Ultrasound-Guided Thoracic Paravertebral Blockade: A Cadaveric Study

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BACKGROUND: Multiple approaches to the paravertebral space have been described to produce analgesia after thoracic surgery. Ultrasound-guided regional anesthesia has the potential to improve efficacy and reduce complications via real-time visualization of the paravertebral space, surrounding structures, and the approaching needle. We compared a single- versus dual-injection technique for ultrasound-guided paravertebral blockade in a cadaver model, evaluating the spread of contrast dye and location of a catheter.

METHODS: Thirty paravertebral injections and 20 catheter placements were performed on 10 fresh cadavers. The paravertebral space was identified using an ultrasound probe in the transverse plane using a linear transducer. An in-plane needle approach was used. Using analine contrast dye, a single 20-mL injection at T6-7 on one side and a dual-injection technique of 10 mL at T3-4 and T7-8 on the contralateral side were performed on each cadaver, followed by insertion of a catheter through the needle. The cadaver was then dissected to evaluate spread of contrast dye and catheter location.

RESULTS: The paravertebral space was easily identified with ultrasound on each cadaver. Contrast dye was seen to surround somatic and sympathetic nerves in the paravertebral, intercostal, and epidural spaces. Contrast dye was present in 19 of 20 paravertebral spaces over 3 to 4 segments (range, 0–10) with no significant differences between single- and dual-injection techniques. Contrast dye spread more extensively across intercostal segments with 4.5 spaces (range, 2–10) covered with a single injection and 6 spaces (range, 2–8) covered with a dual-injection technique ($P = 0.03$). There was epidural spread of contrast in 40% of paravertebral injections in both single- and dual-injection techniques. Catheters were located in the paravertebral space (60%), prevertebral space (20%), and epidural space (5%).

CONCLUSIONS: Transverse in-plane ultrasound-guided needle insertion into the thoracic paravertebral space is both feasible and reliable. However, paravertebral spread of contrast is highly variable with intercostal and epidural spread likely contributing significantly to the analgesic efficacy. A dual-injection technique at separate levels seems to cover more thoracic dermatomes because of greater segmental intercostal spread (rather than paravertebral spread) than a single-injection approach. Catheters are located in nonideal positions in 40% of cases using this in-plane technique. (Anesth Analg 2010;110:1735–9)

Paravertebral block in thoracic surgery is well described and has increased in popularity.[1] Two recent meta-analyses suggest analgesic equivalence between paravertebral blockade and epidural analgesia, but with significantly fewer adverse effects such as hypotension, nausea and vomiting, urinary retention, and pulmonary complications.[2,3]

The thoracic paravertebral space is triangular, delineated by the vertebral body, intervertebral disks, and intervertebral foramina medially; the superior costotransverse ligament, the transverse process, and ribs posteriorly; and the parietal pleura anteriorly. It is continuous with the intercostal space laterally.[4] It contains the intercostal nerves, sympathetic chain, and the dorsal rami of spinal nerves[5] (Fig. 1). Injection of local anesthetic in this space typically results in unilateral block of sympathetic nerves and thoracic dermatomes.[6]

The optimal approach to the paravertebral space remains undefined, with several techniques described, including loss of resistance and "walking off" transverse processes,[7] an intercostal approach,[8] nerve stimulation,[9] and placement under direct vision at the time of surgery.[10] The loss of resistance felt with paravertebral needle placement is much less definite than with epidural insertion.[11] Analgesia and spread of local anesthetic can be inconsistent,[12,13] and failure occurs in at least 10% of cases.[14] Limited evidence suggests analgesia is significantly improved with a continuous infusion technique via a catheter compared with single injection or multiple boluses.[15]

Ultrasound-guided regional anesthesia has been increasingly described over the past decade. Despite the widespread use of single and multilevel approaches to paravertebral blockade, it is unclear how these techniques compare.[6,16]

In this investigation, we used an in-plane ultrasound-guided approach to the paravertebral space using fresh cadavers to evaluate the spread of contrast using both a single- and dual-level injection technique and location of a paravertebral catheter by subsequent dissection.

