REVIEW

Spinal anesthesia in pediatric patients

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ABSTRACT

Spinal anesthesia (SA) in pediatrics began to be used in the late nineteenth century in multiple procedures, with priority for high-risk and former preterm infants, for its suggested protective role compared to the development of postoperative apnea with general anesthesia (GA). In children, higher doses of local anesthetics are required with a shorter duration of action and a greater hemodynamic stability compared to adults. The puncture must be performed in the L4-L5 or L5-S1 spaces to prevent spinal injuries. The practice of SA in pediatric patients requires skill and experience; failure rates of up to 28% have been reported. The drugs most commonly used for SA are tetracaine and bupivacaine alone or with adjuvants. SA complications are rare and often without consequences, except for post-dural puncture headaches and backaches. Although SA is today considered safe and effective for pediatric patients, it remains relatively underutilized compared to GA. *(Minerva Anestesiol 2012;78:78-87)*

Key words: Anesthesia, spinal - Child - Surgical procedures, operative.

Spinal anesthesia (SA) in pediatrics was first used by Bainbridge [1] in 1899 in an infant of 3 months with an incarcerated inguinal hernia. Although the first series of cases describing the use of this technique in children was published in 1909,[2] this technique did not gain widespread popularity in pediatric anesthesia until the early 1980s, when it was reintroduced as an alternative to general anesthesia (GA) in high-risk and former preterm infants. In this population, SA has been proposed as a means to reduce post-operative complications,[3] especially apnea and postoperative respiratory dysfunction, although this utility has been questioned.

Apart from this group of patients at risk, where the blockade is performed as the sole technique, SA may also be practiced in children of all ages with or without sedation.[4]

Indications

SA is a useful technique in infraumbilical and other specific procedures; the surgeries in which this anesthetic modality has been used are listed in Table I.[3, 5-13]

SA would be fundamentally useful in ex-preterm neonates and infants under 60 weeks of post-conceptional age, a population with an increased risk of respiratory complications and postoperative apnea, especially when the hematocrit is below 30% and prior episodes of apnea have existed.

SA could also be indicated in other situations as an alternative to GA, including:

— chronic respiratory disease;
— potentially difficult airway;[14, 15]
— malignant hyperthermia;[16]
— congenital heart disease, to minimize hemodynamic fluctuations;[17, 18]
— bullous epidermolysis, where manipulation of the airway should be avoided whenever possible;[19]
— children who have difficulties in sleeping.

Contraindications

Absolute contraindications are the same as in adults and include allergic reaction to local an-

TABLE I.—*Reported applications of SA.*

General surgical procedures
– Herniorrhaphy: inguinal, umbilical
– Appendicectomy
– Colostomy
– Perineoplasty
– Rectal biopsy
– Incision and drainage of rectal abscess
– Gastrostomy
– Closure of gastroschisis
– Exploratory laparotomy
– Bowel resection
– Extramucosal pylorotomy [4]
Urological procedures
– Orchidopexy
– Hydrocoelectomy
– Circumcision
– Cystoscopy
– Fulguration of posterior urethral valves
– Suprapubic cateter placement
– Vesicostomy
– Hypospadias repair
– Ureteral reimplant
Orthopaedic and lower extremity procedures
– Incision and drainage: hip or lower extremity
– Amputation: foot or lower extremity
– Bilateral adductor myotomy
– Closed reduction of hip
– Spica cast placement
– Club foot repair
– Lower extremity arthrogram
– Open reduction and internal fixation of hip
– Muscle biopsy
– Excision of tumour
– Tendon lengthening
– Staged segmental spinal fusion
Miscellaneous applications
– Neurosurgical procedures: meningomyelocele repair [5, 6]
– Cardiothoracic surgery:[7-11] PDA ligation, ASD/VSD closure, Glenn shunt, etc
– Diagnostic cardiac catheterization[12]
– Radiation oncology
– Chronic pain management

Modified from Tobias.[3]

esthetics (LAs), local or systemic infection (risk of meningitis), coagulopathy, intracranial hypertension, hydrocephalus, intracranial hemorrhage and parental refusal.

