

Spinal anesthesia in children: A review

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Abstract

Even after a vast safety record, the role of spinal anesthesia (SA) as a primary anesthetic technique in children remains contentious and is mainly limited to specialized pediatric centers. It is usually practiced on moribund former preterm infants (<60 weeks post-conception) to reduce the incidence of post-operative apnea when compared to general anesthesia (GA). However, there is ample literature to suggest its safety and efficacy for suitable procedures in older children as well. SA in children has many advantages as in adults with an added advantage of minimal cardio-respiratory disturbance. Recently, several reports from animal studies have raised serious concerns regarding the harmful effects of GA on young developing brain. This may further increase the utility of SA in children as it provides all components of balanced anesthesia technique. Also, SA can be an economical option for countries with finite resources. Limited duration of surgical anesthesia in children is one of the major deterrents for its widespread use in them. To overcome this, several additives like epinephrine, clonidine, fentanyl, morphine, neostigmine etc. have been used and found to be effective even in neonates. But, the developing spinal cord may also be vulnerable to drug-related toxicity, though this has not been systematically evaluated in children. So, adjuvants and drugs with widest therapeutic index should be preferred in children. Despite its widespread use, incidence of side-effects is low and permanent neurological sequelae have not been reported with SA. Literature yields encouraging results regarding its safety and efficacy. Technical skills and constant vigilance of experienced anesthesia providers is indispensable to achieve good results with this technique.

Key words: Additives, children, complications, pediatric, regional anesthesia, spinal, spinal anesthesia

Introduction

August Bier, in 1898, first reported the successful use of SA in an 11-year-old child for surgery of thigh tumor.^[1] Following this, Bainbridge^[2] (1901), Tyrell Gray^[3] (1909), Berkowitz and Greene^[4] (1950) described SA as an excellent alternative to general anesthesia (GA) in children including thoracic surgeries (lobectomy, pneumonectomy).^[5] However, by middle of the century, considerable improvement in techniques of GA (introduction of muscle relaxants and safe intravenous induction agents) along with lack of expertise for SA (fear of adverse effects, lack of patient co-operation) possibly prevented widespread use of SA in children.

In 1970's, an awareness that children feel pain led to a renewed interest in pediatric regional anesthesia (RA) with the realization that RA can be complimentary to GA. But, SA did not gain popularity until 1984, when it was reintroduced as an alternative to GA in the high-risk former preterm neonates, as a means of limiting the incidence of post-operative apnea and bradycardia, by Chris Abajian of Vermont University.^[6] Since then, SA has become a proven standard of care for moribund neonates.^[7-10] The Vermont spinal registry proved its safety in 1554 infants including the ex-premature and advocated its use in all infants undergoing lower abdominal or extremity surgery.^[10] Its efficacy and safety is also established in older children as an alternative to GA.^[11-14]

Several experimental studies in animals have raised concerns regarding susceptibility of developing brain to some anesthetic agents leading to functional and neurobehavioral deficits.^[15] The fact that anesthetic agents can cause human brain cell injury is still not proven. But, such issues may incline pediatric anesthesiologists to choose regional techniques whenever possible, especially in such age groups where rapid brain development is occurring. In this article, we aim to review the practice of SA in children with a special focus on limitations precluding its routine use and to find out the

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Access this article online	
Quick Response Code:	Website: www.joacp.org
	DOI: 10.4103/0970-9185.125687

possible solutions to counter them. The keywords “pediatric spinal anesthesia” in PUBMED revealed a total of 863 titles and 106 review articles published after 1990. The relevant articles along with their references were searched and extensively studied.

