International Journal of Multiphysics
Volume 18, No. 3, 2024
ISSN: 1750-9548

Sacral Multifidus Plane Block Versus Caudal Epidural Block for Postoperative Analgesia in Pediatric Hypospadias Surgery: A Narrative Review

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Abstract

Background: Hypospadias repair is one of the most common pediatric urologic procedures and is frequently associated with significant postoperative pain due to penile and perineal tissue manipulation. Effective analgesia in this population is essential not only for immediate comfort but also to reduce physiological stress, opioid exposure, and potential long-term alterations in pain processing. Caudal epidural block has traditionally been considered the gold standard regional technique for infraumbilical pediatric surgery. However, concerns related to neuraxial access and interest in ultrasound-guided, non-neuraxial alternatives have led to growing attention toward the sacral multifidus plane block as a potential alternative. This narrative review aims to compare sacral multifidus plane block and caudal epidural block for postoperative analgesia in pediatric hypospadias surgery, focusing on anatomical rationale, analgesic efficacy, safety profile, pharmacologic considerations, and clinical applicability from an anesthesia and pain management perspective.

A structured narrative synthesis of the literature was undertaken, emphasizing validated clinical studies, contemporary guidelines, and recent randomized controlled trials relevant to pediatric hypospadias repair. Caudal epidural block provides reliable sacral nerve root blockade with a long-established safety record and proven analgesic efficacy. Sacral multifidus plane block, an ultrasound-guided interfascial plane technique targeting sacral neural pathways, has emerged as a promising alternative that avoids direct neuraxial space entry. Available evidence suggests that sacral multifidus plane block can offer comparable postoperative analgesia and opioid-sparing effects, with potential advantages in terms of safety perception and technical feasibility when performed by experienced practitioners. Pharmacologic strategies using long-acting local anesthetics and adjuvants such as dexamethasone further enhance analgesic duration for both techniques.

Conclusion: Both caudal epidural block and sacral multifidus plane block are effective regional analgesic techniques for pediatric hypospadias surgery. While caudal epidural block remains the benchmark due to its extensive clinical experience, sacral multifidus plane block represents a viable and evolving alternative within multimodal analgesic pathways. Technique selection should be individualized based on surgical complexity, patient characteristics, and institutional expertise. Further high-quality, multicenter studies are warranted to refine technique standardization and optimize analgesic outcomes in this vulnerable population.

Keywords: Sacral Multifidus Plane Block , Caudal Epidural Block , Postoperative Analgesia, Pediatric Hypospadias Surgery

Introduction

Hypospadias

Hypospadias is a congenital malformation of the male external genitalia characterized by incomplete development of the urethral fold and ventral foreskin, resulting in an abnormally positioned urethral meatus on the ventral surface of the penis. The condition may range from mild distal forms to severe proximal variants and is frequently associated with ventral penile curvature (chordee). From an anesthetic and pain-management perspective, hypospadias repair represents a common early-life surgical intervention in which optimal perioperative analgesia is essential to reduce physiological stress responses, opioid exposure, and postoperative morbidity in a vulnerable pediatric population. [1]

The severity of hypospadias is typically classified according to the anatomical location of the ectopic urethral meatus into anterior (glanular and subcoronal), middle (distal penile, midshaft, and proximal penile), and posterior (penoscrotal, scrotal, and perineal) types. Approximately half of cases are anterior, while posterior forms are less common but surgically more complex. This classification has direct implications for postoperative pain intensity and duration, as more proximal repairs usually involve extensive tissue dissection, longer operative times, and greater perineal involvement, thereby increasing analgesic requirements and influencing the choice of regional anesthesia technique. [1]

The etiology of hypospadias is multifactorial and remains incompletely understood. Current evidence supports a combination of genetic susceptibility, endocrine dysfunction, and environmental influences affecting androgen-dependent genital development during early gestation. Polygenic inheritance patterns have been observed, and hypospadias is more frequently reported in males with a positive family history. In addition, impaired androgen production or reduced androgen receptor sensitivity has been implicated, which is clinically relevant when evaluating associated anomalies and tailoring perioperative management strategies. [2]

Environmental and endocrine-disrupting exposures during pregnancy have also been associated with an increased risk of hypospadias. Epidemiological studies suggest that in-utero exposure to estrogenic or antiandrogenic compounds, including certain pesticides, plasticizers, and occupational chemicals, may interfere with normal urethral fold fusion. While causality remains complex, these findings reinforce the importance of a comprehensive preoperative assessment and awareness of potential multisystem involvement, particularly in proximal hypospadias, which may necessitate staged surgical repair and prolonged postoperative analgesia. [2]

From an epidemiological standpoint, hypospadias is the second most common congenital anomaly in males after cryptorchidism and the most common congenital penile malformation. Incidence rates vary geographically, influenced by genetic, environmental, and reporting factors. Regional data from Egypt have demonstrated a notable prevalence of hypospadias among male newborns, emphasizing its clinical significance and the substantial number of children requiring surgical correction and effective perioperative pain control in this population. [3]

The underlying pathophysiology of hypospadias relates to abnormal urethral development during early embryogenesis. External genital formation occurs in two phases: an initial hormone-independent phase between the fifth and eighth weeks of gestation, followed by a hormone-dependent phase requiring adequate androgen signaling. During the second phase, testosterone-driven elongation of the genital tubercle and fusion of the urethral folds form the penile urethra. Disruption at any point in these processes can result in incomplete urethral closure, ventral curvature, and abnormal foreskin development. Understanding this embryologic basis provides insight into the extent of surgical reconstruction required and the expected nociceptive burden following repair. [2]