The interpretation of coagulation tests in infants can be difficult. At birth, only factors V and VIII reach adult levels; however, the full-term newborn is usually well-protected against bleeding. The values of the activated partial thromboplastin time (aPTT) in newborns are often higher, which can be considered physiological at this time of life. A study showed pathological values for the prothrombin time (PT) and the aPTT in 1.9% and 60.4% of preterm infants with a post-conceptional age below 45 weeks, respectively; there was no abnormal bleeding or puncture-related complications.[20] Moreover, the most common congenital abnormality of clotting in the pediatric population is von Willebrand´s disease (incidence of 1.3%), which is poorly detected by screening with the aPTT; no association between von Willebrand's disease, and the development of epidural hematoma in the pediatric population has been published.[21]

Intraventricular hemorrhage is a very common complication in premature infants (incidence of 20-30%). These children usually develop hydrocephalus and require the implantation of a ventriculoperitoneal shunt; they are also at high risk when using GA, because they often have major respiratory problems. Although the presence of a ventriculoperitoneal shunt has traditionally contraindicated neuroaxial techniques because of a risk of shunt infection or dural leak, 5 cases have been reported in children with ventriculoperitoneal drainage and major respiratory problems in which SA was successfully used.[22]

Hypovolemia and spinal deformities, such as spina bifida or myelomeningocele, could be considered relative contraindications for SA; however, this technique has been used in the repair of myelomeningocele in infants without exacerbating previous neurological function.[6, 7]

Anatomical and physiological considerations

The spinal cord ends at the third or fourth lumbar vertebra in the newborn and at the L1-L2 intersection at one year of age; before one year of age, the spinal tap should be performed in the L4-L5 or L5-S1 space.

The requirement for higher doses of LAs and a shorter duration of the anesthetic blockade should be expected, because they may limit the usefulness of SA in procedures exceeding 90 minutes. At birth, the volume of cerebrospinal fluid (CSF) (4 mL/kg^{-1}) is twice the volume in adults, and 50% of this is located in the spinal canal (compared with only 25% in adults), which results in further dilution of the medication administered. In addition, there is a higher proportion of nervous system structures with greater mass compared to muscle and bone mass.[23] As a result of a lower concentration of nodes of Ranvier, the neonate requires a higher concentration of LAs; moreover, there is a proportionally greater blood flow to the spinal cord with a more rapid uptake of drugs from the subarachnoid space.[24] These phenomena are most pronounced in preterm rather infants compared to full-term infants.[23]

An important peculiarity is the hemodynamic stability up to approximately 6 years of age. The blood pressure and heart rate are maintained even with blockade levels of T4[25] and without previous prehydration.[26] This phenomenon can be explained by a lower venous capacitance in the lower limbs,[25] less dependence of vasomotor tone in newborns,[25, 27] and especially a compensatory decrease in vagal activity [28] following heart sympatholysis.

Pure SA without sedation alters ventilation only if high blockade levels (affecting intercostal muscles) are achieved. However, newborn breathing depends primarily on the diaphragm, so they generally tend to maintain acceptable ventilation unless a T1 motor blockade level is reached.[3]

Technique

One hour before surgery, 0.5-1 mL EMLA should be applied at the levels of L3-L4, L4-L5 and L5-S1. In patients at risk of toxicity that is secondary to prilocaine (infants <32 weeks, anemia, or concomitant administration of paracetamol),[29] it might be better to infiltrate the skin with 0.1 mL lidocaine 1%.

The room temperature should be 25 °C or higher, and hypothermia and hyperthermia must be avoided because both can cause apnea. Basic monitoring is also required; the blood pressure cuff should be placed under the level of the blockade so that compression does not disturb the infant. Although a previous venous access is desirable, some authors performed compression in the lower limbs after the SA because the conditions could be more suitable (venous vasodilatation and an immobile patient).[21]


Figure 1.—Spinal puncture.


Figure 2.—Wrong position. Neck flexed.

Previous sedation with intravenous or volatile agents is possible; however, it should be avoided in newborns with a high respiratory risk. SA by itself has sedative effects, probably due to a decrease in afferent input to the ascending reticular system.[30] Sometimes it is enough to offer the child a pacifier dipped in sugar water.