Anatomical and physiological differences between adults and neonates

- Dural Sac:** Terminates at S_3 and spinal cord at L_3 vertebral levels, at birth. Adult level (S_2 and L_1 respectively) is not reached until 2nd year of life [Figure 1]. Thus, it is prudent to use a low approach (L_{4-5} or L_5-S_1) to avoid damage to spinal cord^[16] [Figures 2 and 3]. Intercristal line (Tuffier’s line) still remains a reliable landmark similar to adults since in younger children, it passes through $L_{4.5}/L_5-S_1$. Newborns have a narrow subarachnoid space (6-8 mm) and low CSF pressure, necessitating greater precision and avoidance of lateral deviation.
- CSF:** Children require higher dose of local anesthetic (LA) drug due to higher total CSF (neonates 10 ml/kg, infants and toddlers 4 ml/kg, adults 2 ml/kg) and spinal CSF volumes (50% in children vs. 33% in adults).^[17,18]
- Meninges:** Highly vascular pia mater and high cardiac output lead to rapid re-absorption of LA and shorter duration of block in children, explaining 30% prolongation of block by addition of epinephrine, unlike in adults.^[6]
- Myelination:** In children, endoneurium is loose, presenting little barrier to drug diffusion, with faster onset and offset of block.^[16]
- Spine and Ligaments:** Ligaments are less densely packed, and feel of loss of resistance is less marked. Increased spine flexibility limits normal thoracic kyphosis and facilitates cephalad spread and higher level of sensory block.^[19] Laminae are cartilaginous; hence, paramedian approach should be avoided.

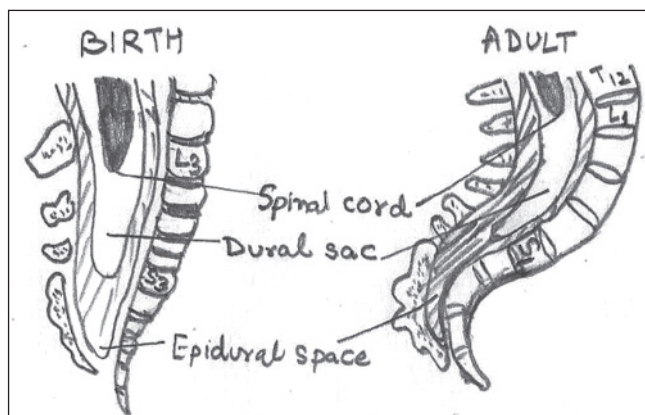


Figure 1: Anatomical differences between pediatric and adult spinal cord

- CVS:** Hemodynamic suppression following SA is absent in children due to a smaller peripheral blood pool, immature sympathetic autonomic system, and compensatory reduction in vagal efferent activity.^[19] Hence, preloading before SA is not a routine in children.
- Respiratory system:** High levels ($T_{2,4}$) of block reduce outward motion of lower ribcage, decrease intercostal muscle activity and may lead to paradoxical respiratory movement in children. However, diaphragm compensates for loss of ribcage contribution in most cases.^[20]

Subarachnoid block in children

Some of the applications of SA in children and large published series on use of SA in children are being summarized in Tables 1 and 2. The contraindication of spinal block in children is similar to those in adults.

Spinal needles, drugs, and dosage

Various types of spinal needles have been described depending upon the length, gauge, tip design (cutting/ pencil point), bevel (long/short), and presence /absence of stylet. The length of spinal needle varies from 25-50 mm (25-30 mm for infants, 50 mm for small children).^[17] Both cutting and pencil point

