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Part 1:

Title: Error Traps in Infant Spinal Anesthesia

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Clinical Implications:

What is already known about infant spinal anesthesia?

Infant spinal anesthesia is a feasible alternative to general anesthesia for short procedures below the upper abdomen.

What new information does this paper add?

This paper discusses five preventable perioperative cognitive and procedural errors that might occur during infant spinal anesthesia with the goal of providing updated expert clinical guidance for successful performance of this technique.

Abstract

Infant spinal anesthesia is a viable alternative to general anesthesia for short procedures below the upper abdomen. It provides a hemodynamically stable anesthetic technique that avoids airway manipulation and associated respiratory complications. Spinal anesthesia allows surgery to be performed without inhaled anesthetic agents or, in certain cases, opioids. This manuscript highlights five preventable perioperative error

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traps that may occur while performing infant spinal anesthesia with the goal of providing expert clinical guidance for provision of safe, effective, and efficient spinal anesthesia in pediatric patients.

Key words: neonate, infant, pediatric, spinal anesthesia, regional

1. Introduction:

Spinal anesthesia (SA) was first described by German surgeon August Bier in 1899 (1). Subsequent years saw many reports of its use in both adult and pediatric patients (2). Significant interest in SA for neonates and infants reappeared in the 1980s after the late Chris Abajian described its use in a high-risk infant for various procedures below the umbilicus (3). Since then, many pediatric anesthesiologists have developed and maintained successful infant SA programs to offer this technique as an alternative to general anesthesia (GA) (4).

The benefits of SA are well-documented (5-7). Notable strengths include lack of airway instrumentation, less risk of hemodynamic changes, and a reduction in postoperative apnea (8). This reduction was noted in the incidence and severity of early apneas, defined as within the first 30 minutes of recovery (9). Additionally, studies have demonstrated the opioid-sparing effect of SA (10-12). Infants with past medical histories significant for prematurity or severe cardiopulmonary disease may benefit from an alternative to GA. Literature strongly supports that SA results in less hemodynamic instability in children as compared to adults (13-15). More specifically, in comparison to GA, SA in infants results in a lower incidence of hypotension and the need for intervention (16). Lastly, more efficient operating room (OR) and recovery room utilization have been demonstrated with SA (17,18).

2.1 Error Trap 1: Failure to appropriately prepare the infant for SA.

In appropriate babies, preparation for SA involves proper topical anesthesia of the skin where the spinal needle will be introduced. To minimize movement and improve positioning, use of premedication may be considered in appropriate patients as proper positioning will optimize chances for success (**Table 1**). **Precaution should be taken in all neonates (as all neonates are at risk of sedation-related apnea) and in infants at high risk for perioperative apnea, where premedication is not required and can be deferred.**

2.2 Prior to obtaining informed consent, a history and physical examination should be performed to assess for any contraindications to SA. Contraindications include local or

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systemic infection, coagulopathy, anatomical deformities, intracranial pathology (e.g. hydrocephalus, hypertension, bleeding), unimaged and concerning sacral dimple, allergy to local anesthesia, or parent/patient refusal (19). Reasons for case cancellation are identical to those for GA (e.g. NPO violation, lower respiratory tract infections).

While practices may differ among institutions, administration of early, correctly placed topical or local anesthesia remains an important consideration for performing successful SA and reducing discomfort in infants (20). LMX cream (4% lidocaine) is commonly employed for this purpose. EMLA cream (mixture of lidocaine 2.5% and prilocaine 2.5% formulated as an oil in water emulsion) is another viable option. A single application of transdermal local anesthetic cream has not been shown to cause clinically significant risk for methemoglobinemia in neonates (21). When used, local anesthetic cream should be placed at least 30 minutes prior to spinal injection to ensure adequate dermal penetration and anesthesia. The site is then covered with an occlusive dressing. Another viable approach is to use a sterile subcutaneous needless lidocaine injection device or administering a small skin wheel with local using a 30G needle just prior to spinal needle puncture.

Proper placement of local anesthetic cream is essential (**Image 2.2**). The infant should be held in the curved spinal position for correct placement. Applying over a straight spine may result in incorrect placement (e.g. over the sacrum) of the local anesthetic cream, as skin may shift over the spinous processes with subsequent spinal positioning. The intercristal or Tuffier's line (i.e. the line between the highest points of the iliac crests) should be identified and used to correctly place local anesthetic cream on the skin overlying the lumbar spine. The intercristal line can be used as an anatomical landmark for the L4-L5 lumbar spinal level, however, studies have shown this can be inaccurate and ultrasound confirmation may be helpful (22,23). As L4-L5 is below the conus medullaris, SA may be performed safely at this level with low risk of spinal cord injury (24).

2.3 In infants without risk of postoperative apnea, premedication administration to allow for easier placement of SA may be considered for more vigorous patients. Common premedications include midazolam (oral or intranasal) or dexmedetomidine (intranasal). The safety of these medications for sedation or anxiolysis has been demonstrated in pediatric patients (25,26). Standard dosing range for midazolam is 0.25-0.5 mg/kg PO or 0.2-0.3 mg/kg IN (27). For dexmedetomidine, the dosing range for intranasal dosing is typically 1-4 mcg/kg. Doses up to 4 mcg/kg have been used with minimal risk of hemodynamic instability upon co-administration of an alpha-agonist (e.g. clonidine) into the intrathecal space. Midazolam should be administered 10-15 minutes prior to spinal injection. Dexmedetomidine premedication should be administered at least 20-30

minutes prior to planned spinal placement. Others have described using intranasal fentanyl with good success (28). Again, precaution should be taken in all neonates (as all neonates are at risk of sedation-related apnea) and in infants at high risk for perioperative apnea, where premedication can be deferred.