METHODS

After approval from the University of Melbourne Research Ethics Committee, 10 unembalmed thawed cadavers were

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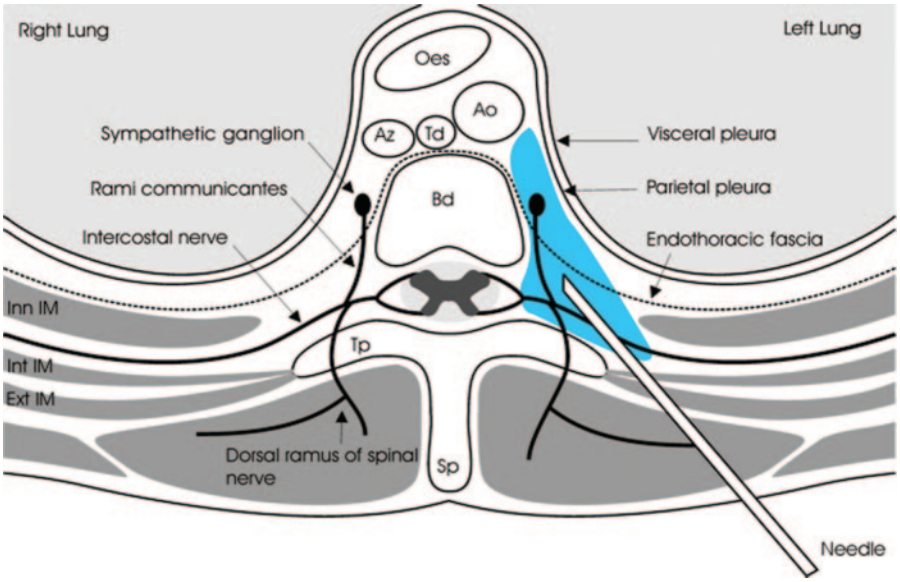

Figure 1. Schematic representation of the paravertebral space with approaching needle and surrounding vertebral body (Bd), transverse process (Tp), and spinous process (Sp). The aorta (Ao), thoracic duct (Td), azygous vein (Az), and esophagus (Oes) sit anteriorly and innermost (Inn IM), internal (Int IM), and external (Ext IM) intercostal muscles laterally. The blue area represents the paravertebral space and likely extent of spread of anesthesia. The superior costotransverse ligament is out of view in this cross-section but blends laterally with the external and internal intercostal muscle/membrane complex as they attach to the transverse process. Here, the paravertebral space merges with the intercostal space.

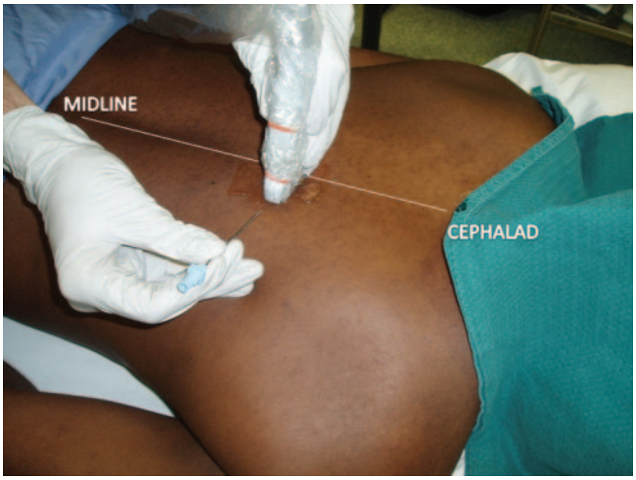

Figure 2. Ultrasound probe and in-plane Tuohy needle at T7-8 for a right paravertebral block, with needle angled from lateral to medial.

