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Erector Spinae Plane Block Versus Caudal Epidural Block in Pediatric Patients Undergoing Lower Limb Cancer Surgery

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ABSTRACT

Caudal epidural block and Erector Spinae Plane Block (ESPB) are two regional anesthesia methods increasingly utilized in pediatric surgical patients. The caudal block is a well-established method involving the injection of local anesthetics into the epidural space via the sacral hiatus. Traditionally performed as a blind technique based on anatomical landmarks, it now benefits from image-guided methods like ultrasound, enhancing accuracy and safety. ESPB, a newer inter-fascial block introduced by Forero in 2016, involves depositing anesthetic between the erector spinae muscles and the transverse process. It enables cranio-caudal, lateral, and anterior spread of anesthetic across multiple vertebral levels, influencing various dermatomes depending on the site of injection. Anatomical differences between children and adults, including less developed bony structures and increased tissue compliance, influence the distribution of anesthetic in both techniques. While caudal blocks may encounter difficulty due to sacral anatomical variation, ESPB can be technically advantageous in children due to their thinner muscle layers and closer proximity of target structures to the skin. Both techniques require careful ultrasound guidance for optimal needle placement, particularly in complex or variable anatomy. This study focuses on comparing the anatomical and procedural characteristics of lumbar ESPB and caudal epidural blocks in pediatric lower limb oncologic surgeries, offering insight into their utility, feasibility, and anatomical considerations in this vulnerable population.

Keywords: *Caudal block, Erector spinae plane block, Pediatric anesthesia, Ultrasound-guided techniques*

1. INTRODUCTION

Caudal epidural blockade in kids is among the most frequently utilized methods of regional anesthesia. Caudal blocks provide effective analgesia prior to the operation for painful sub-umbilical interventions. carried out on sedated kids, they enable not only early ambulation, but additionally peri-procedural hemodynamic stability and spontaneous breathing in patient groups at maximum risk of a difficult airway. These represent significant benefits compared to general anesthesia, particularly in preterm babies and kids with cardiopulmonary comorbidities (1).

The Erector Spinae Plane (ESP) block is an innovative method utilized in several surgical procedures, yielding promising outcomes. In the future, the ESP block may serve as an alternate method to epidural blocks for providing efficient analgesia. The ESP block is an inter-fascial blockade initially identified by Forero in 2016. The procedure involves the administration of a local anesthetic into a fascial plane situated between the erector spinae muscles and the apex of the transverse vertebral process. The anesthetic disseminates along the fascial plane in both cranial and caudal directions, additionally diffusing anteriorly and laterally at many levels. It provides analgesia in a wide range of various clinical situations (2).

ESP provides analgesia including the dorsal and ventral rami of spinal nerves. There are few case reports in the literature about the application of the ESP block for lower limb surgery, indicating its promising potential for future usage. The addition of lumbar ESP block to multimodal analgesia yielded effective analgesia the operation following femur fracture surgery. ESP blocks can be a feasible regional anesthesia technique in the pediatric age group for analgesia in lower extremity surgery when carried out at the lumbar vertebral levels. Controlled clinical trials should be conducted to evaluate its superiority over alternative regional anesthetic procedures (3).

Malignant bone tumors constitute approximately three percent of cancers in kids and adolescents. Osteosarcoma (OS) and the Ewing sarcoma family of tumors (ESFT) are the most malignant bone tumors, collectively accounting for the majority of such neoplasms. The remaining malignant tumors comprise chondrosarcomas, malignant fibrous histiocytomas, and adamantinomas. The identification of a malignant bone tumor may be delayed for weeks or months, as several adolescents and young adults commonly attribute pain to non-specific trauma or acute sports injuries (4).