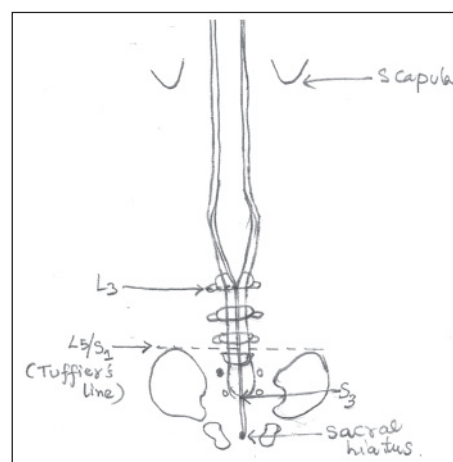


Figure 2: Anatomical landmarks for pediatric spinal



Figure 3: Surface markings for SA in an infant

Table 1: Documented applications of SA in children

Indication	Reported applications
Infra umbilical	Lower limb — Amputations, closed reduction of hip, club foot repair, arthrogram, muscle biopsy, tendon lengthening ^[11,12] GI surgery — Herniorrhaphy, intestinal resections, colostomy, pyloric stenosis, hernia ^[10,12,14,21,22] Urological — Urethoplasty, posterior urethral valve fulgurations, circumcision, orchidopexy, vesicostomy, ureteral reimplant ^[14,21,22] Abdominal Wall defects — Exostophia Vesicae ^[12]
Supra umbilical	Abdominal Wall defects — Gastroschisis ^[12] Thoracic — Cardiac, pulmonary, CDH, TOF, PDA ligation ^[23,24] Neurosurgery — Meningo-myelocele, Terratoma ^[25-27] Spine surgery — Staged segmental scoliosis ^[28]
Medical diseases ^[29-31]	Muco-polysaccharidosis (Morquis Syndrome), muscular dystrophy, arthrogryposis congenita, Hurler-Scheies syndrome, risk of malignant hyperthermia, broncho pulmonary dysplasia
Difficult airway ^[21,32]	Laryngo/tracheomalacia, subglottic stenosis, macroglossia, micrognathia
Premature/ex-premature neonates ^[7-10]	Floppy baby syndrome, failure to thrive
Emergency	Full stomach, intestinal obstruction, ^[4] chest infection
Miscellaneous	Radiotherapy, ^[33] congenital abnormalities, pain management e.g. spinal cord astrocytoma. ^[34]

Table 2: Summary of a few published series on SA in children

Author, year	Age year	N	Complications (number)
Ecoffey C, ^[9] 2010	0-12	387	High spinal (1)
Kachko, ^[14] 2007	<1	505	Failure (24), bradycardia (9), high spinal (3), apnea (4)
Williams, ^[10] 2006	0-1	1554	Failure (18), bradycardia (24), desaturation (10)
Imbelloni, ^[3] 2006	0-12	307	Failure (6), bradycardia (2), hypotension (1), PDPH (3), bronchospasm (1)
Kokki, ^[5] 2005	0.75-17	303	Failure (12), Bradycardia (2), Hypotension (1), Desaturation (3), PDPH (13), TNS (6)
Puncuh, ^[12] 2004	0.5-14	1132	Failure (23), hypotension (17), desaturation (7), airway obstruction (27), PDPH (7), backache (9)
Kokki, ^[1] 2000	0.5-10	195	PDPH (9)
Abajian ^[6] 1984	<1	78	Failure (8), no complications
Berkowitz, ^[4] 1953	<13	350	No neurological sequelae/ PDPH/ mortality
Gray, ^[3] 1909	Infants children	100	Retching (6), vomiting (21)

needles have been used with similar success.^[35,36] A 90 mm adult spinal needle has also been used in children.^[12,22,36,37] A shorter pediatric needle allows more precision in movement, will bend rather than break in case of movement, and has a smaller dead space. A short bevel allows better appreciation of tissue resistance and reduces the chance of incomplete injection of drug. IV catheter's hollow stylet and hypodermic needles have also been used, but they carry a risk of formation of epidermoid tumor from deposition of skin tag.^[38] Kokki *et al.* compared 25G and 29G Quincke spinal needles in children and concluded that puncture characteristics favored 25G.^[37] Use of 1 ml tuberculin syringe allows greater precision in drug delivery.

Local Anesthetic (LA) solutions and additives — Isobaric and hyperbaric Bupivacaine or Tetracaine (0.5%) remain the most popular agents for pediatric SA. Newer drugs like Ropivacaine and L-bupivacaine are also safe and effective. Ropivacaine 0.5% was used in children (1-17 years) at a dose of 0.5 mg/kg with good success.^[39] Duration of motor

block is significantly shorter than equipotent doses of other drugs.^[39] Levobupivacaine has a clinical profile similar to bupivacaine and has been used in similar doses. Kokki *et al.* successfully used 0.5% levobupivacaine in doses of 0.3 mg/kg in children (1-14 years).^[40] Frawley *et al.* found 1 mg/kg of isobaric solutions of 0.5% bupivacaine and ropivacaine and 1.02 mg/kg of L-bupivacaine to be equipotent in infants.^[41] But, such high doses should be used with caution because of risk of neurotoxicity. Dosage of LA agents varies inversely with the body weight as shown in Table 3. Lignocaine has gone out of vogue because of its shorter duration of action and reports of neurological complications in adults. Baricity of LA drug is not as important because both isobaric and hyperbaric solutions have similar block characteristics in children.^[42]