Early surgical correction is recommended for infants diagnosed with hypospadias, with most repairs performed between 6 and 18 months of age to minimize psychological impact and optimize tissue healing. Distal hypospadias is often corrected in a single-stage procedure, whereas proximal forms with significant chordee may require staged reconstruction. These surgical considerations are directly relevant to anesthetic planning, as more extensive repairs are associated with increased postoperative pain and may benefit from longer-lasting or more comprehensive regional analgesia techniques. [4]

Pathophysiology of Pain and Its Relevance to Pediatric Hypospadias Surgery

Pain is defined by the International Association for the Study of Pain as an unpleasant sensory and emotional experience associated with actual or potential tissue damage. This multidimensional concept is particularly important in pediatric anesthesia, where pain perception, expression, and long-term consequences differ significantly from adults. In the context of hypospadias surgery, tissue injury involves skin, subcutaneous tissue, urethral structures, and perineal components, all of which generate nociceptive input that must be effectively attenuated to prevent excessive physiological stress and postoperative morbidity. [5]

Acute postoperative pain represents a predictable physiological response to surgical tissue injury and is mediated primarily through activation of peripheral nociceptors and subsequent transmission of signals through the spinal cord to supraspinal centers. If inadequately treated, acute pain can initiate maladaptive neuroplastic changes in both peripheral and central nervous systems, increasing the risk of prolonged pain states. Pediatric urologic surgeries, including hypospadias repair, therefore demand proactive and effective analgesic strategies to interrupt these pathways early in the perioperative period. [6]

Pain processing involves four fundamental components: transduction, transmission, modulation, and perception. Transduction occurs when noxious mechanical or inflammatory stimuli generated during surgery are converted into electrical signals at peripheral nociceptors. These impulses are transmitted via primary afferent neurons to the dorsal horn of the spinal cord, where second-order neurons relay signals to higher centers. Modulation occurs predominantly at the spinal and supraspinal levels, where inhibitory or facilitatory mechanisms can amplify or suppress pain signals, ultimately shaping pain perception within cortical and limbic structures. Regional anesthesia techniques target these pathways at the level of transmission and modulation, making them particularly effective in pediatric surgery. [7]

In children, the central nervous system is anatomically and functionally immature at birth, yet the neural pathways required for nociception are present and functional by mid-gestation. Neonates and infants demonstrate exaggerated physiological responses to pain, including increased heart rate, blood pressure, and neuroendocrine stress hormone release. This heightened reactivity underscores the importance of minimizing nociceptive input during and after surgery, as repeated or severe pain exposure early in life has been shown to alter subsequent pain sensitivity and stress responses. [8]

Experimental and clinical studies have demonstrated that untreated or poorly managed pain in infancy can lead to long-lasting changes in pain processing, a phenomenon attributed to central sensitization and altered synaptic connectivity within the spinal cord and brain. Children exposed to painful procedures without adequate analgesia exhibit increased behavioral and physiological responses to later painful stimuli. In the context of hypospadias repair, this reinforces the ethical and clinical imperative to provide robust perioperative analgesia, particularly given that these procedures are often performed during critical windows of neurodevelopment. [9]

Acute pain is commonly categorized into somatic, visceral, and referred pain. Hypospadias surgery primarily generates somatic pain arising from skin and soft tissue incision, combined with elements of deep perineal and urethral nociception. These pain components are transmitted predominantly through sacral nerve roots (S2–S4), including branches of the pudendal nerve, making sacral regional techniques—such as caudal epidural block and sacral multifidus plane block—anatomically and physiologically well suited for postoperative analgesia in this population. [10]

Effective perioperative pain management in pediatric patients relies on a multimodal approach that targets multiple components of the pain pathway. While systemic analgesics primarily affect pain perception at supraspinal levels, regional anesthesia techniques interrupt afferent transmission and modulate spinal processing, thereby reducing central sensitization and opioid requirements. In hypospadias surgery, the integration of regional blocks into multimodal analgesic regimens has been shown to improve pain scores, prolong analgesia duration, and enhance recovery profiles, supporting their central role in contemporary pediatric anesthesia practice. [6,11]

Nerve Supply of the Penis and Implications for Regional Analgesia in Hypospadias Surgery

The penis receives a complex and highly organized neural supply composed of both somatic and autonomic fibers, predominantly arising from the sacral spinal cord segments S2 to S4. This neuroanatomical arrangement is central to understanding postoperative pain after hypospadias repair and provides the anatomical rationale for sacral-based regional anesthesia techniques. Surgical manipulation of the penile shaft, glans, urethra, and perineal tissues generates nociceptive input that is transmitted primarily through sacral afferents, making effective blockade at this level particularly advantageous for perioperative analgesia. [12]

Somatic sensory innervation of the penis is mainly mediated by the pudendal nerve, which originates from the ventral rami of S2–S4. The pudendal nerve traverses the pelvis and gives rise to several branches, the most clinically relevant being the dorsal nerve of the penis. This nerve provides dense sensory innervation to the penile shaft and glans, areas that are extensively involved in hypospadias surgery. Inadequate blockade of this pathway can result in significant postoperative discomfort, agitation, and increased opioid consumption in pediatric patients. [12]

The dorsal nerve of the penis is the terminal and deepest branch of the pudendal nerve. It courses anteriorly along the ischiopubic ramus, passes beneath the perineal membrane, and runs on the dorsum of the penis alongside the dorsal penile vessels, terminating in the glans. It supplies the skin of the penile shaft, the glans penis, and contributes sensory fibers to the urethra. Because of its purely sensory role, effective inhibition of this nerve significantly reduces postoperative pain without producing undesirable motor blockade, a key goal in pediatric ambulatory urologic surgery. [12]