Osteosarcoma exhibits a bimodal age distribution, with a 1st peak in adolescence and a subsequent peak in later adulthood. The 1st peak occurs among the ten to fourteen age group, aligning with the pubertal growth spurt. The 2nd peak of osteosarcoma occurs in those who are over sixty-five old; it is more probable to represent a second malignancy or may be associated with Paget's disease. Osteosarcoma frequently happens in the long bones of the extremities next to the metaphyseal growth plates. The predominant locations include the femur (42%, with 75% of tumors in the distal femur), the tibia (19%, with 80% of tumors in the proximal tibia), and the humerus (10%, with 90% of cancers in the proximal humerus). Other probable sites are the skull or jaw (eight percent) and the pelvic (eight percent). Soft-tissue sarcomas (STS) are a diverse group of mesenchymal extraskeletal cancers. During infancy and adolescence, soft tissue sarcomas account for around eight percent of all neoplasms, with fifty to sixty percent classified as rhabdomyosarcomas (RMS), while the balance comprises the diverse category of non-rhabdomyosarcoma soft-tissue sarcomas (NRSTS). Soft tissue sarcomas may develop in nearly any region of the body, typically presenting as a progressively enlarging soft-tissue tumor, occasionally accompanied by pain, impairments in function, and other distinct symptoms related to the affected anatomical site. STS occasionally manifests in the extremities, with the limbs being the predominant location for NRSTS. Rhabdomyosarcoma is the predominant soft tissue sarcoma in kids (5).

The sites of primary tumor of NRSTS were lower limb (thirty-five percent), trunk (eighteen percent), upper limb (sixteen percent), head and neck (sixteen percent), and retroperitoneum (eleven percent). The surgical management of these cancers is primarily categorized into two types: amputation or limb-sparing (conservative) surgeries. The choice between these surgical options is influenced by a variety of critical factors including the type, size, and location of the tumor, its proximity to vital structures, and the overall health and preferences of the patient(6).

Amputation is a procedure used when the cancer has extensively involved the limb (making it impossible to remove the tumor without significantly affecting the limb's function), if the tumor surrounds crucial nerves or blood vessels, if previous limb-sparing surgeries have failed, or if severe infections are present. In some cases, patients may choose amputation to avoid the prolonged treatment course and possible complications associated with limb-sparing surgeries. This type of surgery ranges from partial foot amputation to removing the entire leg up to hip disarticulation. (7)

On the other hand, limb-sparing (salvage) surgery, which aims to preserve both the limb and its functionality, is preferred when the tumor can be removed with clear margins of healthy tissue in early-stage cancers & is particularly considered for younger patients where maintaining functionality and life quality is crucial. This may involve the removal and replacement of affected bone and soft tissues with a graft or an endo-prosthesis. Additionally, reconstructive procedures include muscle flaps, skin grafts, nerve or vascular reconstructions to enhance the functional and aesthetic outcomes (7).

2. ANATOMY

Anatomic considerations in ESPB

1. A set of longitudinally arranged muscles known as the erector spinae originates from; ribs, transverse processes of thoracic and lumbar spines to be inserted into the sacrum and ilium. The elements that make it up from medial to lateral; the spinalis thoracis, the longissimus (capitis, cervicis & thoracis) and the iliocostalis lumborum (Figure 1)(8).