Nonpharmacologic techniques should strongly be considered, specifically using a pacifier with Sweet-Ease (24% concentration of sucrose and purified water) as well as bringing special patient items to the OR (e.g. blanket, toy, music).

2.4 Positioning and immobilization for spinal placement is arguably the most important aspect in successfully performing SA in infants (**Image 2.4a**). Sitting or lateral decubitus positions are both commonly utilized; however, in awake, moving infants, the sitting position may be more beneficial as compared to the lateral decubitus position. Important anatomical landmarks (e.g. interspinous processes, spinal column, iliac crests) are easier to identify in the sitting position. Ultrasound studies have suggested that the sitting position with hip flexion is optimal for increasing the external interspinous distance for successful needle insertion (29). Additionally, the sitting position increases the pooling of cerebrospinal fluid (CSF) and CSF hydrostatic pressure via gravity, allowing for a larger intrathecal target as well as faster detection of CSF (30). The use of lateral positioning has also been described, and the success of lumbar puncture on the first attempt in the lateral position has not been shown to be inferior (31).

Goals of positioning include stabilizing the trunk and hips and appropriately curving the spine to maximize the distance between interspinous processes while ensuring minimal movement and a patent airway (**Image 2.4b**). Extreme neck flexion must be avoided as this may result in inadvertent airway obstruction (32). Use of positioning supports, such as the yellow foam head donut for neonates or a blanket roll under the legs of an infant, may optimize position and increase chances of spinal placement success. The tops of the iliac crest should be marked with a surgical pen prior to sterile preparation to serve as a visual estimation of the L4-L5 interspinous space. Regardless of position, the intrathecal space is usually accessed using a midline approach.

2.5 Lastly, using nitrous oxide delivered via anesthesia mask can be implemented as a last resort to allow the infant to remain more stationary during spinal block placement (33). This technique requires several minutes for adequate sedation but ultimately will allow for more a stationary patient.

The GAS Study, which was a multi-center randomized control study comparing awake regional anesthetic with sevoflurane-based general anesthesia, reported a spinal block success rate of 83% (5). The research protocol precluded routine use of sedative

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premedication or sedation for initiation of neuraxial/regional block. Recent studies demonstrate a higher success rate of more than 90% (34), although this number has been reported to be as high as 97% at some institutions (35, 36). The authors recommend that premedication should be considered to increase SA success rate, but caution should be used in all neonates and infants at high risk for apnea.

Table 1: Preoperative Premedications:

*below

3.1 Error trap 2: Failure to obtain reflux of CSF or obtaining blood in needle hub on the first attempt.

Failure to obtain reflux of CSF is related to the trajectory and depth of needle insertion (19). Blood in the needle hub is a risk factor for SA failure (37).

3.2. The optimal style and size of the needle for SA is controversial (19). Institutional and regional preferences for needles abound, and a variety of needles may be utilized. SA has been performed with 22G, 25G, and 27G needles, 1-inch or 1.5-inch length needles, and with needles with both cutting or pencil-point tips (38). Despite the larger gauge caliber of the 22G needle, the incidence of post-dural puncture headache (PDPH) in infants is extremely low (39), which may be a result of decreased reporting due to horizontal nursing of infants and difficulty in diagnosing PDPH in this pre-verbal patient population. The caliber of the needle and patient position will influence the rate of CSF flow, with faster and more robust flow seen with use of larger caliber 22G needles and with the patient in the sitting position. Needle rotation to 90 degrees can improve CSF flow if the needle aperture is blocked by cauda equina fibers (19).

3.3 Styletted spinal needles are recommended to avoid introducing epidermal tissue into the intrathecal space. The timing of removal of the stylet varies among providers. The stylet may be removed after the needle is advanced through the dermis with further advancement into the intrathecal space without the stylet until a “pop” is felt and a reflux of CSF occurs. The trajectory of the needle insertion is at less of an angle than in adults or older children due to the straighter orientation of the spinous processes in infants (29). The depth of needle insertion has been previously described by various formulas, specifically estimating depth in mm using {0.3 × height (cm)} or {2 × weight (kg) +7} (40-42). As a rough estimate, the distance to the intrathecal space from the skin is less than 15 mm in neonates and 15-25 mm in infants (40). Availability of ultrasound has allowed for pre-procedural anatomical evaluation and estimation of the distance to the intrathecal space.

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3.4 If blood is seen in the needle hub on the first attempt, this likely means that the trajectory of the needle is lateral to the intrathecal space or that the needle is inserted too deep, traversing through the intrathecal sac and entering the anterior internal epidural venous plexus (43). If the needle is too deep, a slight withdrawal of the needle can be attempted to allow the needle tip to re-enter the intrathecal sac, allowing CSF flow to clear blood in the needle hub. If clearing does not occur, the needle should be removed, and a new needle should be redirected toward the midline. Another option is to attempt needle insertion at a space above the previously failed level but only if the new level is at or below the L3-L4 interspace. Using the two-finger technique, with the non-dominant middle and index finger positioned on both sides of the interspinous space, allows the proceduralist to more accurately identify the midline.