In addition to pudendal innervation, the root of the penis and adjacent perineal structures receive sensory input from the ilioinguinal nerve, a branch of the lumbar plexus (L1). While this nerve plays a secondary role compared with sacral nerves, it may contribute to residual pain following penile surgery if not adequately addressed by regional techniques. Cephalad spread of local anesthetic during caudal epidural block or sacral interfascial plane blocks may partially involve these fibers, enhancing analgesic coverage beyond the strictly sacral dermatomes. [12]

Autonomic innervation of the penis is conveyed via the cavernous nerves, which carry parasympathetic fibers originating from the pelvic splanchnic nerves (S2–S4). Although these fibers are primarily responsible for erectile function through modulation of penile vascular tone, they also interact with sensory pathways and contribute to neurovascular responses following surgical trauma. Regional anesthesia at the sacral level may influence these autonomic fibers indirectly, potentially attenuating reflex sympathetic responses and improving perioperative hemodynamic stability in children. [13]

From a regional anesthesia perspective, the convergence of somatic and autonomic afferents at the sacral spinal segments provides a strong anatomical justification for techniques that target these levels. Caudal epidural block achieves analgesia by delivering local anesthetic into the epidural space, resulting in blockade of sacral nerve roots and, depending on volume and spread, lower lumbar segments. Similarly, sacral multifidus plane block aims to anesthetize the posterior branches of sacral nerves with potential anterior and epidural spread, thereby influencing the same neural pathways responsible for penile and perineal pain. [14]

Effective postoperative analgesia for hypospadias repair therefore depends on achieving reliable coverage of the S2–S4 dermatomes, including the pudendal nerve distribution. Failure to adequately block these segments may lead to incomplete analgesia, increased rescue opioid requirements, and heightened stress responses in the early postoperative period. Understanding penile innervation is thus fundamental when comparing caudal epidural block and sacral multifidus plane block, as both techniques derive their analgesic efficacy from modulation of the same sacral neural circuitry through different anatomical approaches. [12,14]

Pain Management Strategies in Pediatric Hypospadias Repair

Effective pain management in pediatric hypospadias surgery requires a structured, multimodal approach that accounts for surgical complexity, patient age, neurodevelopmental considerations, and institutional resources. Inadequate postoperative analgesia in children has been associated with increased physiological stress responses, delayed recovery, behavioral disturbances, and a higher risk of persistent pain states. Consequently, contemporary pediatric anesthesia practice emphasizes the integration of regional anesthesia techniques with systemic non-opioid and opioid analgesics to optimize pain control while minimizing adverse effects. [15]

International and specialty society guidelines support a stepwise, procedure-specific strategy for postoperative pain management in children. The Pain Committee of the European Society for Paediatric Anaesthesiology (ESPA) has proposed a tiered approach for urologic surgeries such as hypospadias repair, stratifying analgesic interventions into basic, intermediate, and advanced levels based on procedural invasiveness and anticipated pain severity. This framework underscores the importance of tailoring analgesic techniques to both surgical and patient-specific factors rather than adopting a uniform approach. [16]

At the basic level, analgesia typically relies on systemic non-opioid medications such as paracetamol and nonsteroidal anti-inflammatory drugs (NSAIDs), administered intraoperatively and continued postoperatively. These agents primarily target peripheral and central prostaglandin-mediated pain pathways and are effective for mild to moderate pain, particularly in distal hypospadias repairs. However, when used alone, they may be insufficient for procedures involving extensive urethral reconstruction or perineal dissection, highlighting the need for adjunctive regional techniques. [17]

Intermediate-level analgesic strategies incorporate regional anesthesia, most commonly single-shot caudal epidural block, combined with systemic non-opioid analgesics. Caudal block has long been considered the gold standard for infraumbilical pediatric surgery due to its technical simplicity and reliable sacral nerve blockade. When combined with long-acting local anesthetics and adjuvants, caudal epidural analgesia can significantly reduce early postoperative pain scores and opioid consumption following hypospadias repair. [18]

Advanced analgesic approaches are reserved for complex or proximal hypospadias repairs and may include ultrasound-guided caudal block, continuous epidural techniques, or newer interfascial plane blocks. These strategies aim to extend the duration and quality of analgesia while maintaining hemodynamic stability and minimizing motor blockade. In this context, the emergence of ultrasound-guided sacral multifidus plane block represents a promising alternative that may offer comparable analgesia with a potentially improved safety profile by avoiding neuraxial space entry. [16,19]

Opioids remain an important component of rescue analgesia for breakthrough pain but are increasingly used judiciously due to concerns regarding respiratory depression, nausea, vomiting, urinary retention, and potential neurodevelopmental effects. Studies in pediatric populations have demonstrated that the incorporation of effective regional anesthesia techniques significantly reduces perioperative opioid requirements, thereby enhancing recovery profiles and parental satisfaction. This opioid-sparing effect is particularly relevant in hypospadias surgery, where urinary catheterization and penile edema can already complicate postoperative care. [15,18]

Adjunctive medications such as alpha-2 agonists, ketamine, and corticosteroids are frequently employed to enhance analgesic efficacy and prolong block duration. Dexamethasone, in particular, has been shown to extend the duration of regional anesthesia and reduce postoperative pain and nausea when used as an adjuvant. The incorporation of such agents into multimodal regimens reflects a growing emphasis on balanced analgesia that targets multiple pain pathways while minimizing side effects. [20]