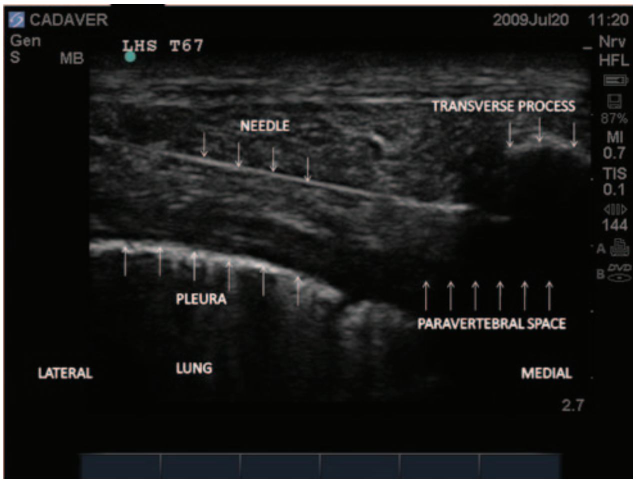

Figure 3. Ultrasound image of the paravertebral space with distinct parietal pleura and underlying lung; the echogenic transverse process with shadowing below; the paravertebral space lying in between and the in-plane needle approach heading toward the transverse process.

studied. Bilateral paravertebral injections were performed on all 10 cadavers in the prone position. The paravertebral space was identified using an M-Turbo ultrasound machine using an L38 10–5 MHz linear transducer (SonoSite, Bothell, WA). The vertebral level was estimated after palpation of the C7-T1 junction and counting caudad (Fig. 2).

The paravertebral space was located with the ultrasound probe in a transverse plane. The spinous process in the midline was located and the probe was then moved laterally locating the transverse process with its distinct sonographic appearance, including acoustic shadow and the parietal pleura. The probe was manipulated slightly cephalad or caudad to locate the intercostal space and avoid acoustic shadowing from nearby ribs. The paravertebral space could be identified on imaging between the transverse process and pleura of the lungs (Fig. 3).

An in-plane approach using an 18-gauge Tuohy needle was used, with the needle advanced lateral to medial from the intercostal space to approach the paravertebral space. Aniline blue contrast dye (0.25% in distilled water) was injected directly through the needle under real-time ultrasound vision with anterior movement of the parietal pleura confirming correct location (Fig. 4).

For the single-injection technique, 20 mL of contrast dye was injected on 1 side at thoracic vertebral level of T6-7. For the dual-injection technique, 10 mL of contrast was injected at each of 2 separate locations on the contralateral side at T3-4 and T7-8. The same cadaver was used to compare the 2 injection techniques to minimize bias from cadavers of varying body mass and image quality.

After contrast dye injection, a single 20-gauge catheter was inserted through the Tuohy needle with the bevel of the needle angled anteriorly. If the catheter was unable to be inserted, the bevel of the needle was rotated until insertion was possible. The ease of catheter insertion was noted as easy, difficult (manipulation or change in angle of needle required), or impossible to feed. The catheter was

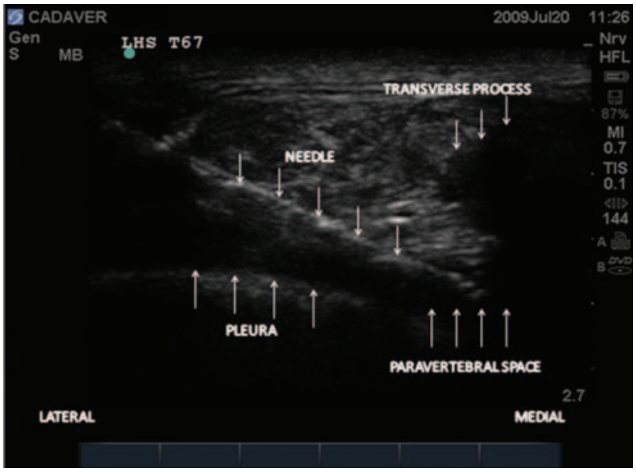

Figure 4. Further anterior angulation of the needle brings it into the paravertebral space. Anterior displacement of the parietal pleura after the contrast injection confirms correct location.

inserted at the site of injection in the single-level technique (T6-7) and the inferior injection site in the dual-level technique (T7-8). Catheters were advanced a maximum distance of 4 cm when possible, consistent with our clinical practice. The catheter was secured and cadavers were placed in the supine position.