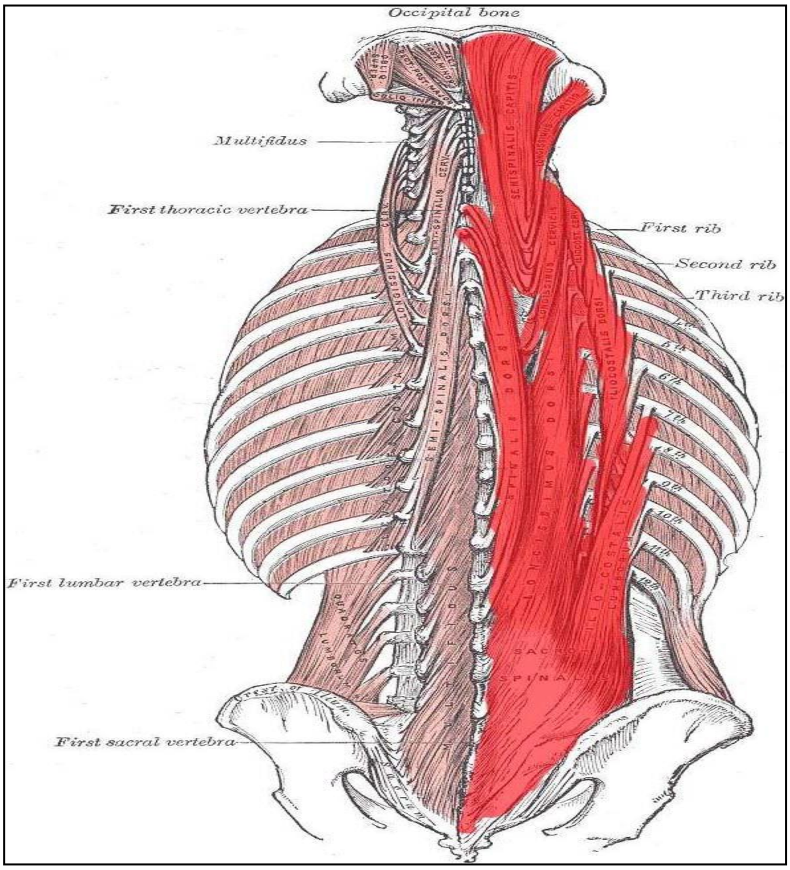

Figure 1: Red indicated structures represent the three erector spinae muscle columns; Medial to lateral: Spinalis, longissimus and iliocostalis (8).

Anatomical difference between adult and pediatric ESPB:

The smaller distance between the skin and the transverse process in pediatric cases necessitates fine needle skills and a stable patient position (under GA) to perform the block. (9).

The presence of; cartilaginous instead of bony laminae, less spinal curvature development, more spine's elasticity & less ligamentous density in pediatric population affects distribution pattern of local anesthetics with more advantageous spread in newborns and smaller children than in adults(9).

Anatomic considerations in caudal epidural block:

The unique developmental fusion that each child's sacral vertebrae and ligaments go through throughout infancy provides a wide range of sacral anatomical variations. It could be challenging to palpate structures for identification if the cornua is very thick, and it might be much more challenging to reach the epidural space in older children if the sacro-coccygeal membrane is impenetrable due to advanced ossification(10).

Lower Extremity Innervation;

The dermatomes:

L1: higher anteromedial thigh and pelvic area (front).
L2: higher anterolateral thigh.
L3: lower anteromedial aspect of the thigh and knee.
L4: medial ankle and anteromedial leg.
L5: anterolateral leg, medial foot, and the dorsum of first three toes.
S1: lateral foot, sole of the foot and the third to fifth toe.
S2: the back of the leg and thigh.
S3 & 4: gluteal & perineal regions.