3.5 After the successful flow of CSF is obtained, the syringe can be attached carefully to the needle for injection (19). It is recommended to immobilize the needle by resting the back of the non-dominant hand firmly against the patient's back and by using the thumb and index finger to hold the hub of the needle (**Image 3.5**). Aspiration prior to injection is dependent on provider preference but is recommended to ensure that syringe attachment did not unintentionally cause migration of the needle tip outside of the intrathecal space, leading to deposition of medication into the epidural space (19). Injection speed should be at moderate speed, about 1mL over 3 seconds.

4.1 Error trap 3: Failure to prepare for challenging intravenous access after successful spinal block.

Some anesthesiologists will obtain intravenous (IV) access in the lower extremities after placement of the spinal block (36,44-45). As described previously, hemodynamic instability after SA in neonates and infants is rare due to underdeveloped autonomic nervous systems (46). All monitors besides pulse oximetry may be applied after successful block placement.

4.2. IV access is routinely done in the lower extremities after spinal placement to take advantage of the sensory and motor block obtained. Commonly used adjuncts for difficult pediatric IV placement should be immediately available (e.g. ultrasound, vein light finder). Since the duration of the spinal block is limited, the authors recommend having the most experienced provider attempt initial IV placement and advocate for early utilization of adjuncts for difficult IV placement if needed, especially for longer surgical procedures. IV placement after infant SA may be difficult due to young age, copious adipose tissue, dehydration from prolonged NPO time, limited limbs with sensory block available for placement, limited time for IV placement relative to spinal block, and lack of vasodilation seen with GA.

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If lower extremity sites have been exhausted during IV attempts, IV placement in the upper extremities may be attempted. If the infant has fallen asleep after spinal placement, IV attempts without topicalization with a local anesthetic in the upper extremities may be successful. Use of a subcutaneous needleless lidocaine injection device or supplemental sedation with temporary nitrous oxide may also be utilized if the baby is inconsolable.

One disadvantage of placing the IV after the spinal block is the lack of intravenous access to rescue bradycardia, respiratory depression or apnea during unexpected high or total spinal. As a result, intramuscular rescue medications should be readily available if this scenario ensues.

5.1 Error trap 4: Failure to create optimal operating conditions for surgeon after spinal block.

After a successful spinal block, infants typically fall asleep naturally due to the phenomenon of sensory deafferentation. The mechanism of sensory deafferentation involves decreased neural signaling and reduced stimulation of the reticular activating system from neuraxial sympatholysis resulting in decreased arousal (47,48). Despite this reduction in cerebral stimulation, some infants will not sleep after spinal placement. In these cases, additional soothing techniques should be considered after confirmation of sensory and motor block. As a precaution, the arms can be gently immobilized with a bandage roll or soft restraints to prevent sterile field contamination in the event of a startle response (**Image 5.1**).

5.2 Fussiness of the infant under SA should be managed in a stepwise fashion beginning with nonpharmacologic methods. The pacifier and sucrose solution utilized for block placement may be continued during surgery. OR conversations and loud noises should be kept to a minimum. “Awake Patient” signage outside the OR doors can be used to alert incoming staff to adhere to quiet conduct. In addition, lullabies or white noise can be played for the infant during the procedure. Forced air warmers are great sources of warmth and ambient noise.

5.3 If nonpharmacologic techniques fail, pharmacologic alternatives, such as dexmedetomidine, midazolam, or fentanyl, may be considered if the patient is not at risk for postoperative apnea. Intravenous dexmedetomidine, administered in 0.25-0.5 mcg/kg increments, should be considered as the first-line sedative agent given its low risk of respiratory depression. Additional options include intravenous midazolam (0.05-

0.1 mg/kg) or fentanyl (0.5-1 mcg/kg). Heavier sedation with propofol is typically unnecessary and may mask a partial or failed spinal block.

5.4 When using isobaric bupivacaine 0.5%, a successful spinal block should be present within 15-30 seconds. Immobility and lack of response to lower extremity IV placement is another confirmatory sign. Occasionally, spinal injection resulting in partial sensory or partial motor block may occur and will manifest by either pain with IV placement or presence of continued movement of the lower extremities, respectively. Partial motor block may be mitigated with a loading dose of dexmedetomidine (0.5-1 mcg/kg). Partial sensory block may be supplemented with local anesthetic infiltration or nerve block administered by the surgeon or with IV sedation. A penile block is appropriate for penile procedures. An ilioinguinal block can be performed for hernia repairs. Maximum dose of local anesthesia should be calculated prior to SA administration for ease in determining the amount of local anesthetic available for the surgeon to administer.

During inguinal hernia repair, traction on the spermatic cord or peritoneum can elicit a pain response from the infant (49). Small case series have described using SA successfully for laparoscopic procedures (50-52). Insufflation during laparoscopic procedures may also cause discomfort. Pain can be treated with the above-mentioned pharmacologic approaches, local infiltration by the surgeon, termination of tension on sensitive structures, and reduction of insufflation pressures (50-52). Open communication between surgical and anesthesia teams is paramount during these critical portions of the procedure.