The puncture can be performed with the child lying on his side or sitting (technically easier) with an assistant trying to hold the highest degree of flexion of the back but with the head slightly hyperextended to avoid obstruction of the airway (Figures 1, 2); both positions could be equally effective for the success of SA in neonates.[31] Elevating the head of the table 45 degrees while the puncture is made in the lateral position may increase the success rate in children under one year (this position could increase CSF pressure, widening the subarachnoid space).[32]

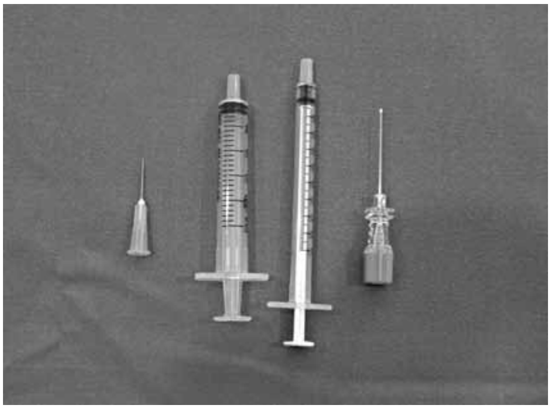
Figure 3.—A 25-gauge, 45-mm-long Quincke needle.

An imaginary line connecting the top of the iliac crests crosses the spinal axis at the L4-L5 interspace in neonates and infants and L3-L4 in older children.[3] The presence in this area of a hairy nevus, a hole or a lumbosacral asymmetric gluteal fold should alert the physicianstaff to the possibility of an occult spinal disorder.[21]

Needles ranging from 22- to 25-gauge with stylets and lengths from 30 to 45 mm are used; in the neonate, Quincke needles with a short bevel are preferable (Figure 3). The subarachnoid space is usually found 7-15 mm below the skin,[24] but may be only 3 mm deep[33]. This space is very narrow (diameter of 6-8 mm in term newborns),[24] so a slight deviation from the midline can result in a puncture failure. Hematic punctures are more common in children under one year of age than in adults,[34] with an estimated incidence of 8-19%, although incidences of up to 33.3% have been reported.[31] Some authors recommend that experienced pediatric anesthesiologists do not make more than 3 attempts at spinal puncture unless GA is contraindicated.[35]

The volumes of anesthetics in SA are very small, and for this reason, some authors make several recommendations. It is advisable to load drugs in a small syringe (1 mL),[36] and it is advisable to load 0.05-0.1 mL additional medication to compensate for the dead space of the spinal needle,[33, 37] or, after completing the injection, to aspirate 0.2-0.3 mL CSF and reinject.[3]

After the puncture, the child is placed supine or with a slight anti-Trendelenburg tilt of 20-30 degrees (2-3 minutes); raising the legs above the height of the trunk should be avoided to prevent an unwanted high spinal block (for example, when applying a electrocautery plate). Isobaric solutions could be more secure because the patient's position would not affect the extension of the blockade.[31]

Motor blockade of the lower limbs is established very quickly. It is difficult to determine the height of the blockade in younger children; the pinprick test is often used, but it can be painful and not entirely reliable. As an alternative, we can observe the progression of paralysis of the abdominal muscles while the baby cries, talks or coughs or the lack of response to tetanic stimulus applied with a peripheral nerve stimulator.[38]

In older children, the technique is similar to that in adults; 25- to 27-gauge pencil-point needles are used.

After the puncture, infants can be calmed with a pacifier without additional sedation, but older children often require it. Beyond 13 years of age, sedation usually is not necessary.[39]

The technique requires a considerable level of skill, especially in small children. Failure rates of blocking up to 28% have been published.[40]

Drugs and dosages

For most infraumbilical procedures performed under SA in neonates, a level T4-T5 is sufficient. The drugs most frequently used are tetracaine 0.5% and bupivacaine 0.5%, and the dose ranges vary greatly between studies. For most common procedures (excluding cardiac surgery, where higher doses are used), the usual doses are 0.6-0.8 $mg.kg^{-1}$ to achieve low-medium levels and 1 $mg.kg^{-1}$ to achieve high levels (T2-T4).[4] The duration of the block is approximately 90-120 minutes for both drugs. Newborns and infants are at an increased risk of toxicity following the administration of amide LAs; the risk is even greater in the case of jaundice.[23]

