A cadaveric study of the erector spinae plane block in a neonatal sample.

Sabashnee Govender[1,2*]; Dwayne Mohr[2]; Adrian Bosenberg[3]; Albert Neels Van Schoor[2].

[1]Department of Anatomy, School of Medicine, Sefako Makgatho Health Sciences University, Ga-Rankuwa, South Africa.

[2]Department of Anatomy, Section of Clinical Anatomy, School of Medicine, Faculty of Health Sciences, University of Pretoria, Gauteng, South Africa.

[3]Department Anaesthesiology and Pain Management, University Washington and Seattle Children's Hospital, Seattle, Washington, United States of America.

*Correspondence: Ms Sabashnee Govender, Department of Anatomy, School of Medicine, Sefako Makgatho Health Sciences University, PO Box 232, Ga-Rankuwa 024, South Africa. Email: Sabashnee.govender@smu.ac.za. Contact: +27125214502.

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Abbreviations:

1. ESP – erector spinae plane

Key words: cranio-caudal, dermatomes, erector spinae plane block, nerve block, ultrasound-guided.

Abstract

Background: The aim of this article was to provide a detailed description of the anatomy related to the erector spinae plane block. As well as to track the spread of the dye within the fascial plane to report on the dermatomal coverage.

Methods: Using ultrasound guidance, the bony landmarks and anatomy of the erector spinae fascial plane space was identified. The erector spinae plane block was then replicated unilaterally in two fresh unembalmed neonatal cadavers. Using methylene blue dye, the block was performed at vertebral levels T5 – using 0.5ml in cadaver 1 – and T8 – using 0.2ml in cadaver 2. The cranio-caudal spread of dye was tracked within the space on the ultrasound screen and further confirmed upon dissection.

Results: Cranio-caudal spread was noted from vertebral levels T3 to T6 when the dye was introduced at vertebral level T5 and from vertebral levels T7 to T11 when the dye was introduced at vertebral level T8. Furthermore, the methylene blue spread was found anteriorly in the paravertebral and epidural spaces, staining both the dorsal and ventral rami of the spinal nerves T2 to T12. Small amounts of dye were also found in the intercostal spaces.

Conclusion: The erector spinae plane block is a novel technique that rivals both the paravertebral and epidural blocks. The anatomy of this novel technique – although slightly different to the paravertebral block – allows for the block to be performed safer and easier as it is performed at a further distance from the neuraxial structures.

Key words: cranio-caudal, dermatomes, erector spinae plane block, nerve block, ultrasound-guided.

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Introduction

Forero and colleagues, recently described the erector spinae plane (ESP) block, as a novel ultrasound-guided interfascial technique to successfully treat thoracic neuropathic pain,[1,2]. Due to the mechanism of action, this interfascial block has further been described to successfully manage acute and chronic pain for truncal procedures,[3,4]. This 'happily accidental' block has been compared to other neuraxial techniques such as the epidural and paravertebral block, and may prove as a safer alternative,[4]. Although the ESP block has been confirmed successful for the adult population, there are only forty two documented cases (as of December 2019) reporting on the success rates in a paediatric population,[5–13,23]. In addition, there have been numerous anatomical studies including computed tomography, magnetic resonance imaging and fluoroscopic guidance describing the efficacy of the ESP block in an adult population, but none in a paediatric population,[14-16]. Even with the increasing number of indications for the ESP block, the anatomy, mechanism of action, concentration and volume of anaesthetic is yet to be determined,[3,5].

It is hypothesized that this interfascial block targets the ventral and dorsal rami of the spinal nerves as the anaesthetic is injected within the fascial plane anterior to the erector spinae muscle, as well as superficial and lateral to the transverse processes. The therapeutic effect of an ESP block is attributed to the cranial-caudal spread of anaesthetic over multiple vertebral levels. It is hypothesised that the anaesthetic spread between vertebral levels T4 to T6 and T7 to T11 provides effective analgesia for thoracic and abdominal surgical procedures, respectively,[16].

Objectives

The aim of this study was to provide a detailed description of the anatomy related to the ESP block. The macro-anatomy seen on a fresh neonatal cadaver is supported by the ultrasound anatomy of the area of interest. The extent of the spread of a fluid – in this case, methylene blue dye – was also determined by injecting the dye into the erector spinae fascial plane under ultrasound guidance. The route and spread of the dye within the fascial plane, as well as the dermatomal coverage, was further confirmed upon dissection of the area.