Since short duration of action of SA is a major limitation in children, a variety of additives like adrenaline, morphine, fentanyl, neostigmine, clonidine have been tried to prolong the block [Table 4]. Addition of epinephrine to LA reduces

the total dose, increases the safety margin, and prolongs the duration (up to 30%), but its use has been questioned because of fear of cord ischemia.^[55] Dexmedetomidine, a new α_2 agonist, has been used as an additive via epidural route in children, but not intrathecally. Though various LA and additives used for SA have been reported to be relatively safe, but the potential spinal cord toxicity with the drugs delivered intrathecally during early phases of development cannot be precluded. Moreover, younger children (infants and neonates) may not be able to report sensory symptoms, and subtle changes may be missed. So, drugs with well documented safety profile with a wide therapeutic index should be used.^[56]

Pre-operative preparation and premedication

Children are apprehensive from the thought of parental separation, pain of surgery, and use of needles. It is very important to discuss clearly the advantages of SA over GA

with parents and older children.^[16] They should be explained about the technique in detail. An informed consent should be obtained from the parents and assent directly from older children.^[35]

EMLA cream should be applied to lumbar puncture area and IV cannulation site 1 hour prior to arrival in OR (not licensed for preterm <37 weeks).^[57] Good dermal analgesia (local infiltration with 1% lignocaine) may avoid the need for sedation in some children. Sedation is generally avoided in preterm and former preterm infants because of risk of apnea. In younger infants, ignorance acts as a safeguard against panic, but older children require some premedication for easy parental separation, IV cannulation, and spinal puncture. Midazolam, atropine, ketamine alone or in combination have been used by various routes (oral/rectal/IM) to provide sedation and anxiolysis. Per-rectal atropine (0.02 mg/kg) and

Table 3: Recommended doses and approximate duration of LA for SA in infants and children

Type of LA	<5 kg	5-15 kg	>15 kg	Duration [minutes] Range (mean)
0.5% bupivacaine /levobupivacaine (hyper/ isobaric) ^[16]	0.5-0.6 mg/kg (0.1-0.12 ml/kg)	0.4 mg/kg (0.08 ml/kg)	0.3 mg/kg (0.06 ml/kg)	30-180 (80)
0.5% hyperbaric tetracaine ^[16]	0.5-0.6 mg/kg (0.1-0.12 ml/kg)	0.4 mg/kg (0.08 ml/kg)	0.3 mg/kg (0.06 ml/kg)	35-240 (90)
0.5% Isobaric ropivacaine ^[39]	0.5-1 mg/kg (0.1-0.2 ml/kg)	0.5 mg/kg (0.1 ml/kg)	0.5 mg/kg (0.1 ml/kg)	34-210 (96)