Overall, pain management in pediatric hypospadias repair has evolved from reliance on systemic opioids to a comprehensive, multimodal paradigm centered on regional anesthesia. Both caudal epidural block and sacral multifidus plane block fit within this framework, addressing the sacral neural pathways responsible for penile and perineal pain. Comparing these two techniques requires careful consideration of analgesic efficacy, safety, technical feasibility, and impact on recovery, forming the foundation for the subsequent sections of this narrative review. [16,19]

Caudal Epidural Block in Pediatric Hypospadias Surgery

Caudal epidural block is one of the most commonly performed regional anesthesia techniques in pediatric practice and has long been regarded as a cornerstone for analgesia in infraumbilical surgeries, including hypospadias repair. Its popularity stems from its relative technical simplicity, high success rate, and ability to provide reliable analgesia of the sacral and lower lumbar dermatomes. When combined with general anesthesia, caudal block significantly attenuates intraoperative nociceptive responses and improves early postoperative pain control in children undergoing urologic procedures. [18]

Anatomically, the caudal epidural space is accessed through the sacral hiatus, which is bordered laterally by the sacral cornua and covered by the sacrococcygeal ligament. In infants and young children, this approach is considered safer than lumbar epidural placement because the spinal cord terminates at a lower vertebral level, and the epidural space is relatively superficial. However, the dural sac also extends more caudally in neonates and infants, increasing the risk of inadvertent dural puncture if the technique is not performed carefully. These anatomical considerations underscore the importance of expertise and, increasingly, ultrasound guidance in pediatric caudal anesthesia. [21]

Traditionally, caudal blocks were performed using landmark-based techniques, relying on palpation of the sacral cornua and tactile feedback during needle advancement. While effective in experienced hands, landmark-based caudal blocks are associated with variable success rates, particularly in older children or in those with atypical sacral anatomy. The introduction of ultrasound guidance has improved block accuracy by allowing direct visualization of the sacral hiatus, sacrococcygeal ligament, epidural space, and real-time spread of local anesthetic, thereby enhancing success rates and reducing complications. [22]

The analgesic efficacy of caudal epidural block is influenced primarily by the volume of local anesthetic administered, which determines the cephalad spread of the block. Classic dosing formulas, such as those proposed by Armitage and Takasaki, have guided clinical practice for decades, with volumes tailored to achieve lumbosacral or thoracolumbar coverage depending on surgical requirements. More recent imaging studies have demonstrated significant age-related variability in epidural space volume, emphasizing the need for individualized dosing to balance adequate analgesia against the risk of local anesthetic systemic toxicity. [23]

In pediatric hypospadias surgery, commonly used local anesthetics for caudal block include bupivacaine and ropivacaine, selected for their long duration of action and favorable sensory–motor separation. The addition of adjuvants such as clonidine or dexamethasone has been shown to prolong analgesic duration and reduce postoperative opioid requirements. Despite these advantages, caudal block may still provide limited duration of analgesia following single-shot administration, particularly in more extensive repairs, prompting interest in alternative or adjunctive techniques. [24]

Large multicenter database analyses have confirmed the overall safety of caudal epidural anesthesia in children, with serious complications being rare. Reported adverse events include block failure, accidental intravascular or intrathecal injection, transient neurological symptoms, urinary retention, and, less commonly, infection or hematoma. Although the incidence of permanent neurological injury is exceedingly low, the neuraxial nature of the technique continues to raise concern among some practitioners and parents, particularly when equally effective non-neuraxial alternatives may be available. [18]

From a clinical outcome perspective, caudal epidural block has consistently demonstrated efficacy in reducing early postoperative pain scores and opioid consumption following hypospadias repair. However, limitations such as potential motor blockade, urinary retention, and the need for precise neuraxial placement have fueled interest in newer interfascial plane blocks. These emerging techniques aim to preserve analgesic efficacy while minimizing neuraxial risks, setting the stage for comparative evaluation between caudal epidural block and sacral multifidus plane block in pediatric hypospadias surgery. [19-21]

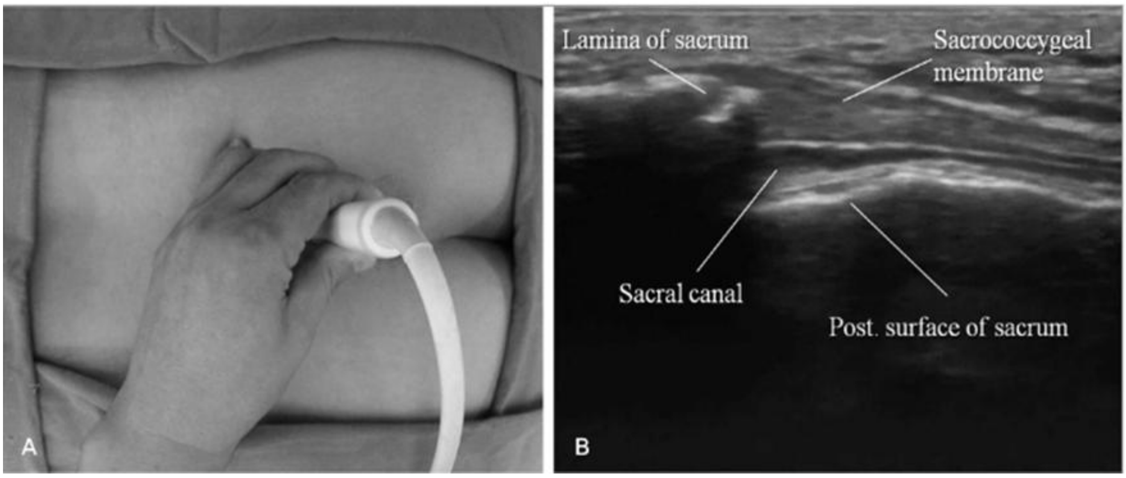

Figure 1: Ultrasound-guided caudal block [16]

