

Brief Report

Ultrasound imaging in cadavers: training in imaging for regional blockade at the trunk

[L'imagerie par ultrason pratiquée sur des cadavres : formation en imagerie pour les blocs régionaux au niveau du tronc]

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Purpose: The unique strategy of using cadaveric models for teaching ultrasound-guided blocks has been described for blocks of the upper and lower extremities. This report considers the parallels between cadaveric and live imaging relevant to scanning of the trunk. The inter-individual variation between subjects (particularly for epidural blocks) is also considered, for practicing ultrasound-guided or supported trunk and central neuraxial techniques.

Technical features: Ultrasound images using a portable machine C60 5-2 MHz curved array probe or HFL38 13-6 MHz linear array probe were obtained from scanning the trunk of a male adult cadaver, and were compared with ultrasound and magnetic resonance images from an adult male volunteer.

Observations: Ultrasound imaging at the midline of the spine in the transverse/coronal plane provided an overview of the vertebral column, while scanning in a medial-to-lateral direction using longitudinal/sagittal plane sequentially localized the spinous, articular and transverse process. At the thoracic spine, further lateral longitudinal scanning will identify costal structures with the rib necks alternating with the hyperechoic ligamentous tissue of the costovertebral joints. Ultrasound imaging in the live subject in the paramedian longitudinal plane could be used at the thoracic and lumbar spinal levels to capture the optimal ultrasound window of the epidural space. Imaging in the cadaver, especially when viewing the epidural space, is primarily limited by the tissue rigidity and lack of spine flexibility.

Conclusion: Cadavers may provide viable training options for practicing ultrasound imaging and real-time ultrasound needle guidance for nerve blocks at the trunk and epidural space. The training can be performed in a stress-free pre-clinical environment without time constraints and the potential for patient discomfort.

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Objectif : La stratégie exceptionnelle qui consiste à utiliser des modèles cadavériques pour enseigner les blocs échoguidés a été décrite précédemment pour les blocs des membres supérieurs et inférieurs. Ce compte-rendu fait état des parallèles entre l'imagerie pertinente au balayage du tronc sur des cadavres ou des sujets vivants. La variation inter-individuelle entre les sujets (particulièrement dans le cas des blocs périduraux) est également prise en compte pour l'exercice des techniques échoguidées ou écho-assistées pour le tronc et le rachis.

Éléments techniques : Les images par ultrason prises à partir d'une machine portable avec sonde à déphasage courbe C60 5-2 MHz ou avec sonde à déphasage linéaire HFL38 13-6 MHz ont été obtenues du balayage du tronc d'un cadavre adulte de sexe masculin et ont été comparées avec des images par ultrason ou résonance magnétique d'un volontaire adulte de sexe masculin.

Observations : L'échographie au milieu de la colonne sur le plan transversal/coronal a procuré une vue d'ensemble de la colonne vertébrale, alors que le balayage effectué avec une orientation médiane à latérale utilisant un plan longitudinal/sagittal a permis de localiser l'une après l'autre les apophyses épineuses, articulaires et transverses. Au niveau de la colonne thoracique, un balayage latéral longitudinal plus poussé permettra d'identifier les structures costales avec les extrémités des côtes alternant avec le tissu ligamentaire hyperéchogène des articulations costovertebrales. L'échographie pratiquée sur un sujet vivant sur le plan paramédian longitudinal pourrait être utilisée aux niveaux thoracique et lombaire de la colonne pour saisir la fenêtre optimale par ultrason de l'espace péridural. Les limites principales de l'échographie pratiquée sur un cadavre, particulièrement lorsqu'on visionne l'espace

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péridural, sont la rigidité tissulaire et le manque de flexibilité au niveau de la colonne.

Conclusion : *La pratique sur des cadavres pourrait constituer une option de formation viable pour exercer l'échographie et l'échoguidage de l'aiguille pour les blocs nerveux pratiqués au niveau du tronc et dans l'espace péridural. La formation peut se faire dans un environnement pré-clinique sans stress, sans contrainte de temps ni inconfort possible pour le patient.*

CADAVERIC ultrasound imaging has been considered previously in the *Journal*.^{1,2} Ultrasound (US) imaging in cadavers can help the novice to acquire an in-depth knowledge of the relevant regional anatomy (including the specific sonoanatomy) in order to facilitate successful identification of nerve structures, and to acquire expertise and confidence in performing these blocks.³ The main benefit from using cadavers is that the training can be performed in a stress-free pre-clinical environment without the time constraints and the potential for patient discomfort. Dissections can be performed to confirm the identity of a nerve or vessel, which is particularly relevant for small peripheral nerves or tips of the transverse processes during paravertebral or lumbar plexus blocks. Finally, the greater time afforded in the laboratory setting is perhaps most beneficial for training in block procedures of the trunk and epidural space, since imaging at these locations can be challenging, and more practice may be necessary than for nerve blocks in the extremities.