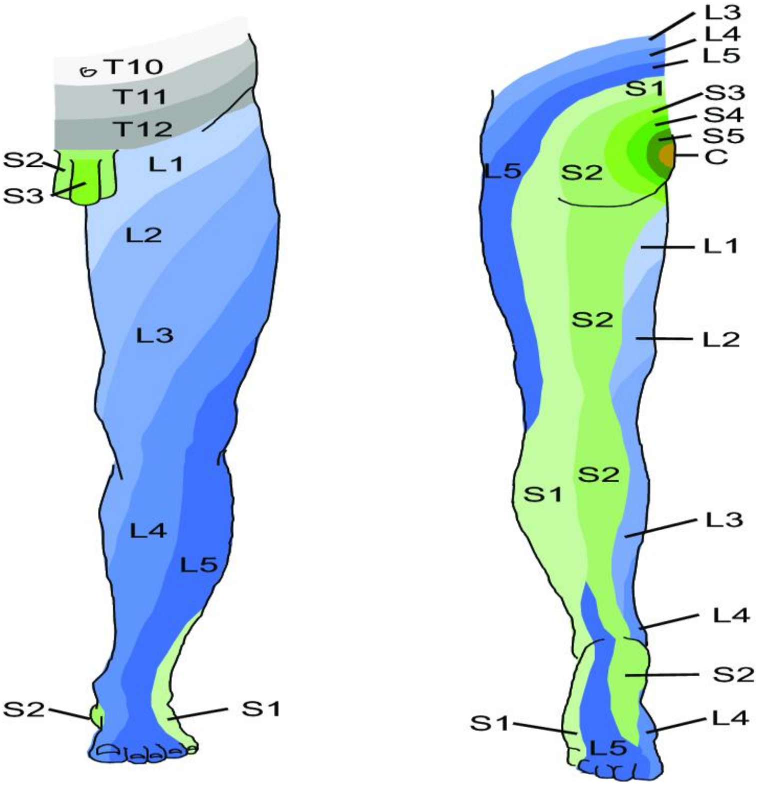

Figure 2: The dermatomes of the lower extremities; A, anterior view. B, posterior view (11)

Role of Ultrasound-Guided Regional Anesthesia

Perioperative peripheral nerve block (PNB) guided by ultrasonography was first investigated in the mid-1990s by anesthesiologists at the Vienna University. Ultrasound had already been used by radiologists to guide biopsy needles, but using it to detect PNB was a new development at that time. Several localized anesthetic procedures benefited from the use of ultrasonography such as femoral and brachial plexus blocks. Coworkers at Canada's University of Toronto started using this innovation a decade later, proving its worth and providing a detailed sono-anatomy of the brachial plexus. Anesthesiologists have come to rely increasingly on ultrasonography at the bedside due to a conglomeration of technological developments, including as more compact and portable ultrasound equipment, higher resolution imaging, and needle identification software (12)

Advantages of ultrasound guidance

Trans arterial approach, palpation of landmark, fascial "clicks," paresthesia technique, and nerve stimulation were some of the surface anatomy-based methods that were previously employed, but they couldn't track where the local anesthetic injected was going. With ultrasound, the target area's anatomy may be seen clearly. Avoiding potentially harmful structures along the needle's route to the target is made easier. Again, ultrasound may see the needle's tip as it penetrates the tissues, ensuring proper guidance and minimizing the risk of harming unnecessary areas. Above all else, real-time ultrasound imaging allows to ensure the administration of LA solutions is monitored continuously, so adjusting the needle tip location to enhance local anesthetic dispersion (13)

Ultrasound and Sonoanatomy

Sonoanatomy pattern recognition and technological expertise are prerequisites for comprehending and identifying three-dimensional anatomical features in two-dimensional images (

Using ultrasound in clinical settings for the best possible nerve and needle imaging

Nerve imaging may be carried out in either short-axis (probe face perpendicular to nerve axis) or long-axis (probe face parallel to axis of nerve) position (13)

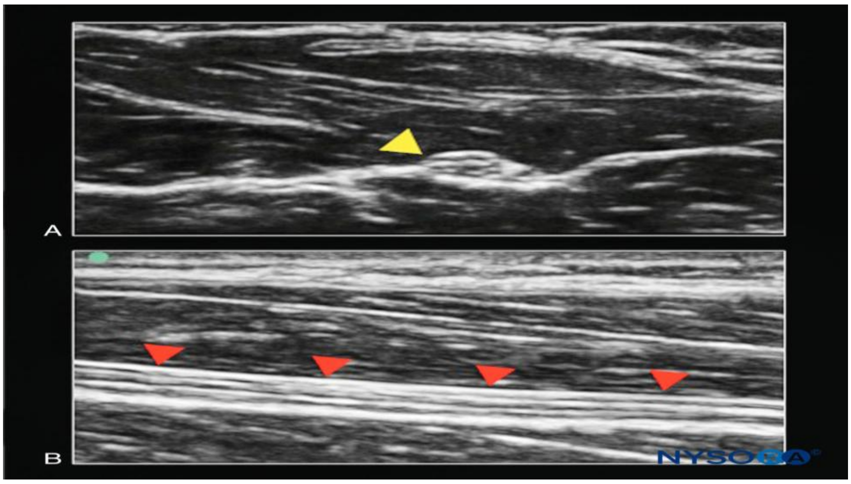

Figure 3: The median nerve. A: Cross-section (out of plane to ultrasound beam; yellow arrowhead). B: Longitudinal section (in plane to ultrasound beam; red arrowheads) (14)