The spread of contrast was evaluated by dissection of cadaveric tissue. The cadaver was dissected by first removing the anterior thoracic wall and then carefully eviscerating the thorax to allow an unimpeded view of the posterior thoracic wall, including paravertebral and intercostal spaces from within the thorax. The spread of contrast dye within the paravertebral and intercostal spaces was measured at each injection location.

Data collected included the vertebral levels of cephalad and caudad spread of contrast in the paravertebral space; the number of spaces and lateral extent of contrast in the intercostal spaces; and spread of contrast anterior to the vertebral bodies. The pleura was inspected for evidence of needle penetration or interpleural contrast. The parietal pleura was then removed and the same measurements were made for confirmation. The anterior vertebral bodies were removed to expose the vertebral canal and determine whether there was spread of contrast into the epidural space. The position of the catheter was noted.

The primary outcome of the study was the total number of paravertebral and intercostal segments involved with the contrast dye injection and the location of the catheter. Data are expressed as a median (range). The Wilcoxon rank sum test was used to compare the number of paravertebral and intercostal segments between single- and dual-injection techniques. A P value <0.05 defined statistical significance; statistical analysis was performed using STATA v10.1 (Stata Corp. LP, College Station, TX).

RESULTS

Ten cadavers were examined and included 7 males and 3 females with a mean age at death of 82 years (range, 50–93 years). The paravertebral space was identified on ultrasound in all cadavers. The mean distance of needle trajectory from skin to paravertebral space was 5 cm (range, 4–6 cm). Contrast dye was present in the paravertebral space in 95% of injections performed and in at least 1 intercostal space in all 20 cadavers (Table 1). No contrast was present in the paravertebral space in 1 cadaver at both levels with the dual-injection technique. However, in this cadaver, contrast had spread over 8 intercostal segments. There was no clear relationship between age of cadaver and spread of contrast. Figure 5 demonstrates the typical extent of contrast dye spread.

Table 1. Contrast Spread

	Single	Dual	*P*
Paravertebral segments	3 (1–7)	4 (0–10)	0.70
Intercostal segments	4.5 (2–10)	6 (2–8)	0.03
Lateral intercostal spread (cm)	11 (9–18)	10 (7–14)	0.22
Epidural spread (%)	40	40	1.0

Data expressed as median (range).
Single is single-level injection technique of 20 mL at T6-7.
Dual is dual-level injection technique of 10 mL at T3-4 and T7-8.

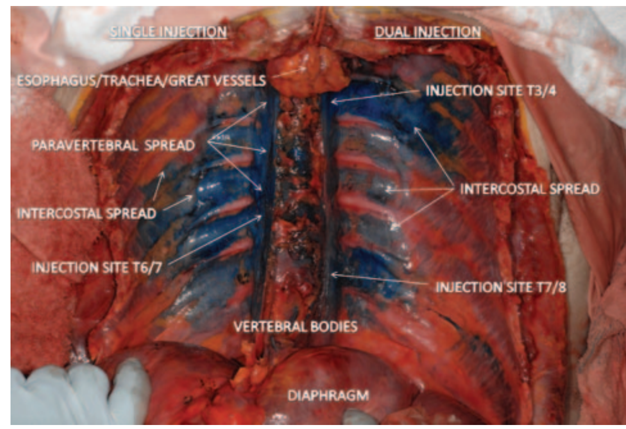

Figure 5. Cadaveric dissection of thorax after removal of intrathoracic viscera. On the cadaver's right, a single-level injection (T6-7) shows paravertebral and intercostal spread over multiple segments. On the left, a dual-injection technique (T3-4 and T7-8) shows paravertebral and intercostal spread over multiple levels with dye most concentrated at the site of injection. Note also the prevertebral spread of contrast. The esophagus, trachea, and great vessels have been removed and tied off superiorly with the diaphragm inferiorly.