Table 4: Additives used for spinal anesthesia in children

Additive ($\mu\text{g/kg}$)	Author	LA	Results
Epinephrine (2-3)	Abajian ^[6] 1984	Tetracaine	Prolonged from 84 (7.2) to 109 (5.3) min [N,I]
	Rice ^[43] 1994	Tetracaine	Prolonged from 86 (4) to 128 (3.3) min [I]
	Fosel ^[44] 1994	Bupivacaine	Prolonged from 50 to 95 min [I]
	Gupta ^[22] 2006	Bupivacaine	Mean duration of block 84 \pm 8 min [C]
Morphine (4-15)	Ganesh ^[45] 2008	No LA	Various surgeries (4-5 $\mu\text{g/kg}$): prolonged post-operative analgesia, no respiratory side-effects [C]
	Finkel ^[46] 1997	Tetracaine	Cardiac surgeries: 10 $\mu\text{g/kg}$ hemodynamic stability with 24 hr analgesia (patients extubated in OR) [I,C]
	EschertzHuber ^[47] 2008	No LA	Scoliosis surgery (15 $\mu\text{g/kg}$): Decreased blood loss, safe and prolonged analgesia [C]
Fentanyl (0.2-2)	Piral ^[48] 2002	No LA	Cardiac surgery (2 $\mu\text{g/kg}$): Prolonged analgesia with cardio-respiratory stability [C]
	Batra ^[49] 2008	Bupivacaine	Lower abdominal and urologic surgery: 1 $\mu\text{g/kg}$, prolonged SA 74(6) vs. 51(5) mins. [I]
	Duman ^[50] 2010	Bupivacaine	Hernia repair: 0.2 $\mu\text{g/kg}$, lowered pain scores intraoperatively, \uparrow post-operative analgesia (50 min) [C]
Clonidine (1-2)	Rochette ^[51] 2005	Bupivacaine	Inguinal hernia: 1 $\mu\text{g/kg}$: \uparrow duration from 70 to 110 min. 2 $\mu\text{g/kg}$: more hypotension, sedation, and respiratory depression [N]
	Kaabachi ^[52] 2007	Bupivacaine	Orthopedic surgery (1 $\mu\text{g/kg}$): \uparrow duration from 110 to 135 minutes and analgesia from 330 to 460 min [C]
	Cao ^[53] 2011	Bupivacaine	Orthopedic surgery (1 $\mu\text{g/kg}$): \uparrow motor and sensory block, reduced propofol requirement [C]
Neostigmine (0.75)	Batra ^[54] 2009	Bupivacaine	Lower abdominal surgery: Significant prolongation, no increase in emesis or delayed recovery [I]

N = Neonates, I = Infants, C = Children

midazolam (0.6 mg/kg) given 15 min prior to procedure, provides excellent sedation.^[12]

Procedural sedation

Performing spinal puncture in a struggling, agitated child may injure delicate neurovascular structures and should be avoided. Most children require additional sedation (ketamine, midazolam, thiopentone, propofol, halothane, sevoflurane, or nitrous oxide).^[11,58] Infants may be soothened with flavored pacifiers or sucrose dipped dummy dip.^[17] Concerns regarding increased risk of neurological injury during needle advancement in anesthetized children are unfounded. In fact, placement of blocks under GA is a standard practice and supported by many regional societies (e.g. French language study of regional anesthetists).^[9] This study confirmed the low complication rate despite performance of 96% of blocks under GA/ heavy sedation. Intraoperative sedation may not be required if SA is successful because de-afferentiation itself produces sedation. This has been proven using bi-spectral index (BIS) in infants under SA.^[59] Loose soft restraints may be applied to the wrists to prevent infant from reaching on to the sterile field. Some older children prefer not to be sedated, opting for music or watching a cartoon.

Technique — Conventionally, SA is performed in a lateral decubitus position, with patient curled up and flexed at neck and hip joint. In neonates and infants, care must be taken to avoid extreme neck flexion [Figure 4] because of resultant upper airway obstruction leading to hypoxia (decreased transcutaneous O₂ tension (T_{cp}O₂) by almost 28 mmHg).^[60] Both sitting and lateral positions have been found to be suitable. A 45° head up tilt may help by increasing the CSF pressure in infants.^[61] Functional/hysterical scoliosis makes puncture more difficult. Depth of insertion at L_{4,5} varies with age (newborn 10-15 mm, up to 5 years 15-25 mm, 5-8 years 30-40 mm). Distance from skin to subarachnoid space (mm)



Figure 4: SA in an infant with head extension

can be calculated by the formula $\{0.03 \times \text{height (cm)}\}$ or $\{2 \times \text{weight (kg)} + 7\}$.^[62]

Recently, ultrasound has been increasingly used for neuraxial imaging in pediatric population. Though its use is mainly limited to epidural blocks, it may find its application for SA in future. In infants (<6 months age), excellent acoustic window for imaging can be obtained because their posterior spinal columns are incompletely ossified.^[62] US imaging may help pediatric anesthesiologist in deciding the puncture point, planning needle trajectory, and gauge the depth of needle insertion from skin.