5.5 Repeating spinal injection in infants after partial blockade or failed spinal has been described (53). Failure of initial spinal injection is presumed to be due to the deposition of local anesthetic into the epidural space instead of the intrathecal space. Prior to attempting repeat spinal injection, one should wait 5-10 minutes to rule out the slow onset of a neuraxial block (53). The second spinal block attempt can be repeated with similar local anesthetic concentrations; however, it should be noted that a higher incidence of a high spinal block has been described with repeat spinal injection (53,54). Rescue caudal block after spinal block using safe levobupivacaine concentrations has been described (55). Signs of higher-than-intended spinal blockade include respiratory compromise, lack of arm movement, and bradycardia. A properly placed shoulder roll can be used to elevate the upper torso once the infant is positioned supine for the surgery as lack of lumbar lordosis in infants predisposes them to higher spinal block when placed supine for the procedure. Finally, a more experienced anesthesiologist should attempt placement of the second spinal block if available.

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5.6 The infant's arms can be softly immobilized with a gauze roll to avoid contamination of the surgical field from inadvertent arm movement. In addition, a towel taped across the lower extremities will minimize leg movement if the motor block starts to recede near the end of the procedure. **Lower extremity immobilization also serves as a reminder to avoid leg-lifting by the OR staff, thus preventing inadvertent iatrogenic high spinal**. The risk is greatest when hyperbaric local anesthetic is used for spinal block. The Bovie pad is routinely applied prior to placing the patient supine. Alternatively, it can be applied after levitating or rolling the patient laterally.

6.1 Error trap 5: Failure of spinal block to have sufficient duration for the surgery being performed.

Appropriate selection of local anesthetic solution (with or without adjuncts) is essential for safe and effective anesthesia. Tetracaine, bupivacaine, levobupivacaine, and ropivacaine have been successfully used for infant SA (55). Dosing for SA in infants is larger on a per kilogram basis than in adults due to a larger volume of CSF per kilogram and more rapid CSF clearance in neonates and infants. Faster turnover of CSF limits the duration of action of SA in infants resulting in reduced length of sensory and motor blockade and subsequent operating time (53). Adjunctive medications, such as clonidine or epinephrine, should be considered to prolong the spinal block and extend surgical time (45). Additionally, OR factors should be optimized to reduce time from spinal injection to surgery start, including requiring the surgeon to be present in the OR for spinal block placement and recommending efficient surgical preparation of the patient and surgical scrubbing.

6.2 Preservative-free isobaric bupivacaine 0.5% is the preferred local anesthetic for infant SA (**Table 2**). Other local anesthetics described for SA include levobupivacaine, tetracaine, and ropivacaine (55,56). Isobaric bupivacaine is more potent than ropivacaine and levobupivacaine and thus, produces a longer spinal block, generally between 45-60 minutes in duration (55). Use of hyperbaric bupivacaine 0.75% has been described, but its use requires a more cautious approach to avoid higher-than-intended spinal block. In addition, hyperbaric bupivacaine 0.75% dosing increments and volumes are reduced, resulting in shorter duration of action. Dosing for isobaric bupivacaine 0.5% is 1 mg/kg or 0.2 mL/kg, with maximum dose of 5 mg or 1 mL for infants > 5 kg. For an infant or child > 12 kg, administration of a maximum volume of 1.2 mL or 6 mg can be considered. There is no evidence that dosing for infants needs to be adjusted based on gender (57).

6.3 Commonly used adjuncts for spinal block prolongation include epinephrine and clonidine. Epinephrine may prolong the duration of SA by 15-30 minutes. Dosing in the

intrathecal space ranges from 1-3 mcg/kg (41,44,59-61). Another common technique is utilization of an “epi wash” which involves washing the inside of a syringe with 1:1,000 epinephrine before filling it with local anesthetic. The goal of an “epi wash” is an epinephrine concentration of approximately 5 mcg/mL.

Intrathecal clonidine, an alpha-2 agonist, in doses of 1 mcg/kg has been safely used to prolong spinal blockade by 30-60 minutes (55, 62-64). This dose of intrathecal clonidine in conjunction with intranasal dexmedetomidine, administered for premedication or intravenously during surgery for sedation, may be used with low concern for hemodynamic instability or respiratory compromise based on the authors’ experience. Doses of clonidine greater than 2 mcg/kg have been associated with increased sedation, respiratory depression requiring caffeine, and hypotension (63).

Intrathecal opioids, like morphine and fentanyl, have been previously described as adjuvants for SA in pediatric patients (41). However, their use is infrequent for infant SA in the OR given the associated risk of apnea and need for prolonged hospitalization for respiratory monitoring.

Table 2: Intrathecal Medications
*below

6.4 It is vital to create a contingency plan to deal with surgeries that exceed the effective duration of the block. A caudal catheter placed after the spinal block can be used to administer a continuous infusion of chloroprocaine to extend the duration of neuraxial anesthesia after the spinal block height is no longer sufficient (65). For bilateral herniorrhaphy, the surgeon should consider repairing both sides prior to closure of the incisions, then using local anesthetic infiltration to supplement the skin closure.