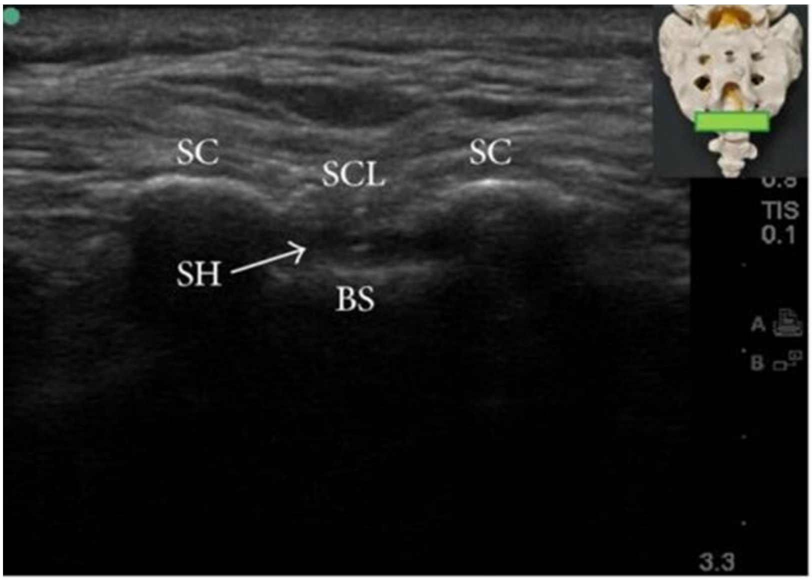

Figure 2:. Short and long axis view of the sacral hiatus during caudal block. BS = base of sacrum; SC = sacral cornua; SCL = sacrococcygeal ligament; SH = sacral hiatus. [16]

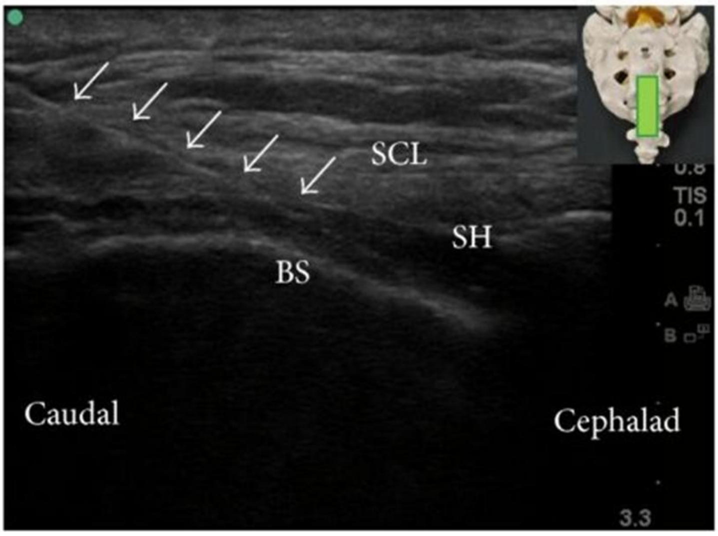

Figure 3: Caudal epidural block: An updated review of anatomy and techniques [16]

Sacral Multifidus Plane Block

The sacral multifidus plane block (SMPB)—closely related to the "sacral erector spinae plane block" described in early reports—is an ultrasound-guided interfascial plane technique performed over the posterior sacrum with injection deep to the multifidus muscle. After Tulgar and colleagues introduced the concept of sacral erector spinae plane blockade targeting the posterior branches of sacral nerves, the technique rapidly attracted interest as a potentially simpler, non-neuraxial alternative for sacral and perineal analgesia. In pediatric urologic surgery, the conceptual appeal is clear: hypospadias pain is predominantly mediated via sacral segments (S2–S4) and pudendal pathways, and SMPB aims to modulate these pathways without accessing the epidural space. [14]

Nomenclature has been debated because "erector spinae" terminology at the sacrum can be anatomically imprecise; the injectate is commonly deposited in the tissue plane deep to multifidus and adjacent to the sacral crests rather than within a thoracolumbar erector spinae compartment. Hamilton argued for clearer anatomical terminology and helped drive adoption of names emphasizing the multifidus-related plane, which aligns better with ultrasound sonoanatomy at the sacrum. For a narrative review, consistent terminology matters because it improves interpretability when comparing case reports, technique descriptions, and trials that may label similar approaches as sacral ESPB, sacral retrolaminar, or SMPB/MPB. [26]

Ultrasound sonoanatomy and technique (practical anesthesia focus)

In practice, SMPB is performed with the child in lateral decubitus (or prone if feasible), under strict asepsis, using a high-frequency linear probe. The operator identifies midline sacral landmarks and then scans parasagittally at approximately the S2 level to visualize the bony sacral surface/crest and the overlying multifidus muscle. A needle is advanced in-plane until the tip contacts the sacrum (a reliable “hard stop”), and local anesthetic is injected to open the plane between the sacrum and multifidus. Many clinicians perform bilateral injections to improve midline and perineal coverage, a feature that becomes relevant in hypospadias where surgical stimulation is midline-dominant but nociceptive input may involve bilateral sacral afferents. [29]