The older the child, the lower the doses that are required; in children between 6 months and 14 years, 0.5% hyperbaric bupivacaine at a dose of 0.2 $mg.kg^{-1}$ has been used with a success rate of 98%.[41] More recently, the successful use of 0.5% ropivacaine in children between 1 and 17 years at 0.5 mg.kg^{-1} [42] and 0.5% levobupivacaine in children between 1 and 14 years at 0.3 mg.kg^{-1} has been reported.[43]

Ropivacaine is an effective agent for neonates at 1.08 mg.kg^{-1}. The duration of the motor block is highly variable and significantly shorter than with equivalent agents; this may represent a disadvantage because the motor block is essential to achieve optimal surgical conditions.[44] Levobupivacaine is an effective agent for neonates at a dose of 1 mg.kg^{-1} .[45] and shows a clinical profile similar to bupivacaine but with a lower incidence of motor block; due to its lower toxicity, its use seems preferable in newborns and very young infants or when the liver function is impaired[46]. The use of 2% isobaric lidocaine in children under 13 years (2 mg.kg^{-1}) has also been reported but does not seem advisable due to its short duration.[47]

Some authors recommend adding epinephrine (1:100, 000 dilution) to extend the duration of the blockade (up to 30%).[48] However, epinephrine has been implicated in some reports of ischemic spinal injury, although this fact has not been demonstrated.[49, 50] The addition of clonidine to LAs,[51, 52] or the use of a combined spinal/epidural anesthesia,[53, 54] have been proposed as well.

The addition of clonidine to hyperbaric bupivacaine extends analgesia but may cause hypotension, bradycardia, and sedation. Doses of 1 mcg.kg^{-1} double the time of full recovery after the block compared with bupivacaine alone without hemodynamic or respiratory changes in the early postoperative period; with doses of 2 mcg.kg^{-1}, the duration of the blockade is similar, but the incidence of adverse effects is higher.[51] Close monitoring of these patients for 24 hours is highly recommended because of some reported cases of respiratory depression and bradycardia after spinal and caudal administration.[52, 55]

Although intrathecal opioids have been widely administered in adults, their use in the pediatric population has been much more restricted. Fentanyl in infants (1 mcg.kg^{-1}) increases the duration of SA for lower abdominal surgery and provides prolonged analgesia without significant respiratory or hemodynamic alterations and without delaying discharge from the Post-Anesthetic Recovery Unit (PACU).[56] In children older than one year of age, the dose should be reduced to minimize side effects.[57] Morphine has been used in doses up to 30 mcg.kg^{-1} in cardiothoracic, spinal, and oncological surgeries; doses of 4-5 mcg.kg^{-1} provide an effective and safe analgesia for a wide variety of surgical procedures.[58]

Recently, the effect of intrathecal neostigmine in children under one year of age who are undergoing lower abdominal procedures has been investigated. The optimum dose added to bupivacaine is 0.75 mcg.kg^{-1}, with a significant prolonging of the effect of SA and lower postoperative pain scores and without a significantly higher incidence of emesis or extension of stay in the PACU. No additional benefits of higher doses were found.[59]

In some procedures, SA may be an alternative to thoracic epidural anesthesia, including thoracic pheochromocytomas, esophageal atresia, upper abdominal surgery, and cardiac surgery. Typically, LA is used in high doses (tetracaine 0.5%, 0.5-2 mg.kg^{-1} or bupivacaine 0.5%, 1 mg.kg^{-1}) combined with morphine (5-20 mcg.kg^{-1}). The LA allows using very low doses of intraoperative systemic opioids, and morphine provides analgesia for the first 24 hours postoperatively.