7 Summary

Spinal anesthesia for infants has seen a resurgence in pediatric anesthesiology practice over the last 40 years. This hemodynamically stable technique avoids airway manipulation and may alleviate some concerns surrounding neurodevelopmental risks associated with general anesthesia in our smallest patients (10,66). Prior manuscripts have summarized technical approaches and pitfalls for performing this technique (67). This manuscript is an updated summary of recommended technical aspects ideally employed for performing SA in the context of the latest literature and evidence as well as expert consensus. We have highlighted five common error traps requiring special attention to increase the success rate of performing SA for infants. This foundation will

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allow for provision of a safe, reliable, and efficient spinal anesthesia program benefiting both patients and families. SA limits the use of anesthetic gases with the potential for environmental benefit as well. Lastly, SA decreases OR and recovery times which may result in significant financial benefit for pediatric hospitals (18, 68-70).

8 Reflective Questions:

1) What are ways to increase the success rate of performing a spinal anesthetic on infants?
2) What positioning techniques are important for performing a spinal block?
3) What intrathecal adjuvants can be added to the spinal dose to increase its duration?
4) What are ways an infant can be calmed during a procedure if they are startled or awakened despite a working spinal block?
5) What are the benefits of spinal anesthesia versus general anesthesia?

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References:

1) Bier A. Experiment regarding the cocainization of the spinal cord. Zentralbl Chir 1899; 51:361e9.
2) Gray, HT. A Study of Spinal Anesthesia in Children and Infants: from a series of 200 cases. Lancet: Research article Volume 174, Issue 4491, P913-917, 9/25/1909.
3) Abajian JC, Mellish RW, Browne AF, Perkins FM, D H Lambert DH, Mazuzan Jr JE. Spinal anesthesia for surgery in the high-risk infant. Anesth Analg. 1984 Mar;63(3):359-62.
4) Mandabach, M. The early history of spinal anesthesia. International Congress Series Volume 1242, December 2002, Pages 163-168.
5) McCann ME, Withington DE, Arnup SJ, Davidson AJ, Disma N, Frawley G, Morton NS, Bell G, Hunt RW, Bellinger DC, Polaner DM, Leo A, Absalom AR, von Ungern-Sternberg BS, Izzo F, Szmuk P, Young V, Soriano SG, de Graaff JC; GAS Consortium. Differences in Blood Pressure in Infants After General Anesthesia Compared to Awake Regional Anesthesia (GAS Study-A Prospective Randomized Trial). Anesth Analg. 2017 Sep;125(3):837-845.
6) McCann ME, de Graaff JC, Dorris L, Disma N, Withington D, Bell G, Grobler A, Stargatt R, Hunt RW, Sheppard SJ, Marmor J, Giribaldi G, Bellinger DC, Hartmann PL, Hardy P, Frawley G, Izzo F, von Ungern Sternberg BS, Lynn A, Wilton N, Mueller M, Polaner DM, Absalom AR, Szmuk P, Morton N, Berde C, Soriano S, Davidson AJ; GAS Consortium. Neurodevelopmental outcome at 5 years of age after general anaesthesia or awake-regional anaesthesia in infancy (GAS): an international, multicentre, randomised, controlled equivalence trial. Lancet. 2019 Feb 16;393(10172):664-677.
7) Sun LS, Li G, Miller TL, Salorio C, Byrne MW, Bellinger DC, Ing C, Park R, Radcliffe J, Hays SR, DiMaggio CJ, Cooper TJ, Rauh V, Maxwell LG, Youn A, McGowan FX: . Association between a single general anesthesia exposure before age 36 months and neurocognitive outcomes in later childhood. JAMA. 2016; 315:2312–20.
8) Welborn LG, Rice LJ, Hannallah RS, Broadman LM, Ruttimann UE, Fink R. Postoperative apnea in former preterm infants: prospective comparison of spinal and general anesthesia. Anesthesiology. 1990 May;72(5):838-42.
9) Davidson AJ, Morton NS, Arnup SJ, de Graaff JC, Disma N, Withington DE, Frawley G, Hunt RW, Hardy P, Khotcholava M, von Ungern Sternberg BS, Wilton N, Tuo P, Salvo I, Ormond G, Stargatt R, Locatelli BG, McCann ME; General Anesthesia compared to Spinal anesthesia (GAS) Consortium. Apnea after Awake Regional and General Anesthesia in Infants: The General Anesthesia Compared to Spinal Anesthesia Study--Comparing Apnea and

