5 mm. The average was 48.1 mm. The similar vertical spread at the level of $T_{6–7}$ was found to be ranging between 13.3 and 101.5 mm. The average was 44.6 mm. The vertical spread at the level of $T_{11–12}$ was found to be ranging between 22.4 and 137.0 mm. The average was 55.04 mm. Conacher in the study on six cadavers demonstrated a cephalad and caudad spread from the PVS injected. The range of PVS into which the resin was observed to have spread was found to be between 1 and 5.[7] Cheema *et al*. studied six patients who were injected 15 ml of anesthetic agent in the PVS in the $T_{9–10}$ region for chronically painful conditions. The authors observed a mean distribution of the somatic block of five dermatomes in the upper and lower limits of T_6 and L_3, and a mean distribution of sympathetic block of eight dermatomes. No bilateral spread was observed.[5] Eason and Wyatt reported that a PVB will cover four spaces.[3]

Tighe *et al*. stated 15 ml of injected anesthetic could spread in craniocaudal direction, into epidural, prevertebral and intercostal spaces to variable extent and could produce a block over three dermatomes and sympathetic block over eight dermatomes. In case of the requirement of more spaces to be covered, then multiple injections would be needed. The authors stated that PVB is a technique used to provide analgesia in the thoracoabdominal region in surgeries such as cholecystectomy, surgery in the breast or thoracic region, appendicectomy. It could also be used to provide relief of pain in case of fracture of ribs or abdominal trauma.[10]

Thus, most authors state that one injection in a PVS will cover over four spaces. Bouman *et al*. did not report the extensive spread of the injected material along the craniocaudal axis.[13] The cephalic spread of up to four dermatomes and caudad spread of up to seven dermatomes has been reported.[15] Beyaz *et al*. stated that the vertical spread of anesthetic agents is variable and has been so reported by various authors and that the spread of local anesthetic within the PVS does not occur like in the epidural space.[6] In the present study, the maximum spread was reported to be over three spaces.

It has been stated that generally, during a TPVB, four PVS are anesthesized by 15 ml of anesthetic.[3,8] In the current study, however, since only 10 ml of dye was injected, the vertical spread may have been lesser than the vertical spread observed in other studies. Thus if more spread of anesthesia is needed, then the amount of injectate could be increased and/or multiple injections could be utilized for a wider zone of anesthesia.

The cephalad spread was found to be less than the caudad spread in the present study, which is similar to reports by Richardson and Lönnqvist *et al*.[15]

Regarding caudal spread from $T_{11–12}$ level into the lumbar region, there have been variable reports. Lönnqvist and Hildingsson studied the caudal boundary of the TPVS on 13 cadavers by the process of injection of dye (10 ml) in this space. The authors injected methylene blue dye in the $T_{10–11}$ PVS and observed the spread of the dye. It was found that the dye-filled the PVS at the level of T_{11} and T_{12} and extended into the 11^{th} intercostal space. Vertical spread to $T_{9–10}$ was observed, but the spread of dye across midline was observed in only one of the 13 cadavers studied. Richardson and Lönnqvist stated that there is some confusion regarding the inferior limit of the spread of injectate in the TPVS. In one of the cases in their study, a small amount of dye was observed to have spread below the level of $T_{12.}$ However, the authors opined that this spread could be due to a tear in the overlying tissue. The authors concluded that the origin of psoas major muscle defined the caudal limit of the TPVS, and it seemed unlikely that space could be continuous caudal to the $T_{11–12}$ vertebra.[8] However, the authors state that the somatic block of the lumbar dermatomes following TPVB has been reported. This spread could be by passing of the fluid through the medial and lateral arcuate ligaments or through extradural spread.[16]

Karmakar described a case, wherein the anesthetic agent (18 ml) injected in the low TPVS at $T_{7–8}$ level was found to have spread in the retroperitoneal space affecting the lumbar spinal nerves. The authors stated that this could be the basis for extended unilateral anesthesia.[4]

Saito *et al*. injected 15 ml of crimson dye in the TPVS at the $T_{11–12}$ level. The authors observed that the dye spread downward along the splanchnic nerves, laterally in the fascia along the upper surface of the diaphragm. It entered the abdominal cavity through the medial and lateral arcuate ligaments and spread widely in the transversalis fascia involving subcostal, iliohypogastric, ilioinguinal, genitofemoral, and lateral femoral cutaneous and femoral nerves. The authors stated that fluid could communicate between the thoracic and lumbar PVS.[17]

In the present study, 64% of the cadavers studied showed a spread of the dye into the lumbar PVS. Cheema *et al*. also reported a caudal spread of dye into the lumbar region following a TPVB.[5]