Table II contains the most usual doses for common surgical infraumbilical procedures.[3, 43, 44, 48-59]

Complications

There are few comprehensive studies about the complications of SA in children. Although some studies have shown an incidence of complications up to 30%, they usually are minor and not clinically significant. However, problems associated with regional anesthesia may be underestimated.[61] One study concluded that the complications associated with SA in children are extremely rare, and therefore, it is a safe and efficient technique in this population.[62]

Hypoxemia, intraoperative apnea and bradycardia are usually due to the prematurity of patients amenable to this type of anesthesia. They can also be the consequence of an excessively flexed neck during the lumbar puncture, a too-high block, or the additional sedation.

Table II.—*Drugs dosages for SA in infraumbilical procedures.*

Drugs	Dosage	Age	Reference
Tetracaine 0.5%	0.6-0.8 mg.kg^{-1} (low-medium level) 1 mg.kg^{-1} (high levels)	Neonates	Marc [3]
Bupivacaine 0.5%	0.6-0.8 mg.kg^{-1} (low-medium level) 1 mg.kg^{-1} (high levels)	Neonates	Marc [3]
Bupivacaine 0.5%	0.5 mg.kg^{-1} 0.4 mg.kg^{-1} 0.3 mg.kg^{-1}	Infants <10 kg Children 11-19 kg Children/Teenagers >20 kg	Kokki [59]
Levobupivacaine 0.5%	1 mg.kg^{-1}	Neonates	Frawley [51]
Levobupivacaine 0.5%	0.3 mg.kg^{-1}	1-14 years	Kokki [48]
Ropivacaine 0.5%	1.08 mg.kg^{-1}	Neonates	Frawley [50]
Ropivacaine 0.5%	0.5 mg.kg^{-1}	1-17 years	Kokki [49]
Lidocaine 2%	2 mg.kg^{-1}	Children <13 years	Imbellioni [53]
Fentanyl	1 mcg.kg^{-1}	Infants <1 year	Batra [54]
Morphine	4-5 mcg.kg^{-1}	All ages	Ganesh [56]
Clonidine	1 mcg.kg^{-1}	Neonates	Rochette [43, 44]
Neostigmine	0.75 mcg.kg^{-1}	Infants <1 year	Batra [58]

A high spinal block occurs in 0.63-0.8% of cases.[35, 52] and can be caused by several causes, including: excessive doses of LA injected too rapidly (an injection time of at least 10 seconds is recommended), extension of the blockade by the inappropriate placement of the child (elevation of the lower limbs above the plane of the head), or performance of a caudal epidural to supplement an inadequate SA. Sometimes, no apparent cause is found. Reducing the dose of LA in patients with a higher relative body mass compared to the spinal cord has been suggested. Dehydratation (prolonged fasting or diuretic intake) can reduce the CSF pressure and may lead to the further spread of LA, and for this reason, a dose reduction is recommended.[63]

The hemodynamic consequences of a high spinal block are usually not important in young children, but the respiratory effects may require ventilatory assistance. The total spinal block may be accompanied by a bronchospasm, probably because of a decrease in circulating endogenous catecholamines[3].

The postdural puncture headache (PDPH) is the most common complication in children, with an estimated incidence of 8-25%.[64] It has always been thought that the incidence was lower in young children because of the increased production and turnover of CSF, lower CSF pressure with lower leakage, hormonal changes with age, and inability to communicate their symptoms. Today, we know that the PDPH occurs with equal frequency in children of all ages.[65]

Like adults, the use of thin needles reduces the frequency of this complication (4-5% with 25- or 27-gauge needles and 12-15% with 22-gauge needles).[66] Contrary to what was thought a few years ago,[65, 67] recent studies have shown that needle design does affect the incidence of PDPH in children, with this incidence being lower with pencil-point needles.[68, 69] Symptoms in children sometimes are unusual, and the diagnosis may be delayed.[66] PDPH is usually moderate, lasts only a few days, and is relieved by rest and minor analgesics; when the headache is severe, prolonged or disabling, it may be necessary to practice an epidural blood patch with a mean volume of autologous blood of 0.2-0.3 mL.kg^{-1}.[70, 71] In most pediatric patients, this technique is performed under GA or deep sedation; given the fact that the patient cannot express pain in such conditions, the blood injection into the epidural space should end if any increase in resistance is found.[71, 72]

Meningitis (septic or aseptic) is very rare. Infectious complications are very low, but they should be considered when the child develops fever after SA, even administering a new spinal tap for CSF analysis if it is deemed appropriate.[3] The diagnosis of aseptic meningitis is always by exclusion.[73, 74]

Back pain is a minor and transitory complication. Its incidence is estimated at 5-10%.[75, 76] Usually, the pain is relieved by a minor analgesic and disappears in a few days.