Author Manuscript

Neurodevelopmental Outcomes, a Randomized Controlled Trial. Anesthesiology. 2015 Jul;123(1):38-54.
10) Ebert KM, Jayanthi VR, Alpert SA, Ching CB, DaJusta DG, Fuchs ME, McLeod DJ, Whitaker EE. Benefits of spinal anesthesia for urologic surgery in the youngest of patients. J Pediatr Urol. 2019 Feb;15(1): 49.e1-49.e5.
11) Ambrose N, Sadacharam K, Burke B, Figueroa TE, Lang RS, Kjelstrom S, Hagerty J. Spinal versus general anesthesia: Comparing outcomes in pediatric patients undergoing urologic procedures. J Pediatr Urol. 2023 Oct;19(5):621.e1-621.e9.
12) Holman, AE, Haydar, B, Harbaugh, C, Lange, A, Malviya, S. Pain and Analgesic Use Post-Procedure and Post-Discharge After Infant Spinal Anesthesia Versus General Anesthesia: A Retrospective Cohort Analysis. Pediatric Anesthesia, 2024; 0:1–3.
13) Oberlander TF, Berde CB, Lam KH, Rappaport LA, Saul JP. Infants tolerate spinal anesthesia with minimal overall autonomic changes: analysis of heart rate variability in former premature infants undergoing hernia repair. Anesth Analg. 1995 Jan;80(1):20-7.
14) Shenkman Z, Johnson VM, Zurakowski D, Arnon S, Sethna NF. Hemodynamic changes during spinal anesthesia in premature infants with congenital heart disease undergoing inguinal hernia correction. Paediatr Anaesth. 2012 Sep;22(9):865-70.
15) Ing C, Sun LS, Friend AF, Kim M, Berman MF, Paganelli W, Li G, Williams RK. Differences in intraoperative hemodynamics between spinal and general anesthesia in infants undergoing pyloromyotomy. Paediatr Anaesth. 2017 Jul;27(7):733-741.
16) McCann ME, Withington DE, Arnup SJ, Davidson AJ, Disma N, Frawley G, Morton NS, Bell G, Hunt RW, Bellinger DC, Polaner DM, Leo A, Absalom AR, von Ungern-Sternberg BS, Izzo F, Szmuk P, Young V, Soriano SG, de Graaff JC; GAS Consortium. Differences in Blood Pressure in Infants After General Anesthesia Compared to Awake Regional Anesthesia (GAS Study-A Prospective Randomized Trial). Anesth Analg. 2017 Sep;125(3):837-845.
17) Ing C, Sun LS, Friend AF, Roh A, Lei S, Andrews H, Li G, Williams RK. Adverse Events and Resource Utilization After Spinal and General Anesthesia in Infants Undergoing Pyloromyotomy. Reg Anesth Pain Med. 2016.
18) Kachko L, Simhi E, Freud E, Dlugy E, Katz J. Impact of spinal anesthesia for open pyloromyotomy on operating room time. J Pediatr Surg. 2009 Oct;44(10):1942-6.
19) Kokki H. Spinal blocks. Paediatr Anaesth 2012; 22:56e64.
20) Pessano S, Romantsik O, Olsson E, Hedayati E, Bruschettini M. Pharmacological interventions for the management of pain and discomfort during

Author Manuscript

lumbar puncture in newborn infants. Cochrane Database Syst Rev. 2023 Sep 28;9(9):CD015594.
21) Gourrier E, Karoubi P, El Hanache A, Merbouche S, Mouchnino G, Leraillez J. Use of EMLA® cream in a department of neonatology. Pain 1996; 68: 431–4.
22) Du J, Roth C, Dontukurthy S, Tobias JD, Veneziano G. Manual Palpation versus Ultrasound to Identify the Intervertebral Space for Spinal Anesthesia in Infants. J Pain Res. 2023 Jan 10;16:93-99.
23) Hayes J, Borges B, Armstrong D, Srinivasan I. Accuracy of manual palpation vs ultrasound for identifying the L3-L4 intervertebral space level in children. Paediatr Anaesth. 2014 May;24(5):510-5.
24) Jung J. et al. The influence of age on positions of the conus medullaris, Tuffier's line, dural sac, and sacrococcygeal membrane in infants, children, adolescents, and young adults. Paediatr Anaesth. 2016 Dec;26(12):1172-1178.
25) Lethin M, Paluska MR, Petersen TR, Falcon R, Soneru C. Midazolam for Anesthetic Premedication in Children: Considerations and Alternatives. Cureus. 2023 Dec 11;15(12).
26) Zhang G, Xin L, Yin Q. Intranasal dexmedetomidine vs. oral midazolam for premedication in children: a systematic review and meta-analysis. Front Pediatr. 2023 Nov 7;11: 1264081.
27) Coté, CJ, et al. A comparison of three doses of a commercially prepared oral midazolam syrup in children. Anesth Analg. 2002 Jan;94(1):37-43.
28) Jefferson FA, Findlay BL, Handlogten KS, Gargollo PC, Warner LL, Woodbury JM, Haile DT, Granberg CF. Spinal anesthesia in infants undergoing urologic surgery duration greater than 60 minutes. J Pediatr Urol. 2022 Dec;18(6):786.e1-786.e7.
29) Oulego-Erroz, I, et al. Ultrasound evaluation of lumbar spine anatomy in newborn infants: implications for optimal performance of lumbar puncture. J Pediatr. 2014 Oct;165(4):862-5.e1.
30) Holland JA, Funnell JP, Mittal R, Krishnakumar D. How to use lumbar puncture manometry in children. Arch Dis Child Educ Pract Ed. 2023 Oct;108(5):340-346.
31) Pessano S, Bruschettini M, Prescott MG, Romantsik O. Positioning for lumbar puncture in newborn infants. Cochrane Database Syst Rev. 2023 Dec 14;12(12):CD015592.
32) Gleason CA, Martin RJ, Anderson JV, Carlo WA, Sanniti KJ, Fanaroff AA. Optimal position for a spinal tap in preterminfants. Pediatrics 1983; 71: 31–5.
33) Vila, R, Lloret, J, Munar, F, Vinzo, J. Spinal anaesthesia for inguinal herniotomy in preterm infants sedated with nitrous oxide: a comparison of lumbar puncture in the lateral or sitting position. Anaesthesia. 2002 Dec;57(12):1164-7.
34) Heydinger G, Roth C, Kidwell R, Tobias JD, Veneziano G, Jayanthi VR, Whitaker EE, Thung AK.A Single Center's Experience With Spinal Anesthesia for Pediatric