Anatomy

The ESP block is performed deep to the erector spinae muscle, which consists of three vertical muscle bands – the spinalis, longissimus and iliocostalis. These muscles lie posterolateral to the vertebral column between the spinous processes medially, and the angle of the ribs, laterally. Located between adjacent transverse processes is an intertransverse connective tissue complex, which consists of a series of ligamentous structures and small muscles. It is formed by two ligaments – the superior costotransverse and intertransverse ligaments – together with the levator costarum, rotator costarum and external and internal intercostal muscles.

Depending on the level at which the block is performed, various musculoskeletal and neurovascular structures can be found overlying the posterior aspect of the erector spinae muscle. Structures from superficial to deep between vertebral levels T2 to T6 include; the trapezius, rhomboids, serratus posterior, erector spinae, external and internal intercostal muscles, intercostal neurovascular bundle and the parietal pleura of the lungs,[17]. Structures from superficial to deep from vertebral level T7 downwards include the same structures previously mentioned levels, except for the rhomboid muscles. The rhomboid muscles terminate at the inferior border of the scapula,[17].

The erector spinae fascial plane space, which is sandwiched superiorly and inferiorly between the heads and necks of the adjacent ribs, is bordered anteriorly by the transverse process of the relevant vertebrae and the superior costotransverse ligament. Posteriorly by the deep fascia of the erector spinae muscle, medially by the lamina and spinous process of the relevant vertebrae and laterally by the distal part of the costotransverse ligament and the rib (Figure 1).

Ultrasound anatomy

Depending on the orientation of the transducer – transverse or parasagittal – over the mid thoracic area, the on-screen anatomy may differ. If the transducer is positioned transverse (perpendicular to the vertebral column), the anatomical structures will appear as follows; the transverse process of the vertebra can be identified as an obliquely elongated, oval, hypoechoic structure. Following the transverse process medially, the spinous process can be identified as a triangular, hypoechoic structure connected to the transverse process by the hypoechoic arch-shaped lamina. Immediately superior to the transverse process and lateral to the spinous process, the erector spinae muscle appears as hyperechoic bands in direct contact with the bony structures. Filling the arch-shaped space lateral to the spinous process, covering part of the transverse process, is the spinalis muscle. Lateral to that, superior to the remainder of the transverse process, is the longissimus thoracis muscle. Superior to the longissimus thoracis muscles is another band-like muscular structure, the rhomboid major muscle. Superior to the rhomboid major muscle, extending from the tip of the spinous process laterally over the muscle is another band-like muscular structure, the trapezius muscle (Figure 2).

If the transducer is positioned parasagittal (parallel to the vertebral column), the anatomical structures will appear as follows: the transverse processes of the adjacent vertebra can be identified as rhomboid-shaped hypoechoic structures in a vertical line. Immediately inferior to each transverse process, the corresponding rib can be observed as an oval hypoechoic structure (Figure 3). Running from the superior border of the transverse process to the superior border of the adjacent transverse process is the intertransverse ligament, which can be identified as a hyperechoic line. Filling the spaces between the transverse processes of the adjacent vertebrae is a hyperechoic mass that is formed by a collection of structures. Running from the superior border of the transverse process to the inferior border of the adjacent rib in a cranial to caudal direction is the superior costotransverse ligament (Figure 3). This obliquely arranged ligament divides this space into a superior and inferior triangle.

The superior triangle is bordered laterally by the intertransverse ligament, medially by the superior costotransverse ligament and caudally by the transverse process of the adjacent transverse process. The superior triangular space is occupied by a group of muscles, namely the levator costarum, rotator costarum, and the external and internal intercostal muscles.

The inferior triangle is bordered laterally by the superior costotransverse ligament, cranially by the transverse process and its corresponding rib and medially by the pleura. This triangular space is known as the paravertebral space. Superior to the intertransverse ligaments are three hypoechoic muscular bands, the erector spinae, rhomboid major and trapezius muscles (Figure 3). These three distinct bands are equal in size and can be traced cranially and caudally. Superficial to these muscles is a layer of fat, which appears hyperechoic on the ultrasound screen.