The superficial location of many upper, and indeed lower extremity structures ultimately enables real-time US visualization of the nerve structures, the needle trajectory, the structures to be avoided (e.g., pleura, vessels) and the spread of local anesthetic solution. In contrast, visibility in the trunk and spine is more challenging since lower frequency probes are required for deeper US beam penetration, leading to reduced resolution. One exception is the higher resolution which is appropriate at the more superficial location of the intercostal nerves, especially in thin subjects. In addition, the bony composition of the spinal column generally leads to poor beam penetration when identifying the neuraxial structures. Consequently, US guidance (or "support") for blocks involving the trunk (with the exception of many intercostal nerves) and epidural space is often limited to pre-procedural identification of important landmarks. Learning how to identify the relevant anatomical structures in the trunk and spinal region in cadavers will, therefore, probably be more beneficial than learning the intricacies

of needle-probe alignment, probe manipulation and needle tracking.

The objective of this report is to demonstrate that US imaging in cadavers, for the purpose of facilitating peripheral blocks of the trunk [paravertebral, intercostal, and lumbar plexus (psoas compartment)], is similar to that in live humans. A secondary objective was to consider the variations between subjects (particularly for epidural blocks) when practicing US-guided blocks, or supported selective trunk and neuraxial techniques.

Technical features

Ultrasound images using a portable machine (MicroMaxx, SonoSite Inc., Bothel, WA, USA; C60 5-2 MHz curved array probe or HFL38 13-6 MHz linear array probe) were obtained from scanning the trunk of a male adult cadaver (embalmed previously according to standard procedures¹ at the authors' institution) and were compared with the US and magnetic resonance imaging (MRI) of a volunteer adult male. The cadaver was in the legal custody of the Division of Anatomy of the authors' institution. Permission to undertake these procedures was obtained from the Division of Anatomy, in compliance with the institutional ethical standards for the use of human material in medical education. Ethics approval was obtained from the Institutional Research Ethics Board for US and MRI scanning on the volunteer (one of the authors).

Several technical issues are important to consider when viewing the images. The portable US system does not allow selection of a specific frequency. Instead, it automatically adjusts the frequency depending on the depth of scanning. Considering the depth of the anatomical structures, the US images of the trunk in this report have lower resolution as compared to many other images in descriptions of superficially-located nerve blocks shown in the current US-guided anesthesia literature. We used a portable US system from our clinical practice, which we find suitable for most nerve block procedures. For each US image, the depth of beam penetration is shown by a number appearing in the lower right corner. Accompanying pictures of a model skeleton are enhanced with a schematic overlay representing the plane of the probe beams. Images from MRI of the same living subject are also included for reference when studying the images.