Paravertebral Spread

Paravertebral contrast dye spread was variable, and there were no significant differences in the extent of spread between single- and dual-injection techniques (Table 1). Contrast dye could be seen to surround intercostal nerves, as well as sympathetic ganglia, rami communicantes, and splanchnic nerves (Fig. 6). There was no pleural penetration or pleural contrast in any of the cadavers.

Intercostal Spread

There was extensive intercostal spread with all 30 paravertebral injections and, in general, contrast dye spread over more intercostal than paravertebral segments. More intercostal segments were involved in dye using the dual-injection technique compared with the single-injection technique (Table 1, $P = 0.03$). Contrast dye was continuous across all

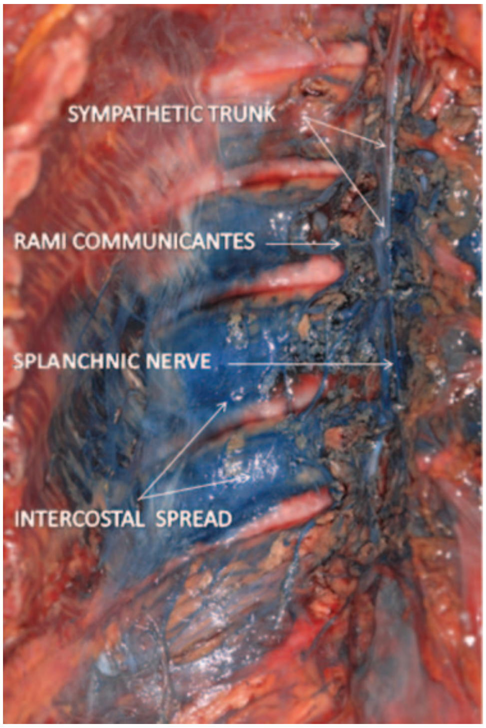

Figure 6. After dissection into the paravertebral space, the sympathetic trunk, rami communicantes, and the splanchnic nerve are observed surrounded with contrast dye.

intercostal segments in the dual-injection technique. Contrast dye was seen to surround the intercostal nerves in this space in all cadavers.

Epidural Spread

Contrast in the epidural space was continuous with contrast in the paravertebral space and was confined to 1 vertebral segment in each cadaver. Communication with the epidural space was through the intervertebral foramen.

Catheter Location

We were able to introduce a catheter after all 20 paravertebral injections. Difficultly advancing the catheter occurred in 50% of cases regardless of whether single- or dual-injection technique was used. Catheter location was highly variable. The catheters were in the paravertebral space on 60% of occasions and in the prevertebral space, anterior to the vertebral bodies, on 20% of occasions. The catheter was unable to be located but definitely not in the paravertebral space in 15% of catheter placements. One catheter was found in the epidural space.

DISCUSSION

In this study, the paravertebral space was readily located with ultrasound guidance in cadavers with excellent imaging of the major landmarks. We demonstrated that there is direct communication between the paravertebral space and the intercostal space laterally and variable communication between the paravertebral and epidural spaces medially. Our data show that there are no differences in paravertebral segment spread after 20 mL of contrast dye injection between a single- and dual-injection technique. However, 1.5 more thoracic intercostal segments were covered with a dual-injection technique. Furthermore, the spread of contrast is often greater between intercostal spaces than paravertebral spaces. These results have not previously been emphasized. Previous clinical and radiological data in an in vivo model have shown that spread of contrast and local anesthesia is confined to the paravertebral space in just 18% of cases, with epidural spread occurring in 70% and unintentional pleural penetration in almost 10%.[13] Naja et al.,[12] using an in vivo nerve stimulator and a chest radiograph model, showed isolated paravertebral contrast in <30% of patients. They postulate better localization of contrast, more extensive paravertebral spread, and less intercostal spread when the needle was more ventral in the paravertebral space and closer to the nerve, as demonstrated by reduced stimulating voltage.[12] A landmark study by Nunn and Slavin[17] specifically examining intercostal nerve blockade showed free spread of contrast into the paravertebral space and free spread across adjacent intercostal segments. Conacher and Kokri[18] showed extensive intercostal spread in patients with detectable analgesia after single-level paravertebral injection. A recent study by Luyet et al.[19] showed when there was contrast in the paravertebral space, there was also contrast in the intercostal spaces over 2 to 6 intercostal levels. However, most of these studies do not specifically detail the extent of intercostal spread. We postulate that intercostal spread as a component of paravertebral blockade may have been underappreciated.