Particularly for those just starting out, short-axis imaging makes it much simpler to see the spherical, usually hyperechoic, neural component. This orientation causes the transducer to be positioned transversely, most nerve blocks are done in the limbs, hence this is the most common approach (14)After the nerve and its surroundings have been located, figure out whether scanning it in plane or out of plane. Optimal method may vary with regard to anatomical or technical considerations, but there is no clear victor when it comes to block success or patient safety. It may be difficult to keep the needle perfectly aligned with the transducer's viewing plan. For example, with in-plane imaging, you can see the whole needle & not just its tip. Because out-of-plane imaging can only show the needle's cross section (a tiny hyperechoic dot from its very beginning to its very end), distinguishing it from the shaft becomes very challenging (14)

While ultrasonography can clearly differentiate between various tissues, when examined in short axis, a nerve and a tendon could seem quite similar. But with anatomical expertise, the operator may trace the caudad-cephalad path of the structure to identify it. Tendons, after some time, will either insert into bones or vanish into the original muscle. The median nerve is difficult to perceive at the wrist because of the presence of the several tendons that comprise the carpal tunnel; however, it is much more apparent in the mid forearm because it lies between two muscle layers and is not surrounded by tendons (14)

Various techniques are available for ensuring the needle's shaft and tip remain always in view. The more parallel the needle is to the face of the probe, the more echoes are transmitted back to the transducer, leading to a better image. This can be achieved through gently indenting the skin at the needle insertion site or by relocating the insertion point further from the probe, so creating a less acute angle of insertion. The limitation of this method is that a larger needle may be necessary, resulting in the traversal of more tissue on way to the target (14).

When you push down on the transducer's edge that's opposite the side where the needle is inserted, it another technique termed heeling that brings the probe face into closer parallelism with the needle. The needle might also be physically changed to make it more echogenic; commercially produced "echogenic needles" often contain crosshatches into the shaft to make the ultrasound beam scatter more (15)

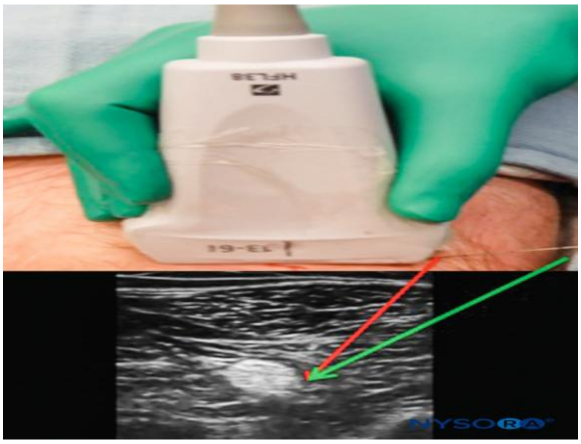

Figure 4: If you place the needle just next to the ultrasound probe, you could have trouble seeing. Although the needle must go through more tissue, it can be better seen (green arrow) and the echo response is greater when inserted at a distance from the probe, which allows for a more superficial method (14)

Safe Needle Guidance with Ultrasound

It is common to find fascial planes that resist needle advancement. As the point presses on these thick layers of connective tissue, they seem to "tent" before abruptly releasing and returning to their previous position. Two possible outcomes may result from this sudden shift: To start with, the needle might move out of plane or advance too rapidly, both of which would be unexpected and frustrating for the operator. Stop moving the needle forward at this point until the in-plane picture is optimized again. Such fascial planes often occur at or near nerve targets. Unanticipated abrupt bending of the fascial plane can cause the needle to surge forward and encroach against the nerve during this action. This is why, instead than aiming for the center of the nerve, it is best to approach it obliquely (14)