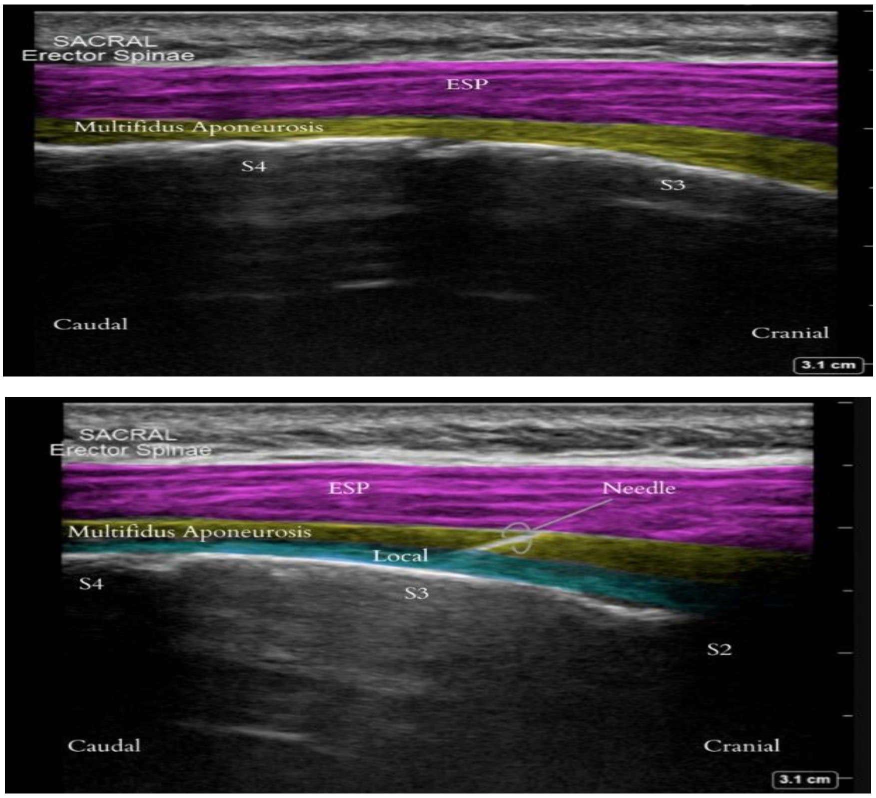

Figure 4 : Sagittal Ultrasound Images for Sacral ESP(pre and post injection of local anesthesia**.** [29]

Proposed mechanism and spread

Mechanistically, the most intuitive component is blockade of the posterior branches of sacral nerves as they exit the dorsal sacral foramina, given that the injectate is deposited in close proximity to these structures. However, clinical observations suggest broader analgesic coverage than purely dorsal rami blockade would predict, raising the possibility of ventral ramus involvement through foraminal or paravertebral-type spread and/or limited epidural extension. Early pediatric clinical descriptions highlighted effective perineal analgesia and hypothesized neuraxial or anterior spread, which—if present—would partly explain why SMPB can resemble caudal epidural block in analgesic coverage while remaining technically “outside” the neuraxial space. [25,27]

Pediatric experience and emerging indications

Although high-quality pediatric evidence is still developing, published clinical experience supports SMPB (and closely related sacral ESP approaches) for procedures involving the perineum, pelvis, and sacrum. Case-level and small-series literature has described effective postoperative analgesia for pediatric and adult sacral/perineal operations, supporting feasibility and suggesting opioid-sparing potential. This broader peri-sacral experience is relevant to hypospadias because it strengthens biological plausibility for reliable sacral segment analgesia, even if procedure-specific trials remain limited compared with caudal epidural block. [28,29]

Dosing concepts and local anesthetic selection

There is no single universally accepted pediatric dosing regimen for SMPB. Most clinical descriptions mirror volumes used for other interfascial plane blocks, with weight-based volumes of dilute long-acting local anesthetic (e.g., bupivacaine or ropivacaine), often divided bilaterally. Reports describing opioid-sparing recovery strategies have used sacral plane blocks as part of multimodal regimens, typically pairing the block with scheduled non-opioid analgesics and reserving opioids for rescue. In hypospadias, dosing strategy should be individualized to surgical extent (distal vs proximal repair), patient weight, and institutional maximum safe local anesthetic dose policies—especially when surgeons may also infiltrate local anesthetic at the surgical site. [30]

Safety profile and potential advantages compared with caudal block

A major proposed advantage of SMPB is avoidance of epidural space cannulation, which may reduce concerns related to accidental dural puncture, neuraxial hematoma/infection, or intrathecal injection—while still providing sacral analgesia. The sacrum also provides a consistent bony endpoint, which can improve needle-tip confidence under ultrasound. That said, SMPB remains a regional technique with standard risks (block failure, infection, bleeding, and local anesthetic systemic toxicity), and meticulous ultrasound visualization and incremental injection with aspiration remain essential—particularly in children where early neurologic symptoms of toxicity may be masked under general anesthesia. In comparative terms, the key question is whether SMPB can match caudal epidural block for analgesic duration and quality in hypospadias repair while improving workflow, safety perception, or side-effect profile—an evidence question addressed most directly by recent pediatric studies. [18,19]

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Pharmacology and Adjuvants in Sacral Blocks for Pediatric Hypospadias Surgery