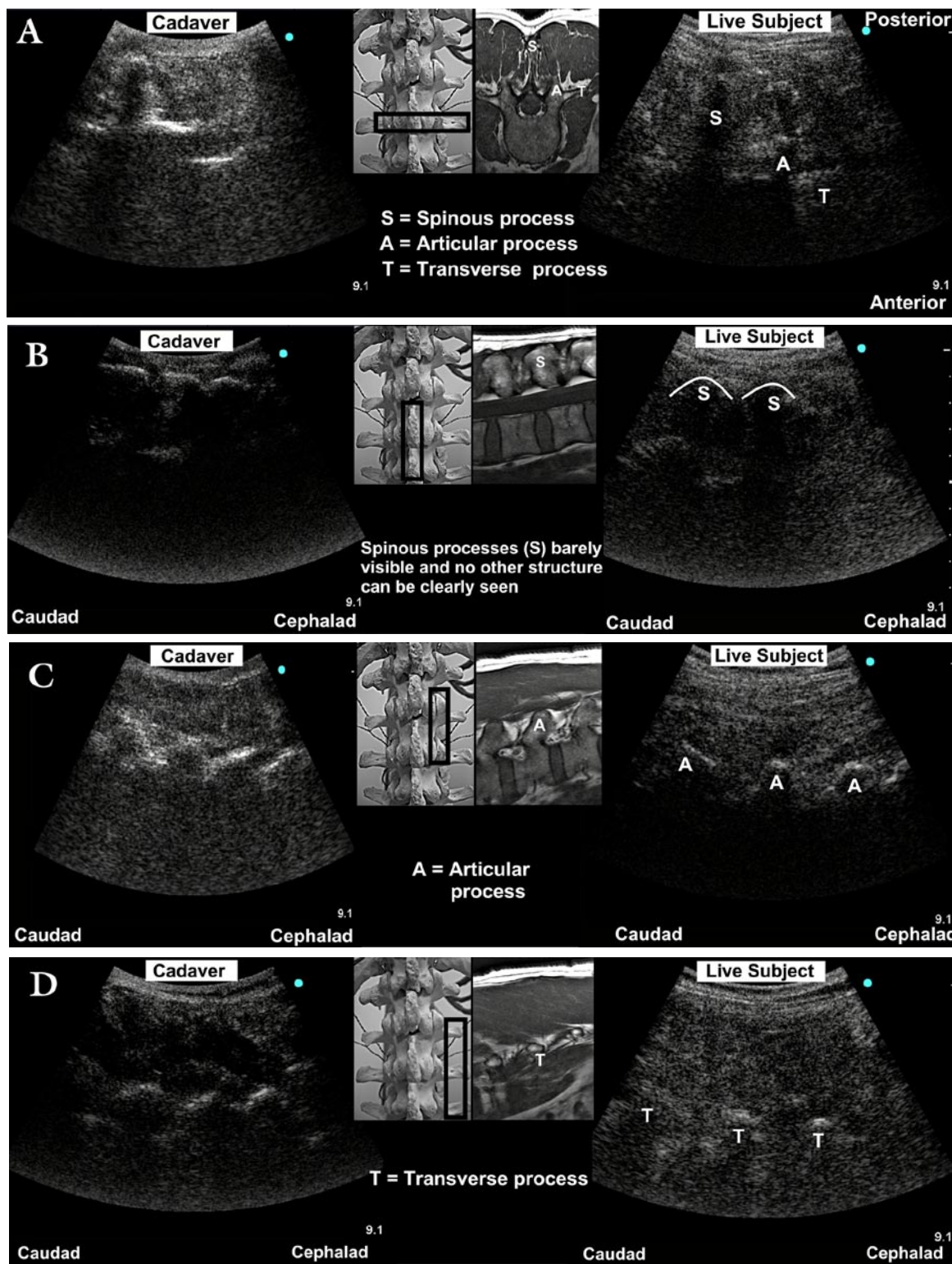


FIGURE 1 Ultrasound imaging at the lumbar spine. Scanning at the midline in the (a) transverse/coronal plane provided an overview, while scanning in a medial-to-lateral direction using the longitudinal/sagittal plane sequentially localized the (b) spinous, (c) articular and (d) transverse processes. The ultrasound scanning window is depicted by the rectangular schematic overlay in the picture of the skeleton model.

Observations

Lumbar plexus (psoas compartment) blocks (generally L3–5)

An US-guided lumbar plexus block is an advanced level deep block and thus best practiced by anesthesiologists experienced with this technique. The most consistently recognized structures of these “US-supported” blocks are the deep bony landmarks; identifying these landmarks will help guide the probe to the appropriate block location and facilitate identification of an optimal needle insertion site. The spinal level can be approximated recognizing that the L4 spinous process is around 1 cm cephalad to the upper border of the iliac crests⁴ (the iliac crests appear lateral to the spine as highly echogenic lines with dorsal shadowing). Alternatively, the transverse process echoes can be counted from the sacrum upward.⁵ Fascicular-appearing muscular landmarks will be useful particularly if the psoas major muscle is adequately viewed with the help of higher resolution systems; the plexus consistently lies at the junction of the posterior third and anterior two-thirds of this muscle (this location is often used as a surrogate marker for the unidentified plexus).^{6,7} In addition to reducing the risks of complications, ultrasonographic visualization of the kidneys and related vessels may allow a more cephalad needle insertion (e.g., L3–4) than that at the more traditional level of L4–5,⁷ which may provide more consistent blockade of the iliohypogastric and ilioinguinal nerves.