Use of Peripheral Nerve Stimulation with Ultrasound

The nerve stimulator may be used as a safety measure during UGRA as it is known that a nerve stimulation threshold below 0.2 mA increases the risk of needle tip insertion into the nerve. Evoked motor response might serve as a warning in this context against injecting a local anesthetic intra-fascicular. When the ultrasound picture isn't as clear as expected or when US-guided blocking of deep nerves is being considered like lumbar plexus block, the nerve stimulator will come in handy to increase efficiency of the block (16)

Additionally, the PNS delineates the nerves during axillary block by their distinct motor response to electrical stimulation, which is useful when it's necessary to distinguish various nerves with greater accuracy. Visual inspection alone may not always be enough to identify specific neural elements; a PNS may be useful in these situations, whether the areas in question are targets of block or just places the needle should not go. With a current intensity of 0.5 mA, 2 Hz frequency & 0.1 msec current duration, the nerve stimulator should be simply calibrated & maintained consistently throughout the procedure to stop needle advancement when motor response occurs to avoid intra-neural injection. (16)

Improving the local anesthetic's distribution to the specific nerve;

To improve the distribution and safety of local anesthetic during nerve blocks, precise techniques and real-time imaging are essential. Administering the anesthetic in small aliquots (3–5 mL) with intermittent pauses allows for early detection of systemic toxicity (LAST), while aspiration before each injection helps avoid intravascular administration. Ultrasound guidance, including color Doppler when feasible, enhances visualization of fluid spread and identification of surrounding vessels, although deeper or smaller vessels may remain undetected. Techniques like creating a "halo" around nerves or filling fascial compartments help target deposition, but anatomical variations, such as those in the femoral triangle or interscalene groove, may render circumferential injection unnecessary. Continuous monitoring for signs of paresthesia, pain, or abnormal injection pressure is vital. Studies show that even small volumes (0.5 mL) injected into nerves can be visualized on ultrasound, enabling immediate correction to reduce nerve injury risk (14)

Ultrasound: Revolutionizing Regional Anesthesia

Ultrasound guidance has revolutionized regional anesthesia by offering real-time visualization that enhances needle placement accuracy, minimizes complications, and increases block success rates. Unlike blind or landmark-based techniques, ultrasound allows precise monitoring of needle trajectory, reducing the risk of nerve injury, vascular puncture, and hematoma . It enables clinicians to visualize anesthetic spread, ensuring effective nerve coverage, decreasing the likelihood of incomplete blocks or the need for repeat injections. Additionally, less anesthetic is often required, lowering the risk of systemic toxicity. Ultrasound guidance also shortens block onset time and procedure preparation, enhancing both healthcare efficiency and patient satisfaction. For trainees, ultrasound provides a dynamic educational tool, offering hands-on experience with complex anatomy beyond traditional theoretical learning(17).

Erector Spinae Plane Block in Pediatrics: Mechanisms and Anatomical Considerations

Since its introduction by Forero in 2016 for thoracic neuropathic pain, the Erector Spinae Plane Block has gained widespread application in pediatric postoperative and non-surgical pain management. Its analgesic effect is thought to occur via three main mechanisms: anterior spread of local anesthetic into the paravertebral and epidural spaces through the inter-transverse tissue complex, direct dorsal rami blockade within the ESP, and lateral spread to anesthetize lateral cutaneous branches via continuity with adjacent fascial planes. In pediatric patients, variable fascial plane laxity may affect block consistency. In the thoracic region, ESPB typically spreads cranio-caudally from T4 to T11 and laterally to muscles like the serratus anterior and external intercostals, influencing dermatomes supplied by ventral rami, though spread to the paravertebral space may be inconsistent. In contrast, lumbar ESP blocks demonstrate limited cranio-caudal and lateral spread, with dorsal rami involvement being more prominent(18).