Patients Undergoing Surgical Procedures. J Pediatr Surg. 2024 Jun;59(6):1148-1153.
35) Eizaga Rebollar R, García Palacios MV, Morales Guerrero J, Torres Morera LM. Pediatric spinal anesthesia at a tertiary care hospital: Eleven years after. Paediatr Anaesth. 2022 May;32(5):617-624.
36) Williams RK, Adams DC, Aladjem EV, Kreutz JM, Sartorelli KH, Vane DW, Abajian JC. The safety and efficacy of spinal anesthesia for surgery in infants: The Vermont Infant Spinal Registry. Anesth Analg. 2006; 102:67–71.
37) Frawley G, Bell G, Disma N, Withington DE, de Graaff JC, Morton NS, McCann ME, Arnup SJ, Bagshaw O, Wolfler A, Bellinger D, Davidson AJ; General Anesthesia compared to Spinal anesthesia (GAS) Consortium. Predictors of Failure of Awake Regional Anesthesia for Neonatal Hernia Repair: Data from the General Anesthesia Compared to Spinal Anesthesia Study--Comparing Apnea and Neurodevelopmental Outcomes. Anesthesiology. 2015 Jul;123(1):55-65.
38) Kokki H, Turunen M, Heikkinen M, Reinikainen M, Laisalmi M. High success rate and low incidence of headache and neurological symptoms with two spinal needle designs in children. Acta Anaesthesiol Scand. 2005 Oct;49(9):1367-72.
39) Wee LH, Lam F, Cranston AJ. The incidence of post dural puncture headache in children. Anaesthesia 1996; 51:1164–6.
40) Celik D, Onal O, Apiliogullari S, Kara I, Celik JB. Estimating the Lumbar Puncture Needle Depth in Children. J Invest Surg. 2021 Feb;34(2):157-163.
41) Gupta A., Saha, U. Spinal anesthesia in children: A review. J Anaesthesiol Clin Pharmacol. 2014 Jan;30(1):10-8.
42) Arthurs OJ, Murray M, Zubier M, Tooley J, Kelsall W. Ultrasonographic determination of neonatal spinal canal depth. Arch Dis Child Fetal Neonatal Ed. 2008 Nov;93(6):F451-4.
43) Pessano S, Bruschettini M, Prescott MG, Romantsik O. Positioning for lumbar puncture in newborn infants. Cochrane Database Syst Rev. 2023; 2023(12): CD015592. Published online 2023 Dec 14.
44) Whitaker EE, Wiemann BZ, DaJusta DG, Alpert SA, Ching CB, McLeod DJ, et al. Spinal anesthesia for pediatric urological surgery: reducing the theoretic neurotoxic effects of general anesthesia. J Pediatr Urol 2017 Aug;13(4):396e400.
45) Trifa M, Tumin D, Whitaker EE, Bhalla T, Jayanthi VR, Tobias JD. Spinal anesthesia for surgery longer than 60 min in infants: experience from the first 2 years of a spinal anesthesia program. J Anesth. 2018 Aug;32(4):637-640.
46) Oberlander TF, Berde CB, Lam KH, Rappaport LA, Saul JP. Infants tolerate spinal anesthesia with minimal overall autonomic changes: analysis of heart rate variability in former premature infants undergoing hernia repair. Anesth Analg. 1995 Jan;80(1):20-7.

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47) Hermanns H, Stevens MF, Werdehausen R, Braun S, Lipfert P, Jetzek-Zader M. Sedation during spinal anaesthesia in infants. Br J Anaesth. 2006 Sep;97(3):380-4.
48) Whitaker EE, Chao JY, Holmes GL, Legatt AD, Yozawitz EG, Purdon PL, Shinnar S, Williams RK. Electroencephalographic assessment of infant spinal anesthesia: A pilot prospective observational study. Paediatr Anaesth. 2021 Nov;31(11):1179-1186.
49) Wang T, Xiang Q, Liu F, Wang G, Liu Y, Zhong L. Effects of caudal sufentanil supplemented with levobupivacaine on blocking spermatic cord traction response in pediatric orchidopexy. J Anesth. 2013 Oct;27(5):650-6.
50) Eizaga Rebollar R, García Palacios MV, Morales Guerrero J, Torres Morera LM. Spinal Anesthesia for Pediatric Laparoscopic Hernia Repair: A Case Report. A A Pract. 2018 Dec 1;11(11):293-295.
51) Islam S, Larson SD, Kays DW, Irwin MD, Carvallho N. Feasibility of laparoscopic pyloromyotomy under spinal anesthesia. J Pediatr Surg. 2014 Oct;49(10):1485-7.
52) Chiao F, Boretsky K. Laparoscopic Surgery in Infants Under Spinal Anesthesia Block: A Case Report of 3 Cases. A A Pract. 2019 Mar 1;12(5):168-170.
53) Frawley G.Second infant spinal anesthetic: Incidence, dose modification, and adverse events after initial failure. Paediatr Anaesth. 2024 Apr;34(4):324-331.
54) Frawley G, Cortinez LI, Anderson BJ. Prediction of levobupivacaine concentrations in neonates and infants following neuraxial rescue blocks. Paediatr Anaesth. 2021 Jun;31(6):655-664.
55) Frawley, G and Ingelmo, P. Spinal anaesthesia in the neonate. Best Pract Res Clin Anaesthesiol. 2010 Sep;24(3):337-51.
56) Frawley G, Smith KR, Ingelmo P. Relative potencies of bupivacaine, levobupivacaine, and ropivacaine for neonatal spinal anaesthesia. Br J Anaesth. 2009 Nov;103(5):731-8.
57) Frawley, G, and Huque MH. Infant spinal anesthesia: Do girls need a larger dose of local anesthetic? Paediatr Anaesth. 2017 Oct;27(10):1037-1042.
58) Kokki H. Spinal blocks. Paediatr Anaesth 2012; 22:56e64.
59) Mahe V, Ecoffey C. Spinal anesthesia with isobaric bupivacaine in infants. Anesthesiology 1988; 68: 601–603.57.
60) Cronin JA, Satterthwaite B, Robalino G, Casella D, Hsieh M, Sohel Rana M, Fink A, Pestieau S. Improving Outcomes through Implementation of an Infant Spinal Anesthesia Program for Urologic Surgery Patients.Pediatr Qual Saf. 2023 May 22;8(3): e615.
61) Rochette A, Troncin R, Raux O, Dadure C, Lubrano JF, Barbotte E, Capdevila X. Paediatr Anaesth. Clonidine added to bupivacaine in neonatal spinal anesthesia: a prospective comparison in 124 preterm and term infants. 2005 Dec;15(12):1072-7.