Reflux of CSF following puncture indicates that needle is in the right place. LA is injected over 20 second period.^[17] As the volume of drug is small, needle and hub dead space (0.02-0.04 ml) should be taken into consideration when calculating the total volume. Caution should be taken not to elevate the lower extremities because of resultant high or “total” spinal anesthesia.^[63] The neurological sequelae can be minimized using appropriate volume, baricity and concentration of drug, puncture site, ensuring free flow of CSF before injecting the drug, and avoiding micro-catheters.

Some pediatric anesthesiologists advocate establishing IV access in the lower limb after onset of block because of absence of hemodynamic instability following SA in infants. But, securing IV access prior to performing of block provides added safety. Oximeter probe and NIBP cuff may be applied to the lower extremity to avoid disturbing infants during surgery. Per-rectal acetaminophen and diclofenac suppositories may be inserted at the end of surgery to provide post-operative analgesia. Peripheral nerve blocks (penile or ilio-inguinal block) performed at the end of surgery may provide prolonged post-operative analgesia.^[35]

Block assessment in children

In awake children, level of block can be ascertained by pinprick, finger pinch, forceps, and ice. In infants and sedated patients, transcutaneous electrical stimulation is a better and reproducible method.^[51] In children requiring deep sedation or GA for performance of block, inability to move the blocked extremity after emergence is a good evidence of successful block. Motor block can be assessed by modified Bromage score and pain by FLACC (infants), CHEOPS (1-7 years), and Visual Analogue scale or VAS (older children) scales.

Advantages of SA over GA

1. SA is a cheaper alternative in countries with limited resources, due to rapid recovery, shortened hospital stay, and more procedures performed on day care basis. Imbelloni *et al.* documented 54% reduction in cost

as compared to GA (49\$ vs. 105\$).^[13] Kokki *et al.* demonstrated a more rapid patient turnover rate in OR as secondary cost saving besides primary cost benefit.^[64]

2. SA provides all components of balanced anesthesia with minimum cardio-respiratory disturbances and PONV, early ambulation, and rapid return of appetite.
3. Tracheal intubation and respiratory effects of GA and IV opioids can be avoided in high-risk patients (with subglottic stenosis, laryngo-tracheomalacia, difficult airway, muscular dystrophy, hyper-reactive airways, bullous epidermolysis) with limited respiratory reserve.^[17,21,28,32,57]
4. SA is more effective than GA or epidural block in blunting the neuroendocrine stress and adverse responses to surgery.^[65] Plasma epinephrine, norepinephrine, lactate, and IL-6 levels are reduced, with improved outcome in neonates and infants undergoing cardiac and other major surgeries.
5. SA is a preferred choice in a child at risk of developing malignant hyperthermia (MH) as amino amide LA can be used safely in MH susceptible patients.^[17] Also, it is an alternative technique in patients with medical and respiratory diseases who are otherwise at high risk under GA.^[61]
6. Recent data from animal studies has raised concerns regarding safety of GA drugs on rapidly growing brain cells, especially in neonates and infants.^[15] However, the neuraxial administration of drugs may also have harmful effects on the spinal cord in early stages of development. Though the literature is limited on this regard at present.^[56]
7. Environmental concerns about ozone layer depletion give an edge to SA over GA, because open tailed pediatric circuits are considered as one of the major contributors.