Techniques of Lumbar Erector Spinae Plane Block (ESPB)

Several ultrasound-guided approaches have been developed for conducting lumbar ESPB, each tailored for anatomical clarity and clinical objectives. The parasagittal approach, first described by Aksu et al. (2019), involves placing the ultrasound probe longitudinally 1–2 centimeters lateral to the midline to visualize the transverse process and inject local anesthetic between it and the erector spinae muscle, using either in-plane or out-of-plane techniques. (19)The transverse approach permits for real-time visualization of dorsal vertebral structures with a convex probe and also supports both needle guidance techniques. The Aksu approach or transverse subcostal method—typically used in pediatric patients under general anesthesia—relies on the

Shamrock technique for optimal transverse process identification, although it offers limited visualization of anesthetic spread. Finally, the Tulgar approach introduces a second injection between the transverse process and the psoas major muscle to block the lumbar plexus, which can be enhanced using a nerve stimulator for improved accuracy.

Local Anesthetic Dosing in Pediatric ESPB

No formal dose-finding studies exist for pediatric ESP blocks; however, most reported practices utilize 0.25% bupivacaine in doses ranging from 0.3–0.6 mL/kg. This dosing generally achieves a spread across 3–8 vertebral levels. The concentration must adhere to maximum weight-based limits. Bupivacaine (0.25–0.375%) and ropivacaine (0.25–0.5%) are most often utilized. Lidocaine may be added to enhance onset (20).

, and epinephrine is routinely recommended to decrease systemic absorption and possibility of local anesthetic systemic toxicity.

Indications of ESPB in Pediatric Surgery

ESPB provides effective analgesia across a broad range of procedures due to its extensive cranio-caudal spread and dermatomal coverage. It is frequently incorporated into multimodal perioperative regimens for Enhanced Recovery After Surgery (ERAS) across thoracic, abdominal, cardiac, and orthopedic surgeries (9).

Thoracic and Cardiac Surgical Applications

In thoracic surgery, ESPB effectively reduces postoperative pain from chest wall incisions, improving respiratory outcomes and minimizing opioid needs. It is considered safer than paravertebral block due to its distance from vital structures (9).. Clinical applications include thoracotomy, sternotomy, rib tumor resection, VATS, chest wall tumor resections, funnel chest repair, lobectomy, pectus excavatum repair, lung decortication, and diaphragmatic plication.

In cardiac surgery, despite anticoagulation challenges, ESPB has proven effective in reducing postoperative opioid use in surgeries such as PDA, VSD repair, coarctation repair, mediastinal teratoma excision, and CABG (21)

Abdominal and Orthopedic Applications

ESPB offers advantages in abdominal surgeries due to its spread into the paravertebral space, enabling both somatic and visceral analgesia, unlike TAP or QLB. It has been used in cholecystectomy, abdominal mass resections, colostomy closures, bowel resections, splenectomy, nephrectomy, hernia repairs, varicocelectomy, orchiopexy, hydrocelectomy, and hypospadias repairs.In orthopedic surgeries, lumbar ESPB has shown efficacy in reducing pain and opioid use after procedures such as ORIF, hip osteotomy, femoral/tibial osteotomies, and proximal femoral resection(22).

Other Uses and Special Applications

In pediatric oncologic palliative care, ESPB has shown promise in controlling severe pain. The sacral ESPB has been employed in para-sacral and gluteal surgeries and postoperative pain control in urological and anal surgeries such as gender reassignment, hypospadias repair, and pilonidal sinus excision(23).

Advantages of ESPB

ESPB is considered a simpler and safer alternative to paravertebral block, avoiding major neurovascular structures. It can be performed under general anesthesia and is feasible in anticoagulated patients. Catheter insertion prolongs analgesia, and ultrasound landmarks are easily identified even in obese patients. ESPB provides wide dermatomal coverage and facilitates early mobilization, effective physiotherapy, and opioid-sparing benefits. It can be safely used in cases with infection, spinal deformities, or prior surgery(24).

Complications and Limitations

Though safe, ESPB may be associated with rare complications such as pneumothorax, Harlequin syndrome, priapism, and lower limb motor weakness. LAST may occur due to inadvertent intravascular injection, leading to seizures, arrhythmia, or even cardiac arrest. Management includes airway support, vasopressors, and lipid emulsion therapy(25).