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62) Batra YK, Rakesh SV, Panda NB, Lokesh VC, Subramanyam R. Intrathecal clonidine decreases propofol sedation requirements during spinal anesthesia in infants.Paediatr Anaesth. 2010 Jul;20(7):625-32.
63) Rochette A, Raux O, Troncin R, Dadure C, Verdier R, Capdevila X. Clonidine prolongs spinal anesthesia in newborns: a prospective dose-ranging study. Anesth Analg. 2004 Jan;98(1):56-59.
64) Heydinger G, Bayer EE, Roth C, Kitio SAY, Jayanthi VR, Thung A, Tobias JD, Veneziano G. Safety of Intrathecal Clonidine as an Adjuvant to Spinal Anesthesia in Infants and Children. Paediatr Anaesth. 2025 Mar 3.
65) Bean CD, Low SA, Novak AB, Chen AL, Elder JS, Liu CA. Awake Combined Spinal Caudal Anesthesia for Longer-Duration Urologic Surgery in Infants: A Case Series. A A Pract. 2024 Jun 3;18(6): e01792.
66) Fiadjoe JE, Nishisaki A, Jagannathan N, Hunyady AI, Greenberg RS, Reynolds PI, et al. Airway management complications in children with difficult tracheal intubation from the pediatric difficult intubation (PeDI) registry: a prospective cohort analysis. Lancet Respir Med 2016; 4:37e48.
67) Shenkman Z, Hoppenstein D, Litmanowitz I, Shorer S, Gutermacher M, Lazar L, Erez I, Jedeikin R, Freud E. Spinal anesthesia in 62 premature, former-premature or young infants--technical aspects and pitfalls. Can J Anaesth. 2002; 49:262–9.
68) Heydinger G, Kim SS, Beltran RJ, Veneziano G, Smith A, Tobias JD, Uffman JC. Ambulatory spinal anesthesia in infants six months of age: A retrospective review of outcomes and safety. J Clin Anesth. 2022 Oct; 81:110920.
69) Ambrose N, Sadacharam K, Burke B, Figueroa TE, Lang RS, Kjelstrom S, Hagerty J.J. Spinal versus general anesthesia: Comparing outcomes in pediatric patients undergoing urologic procedures. Pediatr Urol. 2023 Oct;19(5): 621.e1-621.e9.
70) Handlogten K, Warner L, Granberg C, Gargollo P, Thalji L, Haile D. Implementation of a spinal anesthesia and sedation protocol that reliably prolongs infant spinal anesthesia: Case series of 102 infants who received spinal anesthesia for urologic surgery. Paediatr Anaesth. 2020 Dec;30(12):1355-1362.

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Table 1: Preoperative Premedications

Medication	Dose	Lead time to OR
EMLA (lidocaine 2.5% and prilocaine 2.5%) or LMX cream (4% lidocaine)	1g application: squeeze from the tube, apply cream over lumbar spine 0.2x1.5 inch strip	30 minutes
Dexmedetomidine	2-4 mcg/kg IN	20-30 minutes
Midazolam	0.25-0.5 mg/kg PO 0.2-0.3 mg/kg IN	15 minutes

Table 2: Intrathecal Medications

Medication	Dose	Spinal Duration
Bupivacaine 0.5%	0.2 mL/kg (1 mg/kg) Max volume 1 mL (5 mg) For pts > 12 kg, up to 1.2 mL (6 mg) may be used	60 minutes
Clonidine	1 mcg/kg	30-60 minutes extended
Epinephrine	1-3 mcg/kg	15-30 minutes extended

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Image 2.2



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Image 2.4a



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Image 2.4b



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Image 3.5



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Image 5.1