Materials and methods

This study was approved by the PhD and Research Ethics Committee, University of Pretoria, South Africa. Two fresh unembalmed neonatal cadavers subject to cryopreservation were obtained through the National Tissue Bank from the University of Pretoria. We performed a unilateral ESP block at the T5 vertebral level in cadaver 1 and at the T8 vertebral level in cadaver 2. Both cadavers were preterm still born. The demographic information for the cadavers was as follows; cadaver 1 weighed 1.6kg with a height of 370mm, cadaver 2 weighed 0.6kg with a height of 350mm. An EdgeTM Ultrasound machine (ref: P15000-11, SN-03P55Z) with a 6 - 13MHz linear array probe (footprint size of 2.5cm) covered with a protective plastic sheath was used in both procedures. The methylene blue mixture consisted of 10ml of iodinated contrast material, diluted in 85ml of 0.9% sodium chloride.

Cadavers were placed in the prone position to identify the bony landmarks – the spinous process and its corresponding transverse process. The spinous process of C7 was palpated and marked. With the aid of ultrasound guidance, the spinous process of T5 and T8 was identified by counting inferiorly from the spinous process of C7. Subsequently, an ultrasound scan was performed, with the orientation of the transducer in both a transverse and parasagittal alignment to identify anatomical structures (Figure 4).

For the procedure, the transducer was placed parasagittal, over the transverse process of T5 and T8 – about 1cm lateral to the spinous process. A 21mm needle was then directed using the in-plane approach in a cephalad to caudal direction towards the transverse process (Figure 4). Once the tip of the needle contacted the transverse process, 0.05ml of saline solution was injected to confirm the position of the needle tip. The erector spinae fascial plane space was further confirmed as the erector spinae muscle bundle was hydro dissected away from the transverse process. Methylene blue dye (0.5ml for the first cadaver and 0.2ml for the second cadaver) was then injected while observing the spread of the dye within the plane between the erector spinae muscle group and the transverse processes. Thirty minutes following the dye injection, dissections were done.

A vertical skin incision was made along the midline over the spinous processes of C7 to L1, followed by horizontal incisions from the spinous process of T1 towards the acromion of the scapula. Horizontal incisions were also made at vertebral level T10 laterally towards the midaxillary line. The skin was then reflected laterally, to expose the posterior aspect of the scapular, thoracic and lumbar regions. The surface staining of the methylene blue dye on the muscular structures was noted before further dissection.

The trapezius, rhomboids and latissimus dorsi (superficial muscles of the back) muscles were individually identified and reflected laterally to reveal the serratus posterior – which was removed – and the erector spinae muscle (Figure 5).

Again, surface staining of the muscles was noted before further dissection. Each band of the erector spinae (including the multifidus and rotatores) was cut and reflected from its insertion sites to reveal the bony structures deep to it. The lamina, transverse process, as well as the head, neck and tubercle of the corresponding rib, were cleaned to further view the spread of dye. The bony structures were then cut and removed to expose the ventral and dorsal rami of the spinal nerves within the intercostal space to determine if they were stained by the dye. The cranio-caudal and lateral spread across vertebral levels were noted and counted in both procedures. The spread was described in relation from the 1st to 12th thoracic vertebra.

Results

Surface landmarks were easy to identify. Extensive dye spread was seen in a cranio-caudal direction, both superficial and deep to the erector spinae fascial plane (Figure 6A). In the first cadaver, the dye was injected unilaterally (left side) at vertebral level T5 to determine the spread in the thoracic region. Based on surface staining, the dye spread from vertebral levels T2 to T12. Superficially, the trapezius, rhomboids, latissimus dorsi and erector spinae muscles were stained by the methylene blue dye. Deeper, the dye was located over the posterior aspect of the transverse process, near the costotransverse ligament (foramen) (Figure 6B). The ventral and dorsal roots/ganglion staining spread from T3 to T6 (Figure 6C & D). In the second cadaver, the dye was again injected unilaterally (left side) at vertebral level T8 to determine the spread coverage for the abdominal region. Based on surface staining, the dye spread from vertebral levels T7 to L1. Superficially, the trapezius, latissimus dorsi and erector spinae muscles were stained by the methylene blue dye. Deeper, the ventral and dorsal roots/ganglion staining spread from T7 to T11 T6 (Figure 6C & D). In both cases, methylene blue dye was seen in the paravertebral and epidural spaces. Epidural spread was confirmed with the staining of the dura mater surrounding the spinal cord before it was cut and removed to expose the ventral and dorsal rami.