Our data demonstrate that the paravertebral space is not an isolated anatomical compartment and communicates with the adjacent intercostal and epidural spaces. Our approach of lateral to medial needle insertion with anterior angulation of the needle to facilitate catheter placement, instead of paramedian like most previous studies, may contribute to the extensive intercostal spread noted. Clinical studies that rely on dermatomal mapping after paravertebral blockade are unable to distinguish among local anesthesia in the paravertebral, intercostal, or epidural spaces.[6,20,21] It is likely that the analgesic efficacy of a thoracic paravertebral block is from multilevel paravertebral, intercostal, and epidural spread of injectate.

Injected contrast or local anesthesia will take the path of least resistance. In our single cadaver with no contrast in the paravertebral space, metastatic non-small cell cancer was listed as the cause of death, and pleural involvement or peripleural inflammation may have altered the resistance characteristics and the spread of contrast. Differences in pulmonary and pleural pathology may explain variations in segmental spread among cadavers despite standardized injection techniques. In addition, resistance characteristics may be altered in the spontaneously ventilating patient compared with a cadaver, where epidural pressures fluctuate and at times become subatmospheric.[22] Intercostal space pressures also fluctuate from positive to subatmospheric with respiration,[23] and it may be that the balance of these pressures in the paravertebral, epidural, and intercostal spaces influences spread of contrast.

Our data show that after a paravertebral injection, contrast can enter the epidural space (40% of cadavers in our study) and cover a single epidural segment. Epidural spread has been noted to occur in up to 70% of paravertebral blocks in an in vivo radiological model and is perhaps related to subatmospheric pressures.[13]

Clinical data[6,20,21] are consistent with our cadaver study in which contrast dye was most concentrated in the paravertebral space at the level of injection but spread into adjacent segments was variable. The segmental spread we noted through the paravertebral space (3–4 segments), intercostal space (4–6 segments), and into the epidural space could account for the wide range of block levels noted clinically. Our finding of contrast dye surrounding sympathetic ganglia and their rami communicantes accounts for the sympathetic block seen clinically.[6,21]

Our data also suggest that paravertebral catheter placement is challenging and unpredictable. Even when the introducing needle is correctly placed in the paravertebral space, we found the catheter to be in an ideal location in only 60% of patients. In this study, catheters are often in the communicating prevertebral space anterior to the vertebral bodies (20%), likely in the soft tissues posterior to the paravertebral space (15%), or the epidural space (5%).

Our findings are limited by postmortem changes in core temperature, structure, integrity, and permeability of tissue planes. Pharmacokinetic differences between analine contrast dye and a local anesthesia solution may alter spread and diffusion characteristics, although dissection was performed immediately after the injection. Contrast spread in the prone position may be different from that in the supine or lateral positions and may differ with needle gauge, injectate volume,[12] and speed of injection. Extremes of body mass may alter image quality. Despite these limitations, our findings support the clinical data indicating the extent of thoracic dermatome anesthesia with paravertebral blockade.[6,20,21] The study also provides anatomical evidence for the basis of the block observed clinically.

In conclusion, our data suggest that transverse in-plane ultrasound-guided thoracic paravertebral blockade is feasible with reliable identification of the paravertebral space. However, paravertebral spread of contrast is highly variable with intercostal and epidural spread likely contributing significantly to the analgesic efficacy. A dual-injection technique at separate levels seems to cover more thoracic dermatomes because of greater segmental intercostal spread (rather than paravertebral spread) than a single-injection approach. Catheters are located in nonideal positions in 40% of cases. These findings need to be confirmed in a patient population.

AUTHOR CONTRIBUTIONS

BC, DMG, and MJB helped to design and conduct the study, analyze the data, and write the manuscript. JI helped to conduct the study, analyze the data, and write the manuscript.

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