An overview of the relevant anatomy can be captured by placing the probe at the midline in a transverse plane (Figure 1a). Imaging quality in the cadaver for this block will partly depend on the age and body composition, but especially on the embalming process and the length of time the specimen has been supine. The vertebral body elements (spinous, articular and transverse processes, and often the lamina) can be appreciated with their hyperechoic borders and dorsal shadowing. Ultimately, the location of the kidneys (inferior edge at L2/3, the right kidney generally being 1 cm lower than the left) and their related vessels should be marked. It should be noted that the kidneys are often best appreciated in real-time scanning on live subjects due to their caudad movement upon inspiration (not shown here). To verify the location of the transverse processes, the main landmarks for this block, the probe can be rotated at the midline to the longitudinal axis and a survey can be performed in the medial-to-lateral direction to identify consecutively the spinous, articular and transverse processes (Figure 1b–d). To differentiate between articular (Figure 1c) and transverse processes (Figure 1d), the operator needs to use a progressive scan and identify the most

lateral nodular-appearing structure. The transverse processes are typically located 3 cm lateral to the tips of the spinous processes;⁵ the initial transverse scan will help identify the relative location of the bony structures. The point at which the transverse processes end is immediately beyond the ideal block location. The depth and lateral displacement of the transverse process tips should then be marked. More relevant in the living subject due to tissue compressibility, consistency in measurements between the pre-procedural scan and actual block will depend on pressure from the probe which can reduce the measured skin-transverse process distance.

If attempting to practice a real-time needle insertion technique during lumbar plexus or paravertebral blocks, in-plane (longitudinal) needle alignment to a longitudinally/sagittally placed probe, or out-of-plane (perpendicular) needle alignment to a transversely/coronally placed probe (but not alternatives such as out-of-plane alignment to a longitudinally placed probe) will likely provide the safest needle insertion. The sagittally-directed needle trajectory will not have as much potential risk for injury as would a medial (spinal column) or lateral (retroperitoneal) angle of insertion.

Paravertebral and intercostal blocks

Ultrasound guidance for these blocks uses an approach similar to that for the lumbar plexus block, but there is some variation in the appearance of structures at the thoracic as compared to lumbar spine (e.g., the erector spinae musculature is much more prominent and visible on longitudinal scanning) (Figure 2). Of note, intercostal nerve blockade is usually amenable to real-time visualization of the needle path and bony structures, especially in the mid-thoracic region where the structures are quite superficial. A drawback of cadaver imaging is the absence of dynamic “lung sliding” with respiration. One feature of imaging at the mid- to high-thoracic region is the ability to obtain higher image resolution from higher-frequency linear array US probes in slim individuals (or likewise in the cadaver, where supine placement often pushes the bulk of the erector spinae musculature laterally). Using this probe selection would be beneficial especially for paravertebral blocks, since the spinous processes are essentially touching each other, and limited delineation occurs. The skin-to-paravertebral space depth is greater at the mid-thoracic as compared to the high and low-thoracic regions.⁸ Moving the probe from the initial transverse, midline placement to the sagittal plane, and surveying in a medial-to-lateral direction will sequentially identify the spinous process, laminae and tips of the trans-