Transient neurologic symptoms occur in 1.5% of children after SA with bupivacaine,[76] and are the consequence of nerve root irritation such as direct mechanical trauma with the needle, extravasated blood from vessels and hemolysis around the dorsal root ganglia, or subdural injection of the anesthetic. One of the measures recommended for preventing this complication is to obtain a reflux of CSF by the cone of the needle before injecting the LA.[76]

A rare complication is the appearance of a lumbar epidermoid tumor due to the dragging and implantation of epidermal cells into the spinal canal through the needle. Needles should always be used with a positioned stylet during the puncture.[4]

Subarachnoid anesthesia *versus* general anesthesia in neonates

SA appears to be a good alternative to GA in neonates and infants. However, it remains relatively underutilized compared to GA in children in most institutions. In fact, most studies of SA in children have focused on a selected group of high-risk patients, and the role of this type of anesthesia in other groups of patients is not entirely clear. Epidemiological data suggest that infants have an increased risk of complications with GA compared to older children and adults.[77-80]

Postoperative apnea is a cause for great concern in ex-premature infants. Its frequency is particularly high when there is a previous history of premature apnea. There is no consensus on the exact incidence of apnea in preterm infants who receive GA (probably between 10% and 30%). Its appearance is directly related to prematurity, airway obstruction, anemia (hematocrit less than 30%), decreased respiratory drive, hypothermia, diaphragmatic fatigue,[81] increased production of endogenous opioids during the first 72 hours postoperatively, and perioperative administration of sedatives and anesthetics. Usually, there is a pause in breathing and bradycardia with hypoxemia, which spontaneously disappear. The origin of the respiratory pause may be central (70%), obstructive (10%) or combined (20%),.[4] and it happens mostly in the first 12 hours postoperatively, but may occur later (even 72 hours after surgery).

In several studies, SA in infants was associated with a reduced incidence of hypotension, hypoxemia, bradycardia and postoperative apnea compared to GA. Other studies suggested that this was true only when no additional sedatives were used with the regional technique.[82] In fact, it was noted that children who failed SA and required supplementation were especially prone to early postoperative apnea (in the first hour);[83] the most important predictor of late apnea is postconceptional age, so SA does not guarantee its absence.[84] Therefore, performing SA alone or in combination with sedation does not preclude adequate postoperative monitoring (it is recommended at least 12 hours from the surgery or from the last episode of apnea).[85] According to a recent meta-analysis, there is currently no convincing evidence to support the use of SA as part of the standard practice in inguinal hernia repair in ex-premature infants; this technique only reduced postoperative apnea in children who were not pretreated with respiratory depressants.[86] Still, pediatric anesthesiologists continue to prefer the use of SA in high-risk patients, especially former preterm infants and children with respiratory problems.

In vitro experiments and in vivo animal studies suggest detrimental effects of some anesthetics to brain cells. It is not clear whether anesthetics can cause human brain cell injury, and further investigations into the role that anesthetics may have in neonates and preterm patients during the period of rapid brain development are necessary.[87]

The anatomy of children differs from adults, so an ultrasound-guided block allows the physician to avoid injuries in central blocks and epidural catheter placement, for which the use of echoguided techniques in pediatrics represents an important advantage demonstrated in several papers. Training is necessary to correctly perform these new techniques, as affirmed by the American and European Society of Regional Anesthesia (ASRA, ESRA).[88]

SA in neonates not only appears safe and effective but also efficient. Traditionally, the spinal tap in these patients is difficult due to their small size; however, an experienced pediatric anesthesiologist takes no more than a few minutes to complete the blockade. Once the surgical procedure has been concluded, the patient can be immediately transferred to the PACU without losing additional time, as with GA.

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