Focus on Bupivacaine and Dexamethasone

The pharmacologic profile of local anesthetics and adjuvants used in regional anesthesia is a critical determinant of analgesic quality, duration, and safety in pediatric hypospadias surgery. Both caudal epidural block and sacral multifidus plane block most commonly employ long-acting amide local anesthetics, with bupivacaine remaining one of the most frequently used agents. Selection of drug concentration, total dose, and adjunctive medications must balance prolonged sensory blockade against the risk of systemic toxicity, particularly in young children with limited physiologic reserve and reduced ability to manifest early neurologic signs of overdose. [32]

Bupivacaine is an amide-type local anesthetic introduced into clinical practice in the early 1960s and is characterized by high lipid solubility and strong protein binding, properties that account for its potent and long-lasting sensory blockade. Its primary mechanism of action involves reversible inhibition of voltage-gated sodium channels in neuronal membranes, thereby preventing action potential initiation and propagation along afferent pain fibers. In both neuraxial and interfascial plane blocks, this mechanism results in effective interruption of nociceptive transmission from sacral dermatomes involved in hypospadias surgery. [33]

In pediatric caudal epidural anesthesia, bupivacaine is typically administered in dilute concentrations (0.125–0.25%) to maximize sensory analgesia while minimizing motor blockade. The duration of action is influenced by concentration, total dose, and the vascularity of the injection site. In sacral multifidus plane block, similar concentrations are commonly used, with the expectation that interfascial spread and gradual absorption may produce prolonged analgesia with limited motor involvement. These characteristics are particularly desirable in hypospadias repair, where preservation of lower limb motor function and early mobilization are advantageous. [34]

Local anesthetic systemic toxicity (LAST) remains the most serious pharmacologic risk associated with bupivacaine use. In children, early central nervous system manifestations such as tinnitus, metallic taste, or circumoral numbness are often unobservable under general anesthesia, making cardiovascular collapse a potentially first sign of toxicity. Adherence to weight-based maximum dosing recommendations and careful accounting of all local anesthetic sources—including surgical field infiltration—is therefore essential when performing either caudal or sacral plane blocks. Lipid emulsion therapy remains the cornerstone of management in cases of severe bupivacaine toxicity. [35]

Dexamethasone has gained widespread acceptance as an adjuvant to local anesthetics in regional anesthesia due to its ability to prolong analgesic duration and reduce postoperative pain and opioid requirements. Its analgesic-enhancing effects are attributed to anti-inflammatory actions, suppression of ectopic neural discharge, and modulation of potassium channel activity at the nerve membrane. In pediatric hypospadias surgery, dexamethasone is frequently added to caudal bupivacaine or administered perineurally in sacral plane blocks to extend analgesia into the late postoperative period. [36]

Pharmacodynamically, dexamethasone exerts potent glucocorticoid effects with minimal mineralocorticoid activity, making it suitable for single-dose perioperative use. Beyond analgesia, dexamethasone provides additional benefits relevant to pediatric urologic surgery, including reduction of postoperative nausea and vomiting, attenuation of surgical edema, and improved overall recovery quality. These pleiotropic effects support its incorporation into multimodal analgesic regimens for hypospadias repair, particularly in ambulatory or short-stay settings. [37]

Clinical studies evaluating dexamethasone as an adjuvant in pediatric caudal anesthesia have demonstrated significant prolongation of analgesic duration without a corresponding increase in adverse effects when used at appropriate doses. Similar benefits are increasingly reported in interfascial plane blocks, although high-quality pediatric data remain limited. Importantly, current evidence suggests that perineural dexamethasone does not confer additional neurotoxicity when compared with systemic administration, though ongoing vigilance and adherence to established dosing recommendations are required. [24]

From a comparative perspective, the pharmacologic behavior of bupivacaine and dexamethasone is largely independent of whether the drug is delivered via the caudal epidural space or the sacral multifidus plane. Differences in clinical effect are therefore more likely related to anatomical spread and tissue absorption kinetics than to intrinsic drug properties. Understanding these pharmacologic principles is essential when interpreting comparative analgesic outcomes between sacral multifidus plane block and caudal epidural block and when designing future trials to optimize dosing strategies for pediatric hypospadias surgery. [36]

Clinical Decision-Making: Choosing SMPB Versus Caudal for Pediatric Hypospadias Repair

In contemporary pediatric anesthesia, the choice between caudal epidural block and sacral multifidus plane block should be framed around procedure-specific analgesic targets (S2–S4 coverage), anticipated pain burden (distal vs proximal repair), institutional expertise, and risk tolerance for neuraxial access. Caudal block remains the most established technique with extensive safety and efficacy experience, while SMPB is a newer interfascial option that may provide comparable analgesia and opioid-sparing benefit in hypospadias repair based on emerging randomized evidence. A pragmatic approach is to view SMPB as an “evidence-growing alternative” rather than a universal replacement, with technique selection individualized to patient and surgical factors. [16,31]

When caudal epidural block is favored, the strongest indications include situations where clinicians desire predictable neuraxial sacral root blockade and have consistent ultrasound/landmark success in their setting. Caudal block can be especially practical when the anesthetic plan already includes neuraxial considerations or when prior institutional pathways (ordersets, dosing protocols, monitoring) are optimized around caudal analgesia. Its large-scale safety data and long track record in pediatric infraumbilical surgery remain persuasive for many teams and families. [18]

When SMPB is favored, it is most attractive when avoiding neuraxial space entry is a priority (e.g., heightened concern about dural puncture risk, parent preference, or clinician comfort) and when ultrasound expertise in interfascial plane blocks is strong. The block's "bony endpoint" and superficial sonographic landmarks can support reproducibility, and recent hypospadias-specific RCT evidence suggests it can deliver high-quality analgesia with an opioid-sparing signal. These features make SMPB a reasonable first-choice option in centers with established technique proficiency. [31]