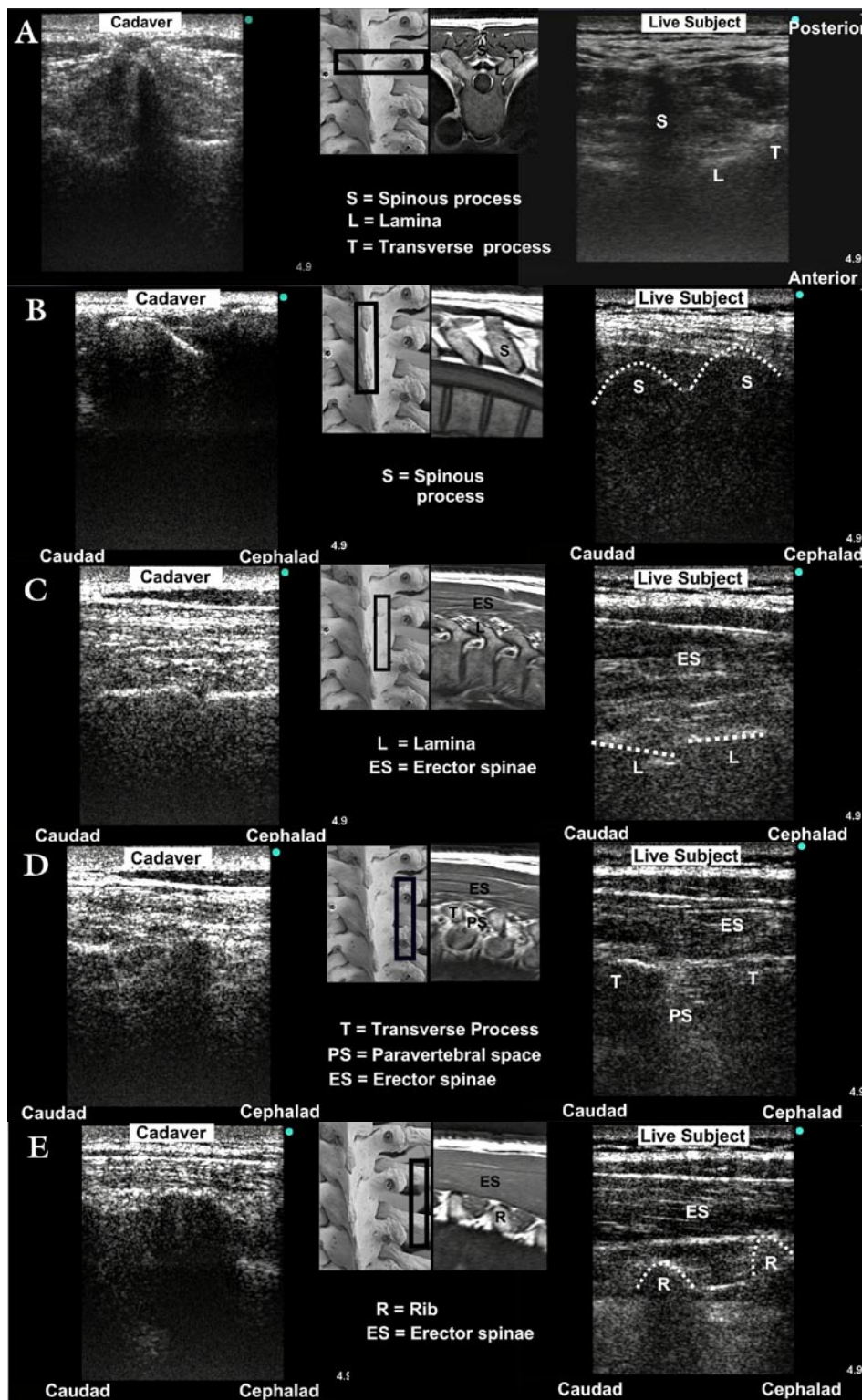


FIGURE 2 Ultrasound imaging at the thoracic spine. Placing the probe (a) transversely at the midline captured the vertebral and costal structures, and scanning longitudinally in a medial-to-lateral direction sequentially captured the (b) spinous processes, (c) the laminae, (d) the transverse processes with the deeper paravertebral space, and (e) the ribs. The erector spinae musculature was well-demarcated in the longitudinal images taken lateral to the spinous processes. The ultrasound scanning window is depicted by the rectangular schematic overlay in the picture of the skeleton model.