Discussion

The ESP block is a novel technique that can be used as an alternative block for truncal procedures. This study aimed to investigate the spread of the dye and subsequent dermatomal coverage by replicating the procedure in two fresh unembalmed neonatal cadavers. Results from this study revealed that injecting 0.2ml&0.5ml of dye into the erector spinae fascial plane space at vertebral level T5 and T8 will provide 4-5 levels for the thoracic and abdominal regions respectively. Although the exact dose for paediatric patients of different age group have not been established, the volumes in this this study were determined by using the formula of 0.1ml/kg per dermatome. Additionally, as the block was performed the anaesthesiologist used his discretion to increase the volume depending on the spread as seen on the ultrasound screen.

Since dye was injected in close proximity to the costotransverse foramen, we found that the dye penetrates anteriorly through the intertransverse connective tissue, into the paravertebral, epidural and intercostal spaces to stain the ventral and dorsal rami of the spinal nerves,[15].

Hamilton and colleagues stated that the erector sheath is the reason for the success of the ESP block,[18]. They suggested that the individual muscles of the erector spinae together with their associated sheath exhibit a complex three-dimensional cylindrical anatomical structure which separates its contents from other muscular compartments in the region. The sheath is intermittently tethered anteromedially to the bony structures – the spinous and transverse process – along its course, resulting in multiple varied apertures or perforations,[18]. Supporting both Hamilton and Manikam, we believe that the erector sheath and the thoracolumbar fascia combine to form a continuous tissue plane over multiple vertebral levels, allowing for the cranio-caudal spread of dye. Furthermore, the anterior perforations within the sheath explain the mechanism of anterior spread into the paravertebral, epidural and intercostal spaces as seen in this study. We hypothesize that the anterior perforations may be attributed to the porous tissue found around the superior costotransverse ligament. Additionally, the spread could have been further facilitated through the costotransverse foramen which acts as a bony gap. Results from this study are similar to that of other authors who suggest that the success of this block is due to the diffusion of anaesthetic through soft tissue gaps,[3,19]. Upon dissection, slight staining was also noted in the overlying muscular structures – the trapezius and rhomboid muscles – posterior to the erector spinae muscle at vertebral level T5. Barks and Briggs, concluded in their study, that a layer of the thoracolumbar fascia fuses with the muscular fascia of the trapezius and rhomboid muscles, which may account for the posterior staining seen in this study,[20].

To date, this block has been used for open thoracic surgery,[21], thoracic lipoma and tumours,[22], Pectus excavatum,[23], nephrectomy,[24], inguinal hernia,[25,26], laparoscopic cholecystectomy,[27] and hip dysplasia,[5] (in a child). Although this block proved successful, there are technical difficulties in the application of this block due to the thinner muscle layers, sliding fascial planes and loose connective tissues in children,[24,28]. As a result, a finer needle – 27 gauge – is required to position the needle tip within these thin layers. Furthermore, the “in-plane” approach is preferred to maintain a constant view of the needle during the procedure.

Although the ESP block has been performed in a number of adult cases it is still under trial and error. Ivanusic and co-workers, reported on the lack of spread to the ventral rami in the adult population,[1]. However, in a magnetic resonance imaging and anatomical study, Adhikary and others, not only reported a ventral and dorsal rami spread but also an epidural and intercostal space spread in adults,[3]. Takata and colleagues reported that although the ESP block provided tolerable anaesthesia for thoracoscopic lobectomy, it also provided weak dermatomal spread towards the anterior cutaneous region[3]. Several authors, including Chin co-workers, confirmed analgesic spread for the thoracic and abdominal regions when performing the block at vertebral levels T4/T5 and T7/T8 respectively,[17,19].