A key clinical differentiator is how each technique behaves with respect to **spread and predictability**. Caudal block directly targets epidural spread and sacral root blockade but may show variability in cephalad distribution depending on volume, age-related epidural capacitance, and technique. SMPB depends on interfascial plane spread with proposed sacral nerve involvement; it may offer excellent perineal analgesia but its mechanistic pathways (including any epidural extension) are less standardized across studies, which is important when translating evidence across institutions and operators. [22,27]

Practical "selection rules" for hypospadias cases

For **distal/anterior repairs**, either technique is typically sufficient when paired with scheduled paracetamol/NSAIDs, and workflow considerations often dominate (block time, turnover, local expertise). For **proximal repairs**, staged reconstructions, or cases expected to have greater perineal dissection and catheter discomfort, the anesthetic team should prioritize a technique with the highest local success rate and consider whether prolonged analgesia strategies (e.g., adjuvants, catheter techniques, or enhanced multimodal regimens) are required. The ESPA guidance supports tailoring the regional technique to severity and expected pain, with escalation in complex reconstructions. [16]

Safety and monitoring: what to standardize regardless of technique

Regardless of block choice, a pediatric regional protocol should include strict adherence to maximum safe local anesthetic dosing, incremental injection with frequent aspiration, and structured postoperative monitoring. This is especially important because early neurologic signs of local anesthetic systemic toxicity may be obscured under general anesthesia, making vigilant cardiovascular monitoring and a prepared LAST response plan essential. Institutional use of nomograms or standardized maximum-dose tools can reduce dosing errors when combining block dosing with surgeon infiltration. [32]

For caudal block specifically, error prevention includes careful aspiration and the use of a test-dose strategy to detect intravascular injection, recognizing that detection can be imperfect in anesthetized children. Ultrasound guidance can further improve safety by confirming sacral hiatus anatomy and visualizing injectate spread, reducing the likelihood of subcutaneous injection and potentially lowering complication rates. These measures become particularly relevant in high-throughput pediatric lists where small technical missteps can have outsized safety consequences. [22]

Outcomes that matter clinically and in future trials

Future comparative research should not rely solely on pain scores; it should incorporate time-to-first rescue analgesia, total opioid dose within 24 hours, block performance time, block failure criteria, parental satisfaction, PACU readiness, and adverse events (urinary retention, motor weakness, PONV, and LAST). Many hypospadias studies already use validated observational scales such as FLACC, which strengthens comparability across trials and allows clinically meaningful interpretation of analgesic differences between techniques. [31,38]

Evidence gaps and priorities for the field

Although the 2024 double-blind RCT is an important milestone, the evidence base still needs replication across centers and surgical subtypes (distal vs proximal, single-stage vs staged) with standardized SMPB technique definitions. Studies should also clarify optimal dosing strategies (volume/concentration, unilateral vs bilateral injection, and adjuvant selection) and explicitly report surgeon infiltration practices to avoid confounding. Mechanistic studies using imaging or ultrasound assessment of spread could help explain inter-study variability and improve technique standardization. [23,31]

Finally, a realistic synthesis for clinicians is that caudal epidural block remains the benchmark due to its proven track record, while SMPB is an increasingly supported alternative that may offer comparable analgesia with potential practical and safety-perception advantages in experienced hands. The most defensible current recommendation is procedure- and center-specific: use the technique your team performs most reliably and safely, while expanding SMPB adoption through structured training, protocolized dosing, and ongoing audit of outcomes in pediatric hypospadias repair. [18,31]

Conclusion

Optimal postoperative analgesia is a central component of safe and effective pediatric hypospadias surgery, given the vulnerability of the developing nervous system and the significant nociceptive burden associated with penile and perineal reconstruction. Regional anesthesia techniques that reliably target sacral dermatomes play a pivotal role within multimodal analgesic strategies, reducing perioperative stress responses, limiting opioid exposure, and improving recovery quality.

Caudal epidural block remains the most established regional technique for infraumbilical pediatric surgery, supported by decades of clinical experience and large safety datasets. Its ability to provide predictable sacral nerve root blockade makes it a dependable option across a wide spectrum of hypospadias repairs. However, its neuraxial nature, potential for motor blockade, urinary retention, and the need for meticulous technique have prompted ongoing exploration of alternative approaches.

Sacral multifidus plane block has emerged as a promising ultrasound-guided interfascial plane technique that targets the same sacral neural pathways without direct entry into the epidural space. Available clinical evidence, including randomized comparative data in hypospadias surgery, suggests that sacral multifidus plane block can provide postoperative analgesia comparable to caudal epidural block, with effective opioid-sparing benefits and a potentially favorable safety profile in experienced hands.

From a clinical decision-making perspective, neither technique should be viewed as universally superior. Instead, the choice between caudal epidural block and sacral multifidus plane block should be individualized based on surgical complexity, patient factors, institutional expertise, and practitioner proficiency with ultrasound-guided regional anesthesia. Importantly, consistent adherence to pediatric dosing limits, vigilant monitoring, and integration within a structured multimodal analgesic pathway are essential regardless of block selection.

As pediatric regional anesthesia continues to evolve, sacral multifidus plane block represents a valuable addition to the anesthesiologist's armamentarium for hypospadias repair. Further multicenter trials, standardized technique definitions, and long-term outcome assessments will be crucial to refining its role alongside caudal epidural block and to establishing evidence-based, procedure-specific analgesic recommendations for pediatric urologic surgery.

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