The present study also reported the medial spread of the injected dye. This spread was observed in relation to the lateral and anterior surface of the vertebral bodies in most cases. In 20% of the cadavers studied, the spread was observed in the contralateral PVS also. No contralateral spread was observed at the level of $T_{1–2.}$ No reason could be found for this observation and further studies are needed to study this. Here, the dye continued to spread vertically and laterally, as observed on the ipsilateral side. Spread of dye to the contralateral side without passing anterior to the vertebral body was also reported in the present study, indicating a contralateral spread through the epidural space. Batra *et al*. stated that the TPVS is continuous with the contralateral PVS medially through the epidural space and anteriorly along the lateral surface of the vertebral bodies through the PVS.[1]

Tighe *et al*. reported that in 10% of the cases of PVB, the bilateral block was observed indicating spread of the anesthetic agent across the midline either through the epidural space or through the prevertebral plane.[10]

Bouman *et al*. conducted a cadaveric study of the TPVS by injecting 8–10 ml of plastic and methylene blue on the right and left side at varying levels in the thorax. The study was conducted using two formalin-fixed cadavers and one unembalmed cadaver.[13] They did not report any contralateral spread of dye in their study.[3] The study by Cheema *et al*. also did not report the bilateral spread of the injectate.[5] Karmakar and Tenicella injected 20 ml contrast medium in the TPVS at the level of the fifth thoracic spine ($T_{5–6}$) and demonstrated the fluid could spread cranially, caudally, into the intercostal space laterally and into the epidural space medially. However, they also found that it could spread on the lateral and anterior surface of the adjacent vertebrae with the contralateral extension.[18] Lönnqvist and Hildingsson reported a spread across the midline in one out of the 13 cadavers used for their study.[8] Conacher reported the spread of injected resin along the lateral surface of bodies of vertebrae though in none of the cases studied did the resin cross the midline. In two cadavers, resin was also found in the extradural space having entered into space through the ipsilateral intervertebral foramen.[7] The resin being a more viscous medium could be a cause for this limited spread. Methylene blue has a viscosity of 1.03 cP while resin has a viscosity of 1000 cP (for scale, water has a viscosity of 1 cP and honey has a viscosity of 1000 cP). This may be the reason for no findings of contralateral spread in the studies conducted using resin as in Conacher's study.[7]

The limitations of the present study are the differences in viscosity of the fluid used for the present study versus that used for the purpose of anesthesia. The present study was conducted on formalin preserved cadavers which do not imitate true lifelike conditions due to the relative hardening of the tissues. As the method of injection used in this study is risky as it is likely to puncture the pleura, the method of the present study could be repeated on soft embalmed cadavers so that a more lifelike condition can be reproduced before use of this data on living persons.

CONCLUSIONS

The present study aimed at observing the extent of TPVS at the levels of $T_{1–2}$, $T_{6–7}$, and $T_{11–12}$ by measuring the horizontal and vertical spread of the dye. It also tried to determine an average depth to which the needle is needed to be inserted to reach the TPVS at the same levels in the Indian population. A total of 25 cadavers were studied at the level of $T_{1–2}$, $T_{6–7}$, and $T_{11–12}$. Methylene blue dye was injected in the TPVS and the spread of dye was observed. Spread of the dye to cervical and lumbar PVS as well as to the contralateral side of the corresponding TPVS was noted.

The present study gives the specific measurements of the extent of horizontal the spread as an average of 83.0 mm at the level of $T_{1-2,}$ 103.0 mm at the level of T_{6-7}, and 88.2 mm at theT_{11-12} level also.

The average vertical spread in the intercostal space at the level of T_{1-2} was found to 48.1 mm, at the level of T_{6-7} was found to be 44.6 mm, and at the level of T_{11-12} was found to be 55.04 mm. The maximum vertical spread of dye was over three intercostal spaces which is lesser than that reported by other authors which could be possibly due to the use of 10 ml dye compared to 15 ml used by many other researchers. Thus if more spread of anesthesia is needed, then the amount of injectate could be increased and/or multiple injections could be utilized for the wider zone of anesthesia. Sixty-four percent of the cadavers studied showed a spread of dye from TPVS to lumbar PVS. Thus, the present study indicated continuity between the TPVS and the lumbar region.

In 20% of the cadavers, a contralateral spread of injected dye was observed at times without the dye passing anterior to the vertebral bodies indicating passage through the epidural space. The average depth of the needle to reach the TPVS was observed to be 36.8, 35.7, and 36.1 mm for T_{1-2}, T_{6-7}, and T_{11-12}, respectively.

A PVB has immense potential in regional anesthetic techniques involving thoracic and lumbar dermatomes and is an effective way of anesthesia for both operative procedures like thoracic and breast surgeries as well as nonoperative procedures like rib fractures. The present study will be helpful for surgeons and anesthesiologists to reduce uncertainties of the spread of anesthetic agent in TPVB. It will also help in understanding the complications of TPVB.

The current study can be supplemented with detailed research involving a study of the spread of a radiological dye with the use of ultrasonography for needle insertion and sialograms as radiological evidence and spread of anesthetic agent with the use of nerve stimulation technique on live subjects.

Financial support and sponsorship

Indian Council of Medical Research funded Rs. 10,000 to the first author.

Conflicts of interest

There are no conflicts of interest.

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