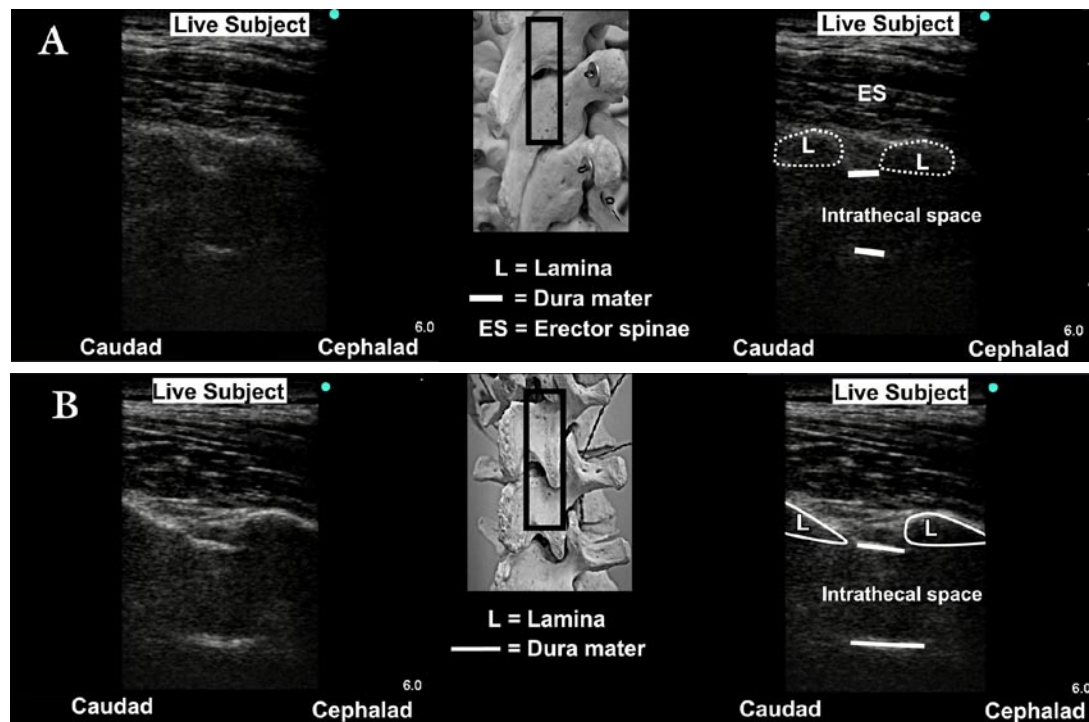


FIGURE 3 Ultrasound imaging in the paramedian longitudinal plane at the (a) thoracic and (b) lumbar spine in order to capture the optimal ultrasound window of the epidural space.

verse processes (Figure 2b–d). The paravertebral space appears deep to the hyperechoic fascicular-appearing erector spinae muscles and immediately beyond the midpoint between two transverse processes (Figure 2d). The ideal location for paravertebral blockade is the point just medial to the costovertebral joint (Figures 1d and 2d), while for the intercostal blocks the scanning will need to continue laterally to the point of the rib neck (Figure 2e). The latter images are similar in appearance to those of the transverse processes with the exception that they are smaller and alternate with the more hyperechoic ligamentous tissue of the costovertebral joints. Of note, while visibility of the lungs and pleura is important to prevent their unintended puncture during intercostal blocks, scanning in cadavers will not allow appreciation of these structures. Additionally, the subcutaneous tissue compression and rigidity of the cadaver requires the application of generous amounts of gel to facilitate beam penetration.

THORACIC AND LUMBAR EPIDURALS

Ultrasound imaging of the neuraxial structures using a portable system is most suitable for young infants and children (i.e., zero to six months is optimal) as a result

of lower bone density, although it can be of some use for adults as well. This is especially true when there is spinal deformity. Particularly at the thoracic spine, penetration of the US beam into the vertebral canal is minimal due to a larger bony covering, leading to excessive bony shadowing and obliteration of much of the epidural space window (i.e., area of visibility).

The most effective probe placement for obtaining a better window into the epidural space is in a paramedian longitudinal plane with the subject's spine flexed.⁹ This technique ultimately improves visibility of the dura mater, particularly in the lumbar region (Figure 3a and b). Obtaining a good paramedian probe placement, and thus view of the epidural space, was difficult in the cadaver and therefore not shown. This is due mainly to paraspinal muscular rigidity limiting flexibility of the spine, and also the highly compressed state of the paravertebral muscles. The degree of muscular rigidity depends largely on the timing of embalment and the subsequent positioning of the cadaver. As an alternative to the longitudinal view, the epidural depth may be estimated more consistently by measuring the well-demarcated laminae (at a similar depth but more laterally) as seen through a transverse view (Figure

2a). The majority of the beam is reflected by the laminae and facet joints (Figures 1a and 2a), and similar to the epidural space depth, these landmarks can be used for estimating the best needle puncture point and insertion angle. The transverse views were similar in both models, although the degree of similarity will likely be age-dependent.

Conclusions

Cadavers may provide a viable training option for practicing US imaging for peripheral blocks at the trunk, and for estimating the epidural space depth. Limitations associated with cadaver studies include muscle rigidity, and limited flexibility of the spine. However, the ability to gain an advanced knowledge of the relevant regional anatomy and sonoanatomy, in addition to learning US-guidance techniques where appropriate, can be very useful in the clinical setting.

The clinical applicability of this indirect (i.e., 'offline' or 'supported') US survey of the trunk should not be underestimated. Accurate determination of optimal needle insertion placement and needle angle may improve needle localization in order to provide more accurate and successful local anesthetic application. Aberrations in spinal and costal anatomy (e.g., scoliosis, vertebral fusion) may be identified¹⁰ and the practitioner can plan for modified techniques. Additionally, since there is a positive correlation between weight, or body mass index, and skin-to-lumbar plexus distance,^{4,5} US guidance has the potential to improve the block success rate in individuals with excess subcutaneous tissue. As technology advances, visibility to the depth of the paravertebral and intervertebral structures may improve to the point where needle alignment can be more consistently directed, dynamically, towards the target nerve structures.

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