Limitations include variable LA spread and need for bilateral blocks in midline surgeries. Using high-volume diluted LA with epinephrine may reduce systemic toxicity risk.

Pediatric Oncologic Limb Surgery

In pediatric limb surgeries, ESPB has demonstrated significant reductions in opioid requirements and better pain control within 24 hours compared to systemic opioids or PCIA. It also shows comparable analgesia to Quadratus Lumborum Block (QLB) in lower abdominal procedures, offering flexibility based on clinician preference. Given the focus on minimizing opioid use, ESPB presents a promising alternative, particularly in complex oncologic surgeries(26).

Overview of Caudal Epidural Block

Caudal epidural block includes accessing the epidural space through the sacral hiatus, making it one of the most commonly used regional anesthesia methods in pediatric patients for surgeries below the umbilicus. It is also utilized in adult chronic pain management. Initially performed using a landmark-based blind technique, its success rate varies—about 96% in children and 75% in adults. With advancements, image-guided techniques, especially ultrasound and fluoroscopy, have significantly improved precision and success rates(27).

Indications and Contraindications

Caudal anesthesia is indicated for various surgical procedures in the sub-umbilical region such as inguinal herniorrhaphy, hypospadias repair, and clubfoot surgery. Absolute contraindications include coagulopathies, infections, neurological disorders, or refusal. Additionally, skin anomalies near the puncture site may require imaging to rule out spinal malformations. Mongolian spots, however, are not contraindications (28)

Blind Technique for Caudal Block

In the blind technique, the child is positioned laterally or prone, and anatomical landmarks like the sacral cornua and sacrococcygeal ligament (SCL) are used to locate the sacral hiatus. A short bevel needle (22–25G) is preferred to reduce complications. The needle is inserted at 45°, and after penetrating the SCL, redirected to a shallower angle. Correct placement is confirmed by the absence of blood/CSF reflux and ease of injection without subcutaneous bulging. The "swoosh test" and surgical incision response are traditional indicators of success(29).

Ultrasound-Guided Technique

First described in 2003, ultrasound-guided caudal blocks offer superior anatomical visualization and near-perfect success rates (96.9–100%). High-frequency linear probes (7–13 MHz) are standard, with curved probes for obese patients. The transverse view reveals the "frog-eye sign" of sacral cornua and SCL, while the longitudinal view may show the dural sac and surrounding structures in infants. Needle insertion can be carried out utilizing either in-plane or out-of-plane techniques, with real-time visualization and saline test bolus to confirm epidural placement(29)..

Local Anesthetics and Adjuvants

Common agents include bupivacaine (0.125–0.25%) and ropivacaine (0.1–0.375%), with dosing volumes based on targeted dermatomes—0.5 mL/kg for sacral, 1.0 mL/kg for lumbar, and 1.25 mL/kg for lower thoracic regions (Suresh et al., 2018). Additives like clonidine, dexmedetomidine (1–2 µg/kg), preservative-free ketamine (0.5–1 mg/kg), and morphine (10–30 µg/kg) are endorsed by anesthesia societies to prolong block duration and reduce postoperative opioid need. Each has potential side effects—pruritus, nausea, respiratory depression (opioids), sedation (clonidine), or hallucinations (ketamine) (29).

3. COMPLICATIONS

Although rare (0.7 per 1000), complications are more common in infants or when proper equipment and technique are lacking. They include:

Dural puncture and extensive spinal anesthesia if the needle is advanced too far

Intravascular injection, increasing the risk of local anesthetic systemic toxicity (LAST), prevented by slow injection and frequent aspiration.

Overdosage of LA, leading to cardiovascular or neurologic compromise.

Respiratory depression, particularly with caudally administered opioids.

Urinary retention, requiring observation before discharge.

Sacral perforation, possibly damaging pelvic organs.

Sacral osteomyelitis, though extremely rare.(30)

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