Due to contradicting results from various cadaveric studies,[15-17], the question of anatomical differences between age groups arises. Apart from the demographics such as weight, height and body shape, anatomical differences in the anatomy between the paediatric population (neonates, infants, children) and the adult population do exist. Factors such as the developmental formation of the vertebral curvature may attribute to the differences in paravertebral tissue and muscle thickness seen between the age groups affecting the depth at which the ESP block is performed. Incomplete myelination of nerve fibres in a paediatric group contributes to the lower concentration and volume of anaesthetic required to perform the block,[29]. Furthermore, given the more elastic paediatric spine[30], together with the less dense ligaments and cartilaginous laminae this could allow for the favourable spread as seen in a paediatric sample,[31]. Additional factors such as less fat and a thinner dermis layer also contribute to the efficiency of this block.

Although there are disparities between age groups, the major anatomical borders to performing this block remain consistent in both paediatrics and adults. We believe that the clinical effects, mechanism of action and route of spread is similar for both these age groups.

Limitations

A major limitation of this study was the difficulty in obtaining neonatal cadavers – a sample size of two – due it's sensitive nature. As well as the use of cadaveric material to replicate the spread in a living model. This may be an inaccurate representation due to in vivo factors such as a lack of intrathoracic pressure changes, muscle tone or tissue tension, which may limit the spread of dye,[1,4]. Other limitations include; the gravitational effect on the spread of dye as well as variability in the volume and mixture of dye used,[32].

Conclusion

This study aimed to replicate the spread of the ESP block, a novel technique that can be used as an alternative to paravertebral and epidural blocks. The ESP block gains indirect access to the paravertebral, epidural and intercostal spaces, providing an extensive spread over multiple dermatomal levels while targeting the ventral and dorsal rami in both the thoracic and abdominal regions. The risk of complication is reduced as the needle is inserted into a tissue plane distant from neuraxial structures making it safer and easier to perform. In this study, the methylene blue spread was found anteriorly in the paravertebral and epidural spaces as well as laterally in the intercostal spaces staining both the dorsal and ventral rami of the spinal nerves T2 to T12.

Author contributions

S Govender: The conception and design of the study, acquisition of data, analysis and interpretation of data, drafting the article, revising it critically for important intellectual content, final approval of the version to be submitted; D Mohr: Acquisition of data and revising it critically for important intellectual content; A Bosenberg: Revising it critically for important intellectual content; AN Van Schoor: The conception and design of the study, revising it critically for important intellectual content and final approval of the version to be submitted.

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Competing interests

None declared.

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Figure legends:

Figure 1: Anatomical structures that form the boundaries of the erector spinae fascial plane space.

Figure 2: The ultrasound anatomy as seen on the ultrasound screen of a transverse section scan taken at vertebral level T5. Key: green – spinalis muscles, pink – longissimus muscle, blue – iliocostalis muscle, orange – rhomboid muscle, yellow – trapezius muscle, white arrow – transverse process of T5, red arrows – rib.

Figure 3: The ultrasound anatomy as seen on the ultrasound screen of a parasagittal section scan taken at vertebral level T5. The muscular complex consists of the levator costarum, rotator costarum and external intercostal muscles. Key: green arrow on the ultrasound scan – the transverse process of T5, green arrow on the diagram – needle insertion, white arrows – superior costotransverse ligament, orange circle – trapezius muscle, pink circle – rhomboids muscle, blue circle – erector spinae muscle, ESPFS – erector spinae fascial plane space, PVS – paravertebral space.

Figure 4: Ultrasound image of the bony landmarks in a transverse (figure A) and parasagittal orientation (figure B) taken at vertebral level T5. The white arrows represent the actual course of the needle insertion in a parasagittal orientation, whereas, the green arrow represents the hypothetical course of the needle in a transverse orientation .

Figure 5: Photographic image displaying the trapezius muscle (reflected superolateral), rhomboid muscles and the three vertical muscular band of the erector spinae muscle during the dissection process.

Figure 6: A – photographic image showing the superficial staining of the erector spinae muscle as well as the spread of dye deep to it. B – photographic image displaying the cleaned lamina, transverse process and parts of the ribs. C – photographic image revealing the staining of the rami of spinal nerves. D – photographic image showing the dye staining of the intercostal nerves as the dye partially spread into the intercostal spaces.