SA in ex-premature infants

SA has been termed as a 'Gold standard' technique in the former preterm infant (<60 weeks PCA) for lower abdominal and lower extremity surgeries under 90 minutes duration.^[10,51] These patients have an increased incidence of apnea (45% in <48 wks PCA), which is further increased because of associated broncho-pulmonary dysplasia, intracranial hemorrhage, and anemia. SA has been found to be associated with reduced incidence of apnea, bradycardia, desaturation, and post-operative ventilatory requirements in this group of patients.^[6-10] Krane *et al.* (1995) confirmed a lower incidence of apnea under SA by pre- and post-operative pneumograms.^[8] Cochrane meta-analysis also supported a reduction in apnea with SA in children who had not received sedatives and suggested the need for further large multi-centric trials to prove the effect.^[66] However, decreased incidence of apnea does not preclude routine monitoring of these high-risk infants for 24 hours in PACU until further evidence proves the contrary.

Recovery and discharge

Before shifting the patient to recovery room, one must ensure stable vital signs, intact gag, swallowing and cough reflexes, and adequate respiration. Criteria for discharge should include ambulation (appropriate for age), orientation to time, place and person appropriate for child's age, tolerating oral fluids with minimal nausea, and vomiting. Voiding, though not necessary, helps establish fluid status and degree of residual block.^[16] If residual sensory block is present, instructions to protect the child from hot, cold, or sharp objects should be given.

Side-effects and complications

Complications of SA in children are usually minor and infrequent [Table 2]. ADARPEF's prospective study in preterm to adolescent patients reported only one complication after 506 SA (IV injection).^[9] Vermont spinal registry also confirmed the rare incidence of complications in infants.^[10] No report in literature mentions any fatal complication or permanent neurological sequelae following SA. Some of the complications, which can occur include:

- **Cardio-respiratory insufficiency:** Hypotension and desaturation are rare in children. If at all, it is usually due to high block or use of sedatives. One report mentions occurrence of bronchospasm with higher block.^[13]
- **Post-dural puncture headache:** PDPH was thought to be rare in children <10 years age, because of low CSF pressure, highly elastic dura and non-ambulation. Lately, it was reported in children as young as 2 years, suggesting that its occurrence is independent of age.^[67] Overall incidence of 4-5% (as in adults) has been reported in 2-15 years age group.^[17,35] Symptoms are generally mild. Severe PDPH is very rare (0.1%). Treatment is conservative. Epidural blood patch (0.2-0.3 ml/kg) should be considered if headache persists for >1 week.^[17] Results of studies comparing the effect of needle tip design on incidence of PDPH are contradictory. While earlier studies reported similar incidence of PDPH with pencil point and cutting needles,^[36] recent article found lesser incidence with pencil point (0.4% vs. 5%).^[68]
- **Backache:** (5-10%) is a common complaint, but its causal relationship has not been established.^[17]
- **High or total spinal anesthesia:** (0.6%) can result if infant's legs are lifted after injection of drug or with overdose and barbotage.^[10,59] Limited thoracic kyphosis facilitates cephalad spread resulting in apnea, requiring assisted ventilation.^[19]
- **Transient neurological symptoms:** (3-4%) is described as new onset pain and dysesthesia originating in gluteal region and radiating to lower limbs.^[17] In most cases, symptoms are mild. Neurological examination, imaging studies, and electro-pathological testing are usually negative.

No TNS was observed in 307 patients undergoing surgeries under SA with 0.5% bupivacaine or 2% lignocaine.^[13]

- **Infection:** Only anecdotal reports of meningitis (aseptic and septic) are reported with SA in children, that too with no proven causal relationship.^[69] In case of post-spinal fever, prompt LP is indicated for quick diagnosis.

Neurotoxicity potential of spinal additives

Many of the currently used spinal analgesic adjuvants have not undergone systematic evaluation of spinal neurotoxicity before their introduction into clinical practice.^[70] Recently, effort has been there to define safety of neuraxially delivered drugs through pre-clinical models in adult animals,^[71] but scarce data is available regarding their effect in early post-natal period. Similar to the potential pro-apoptotic effects of general anesthetics on developing brain,^[15] even neuraxially administered agents can lead to increased apoptosis in developing spinal cord during rapid growth spurt. Intrathecal drugs can lead to specific patterns of toxicity by altering neural activity in cord.^[70] Post-natal development of A and C- fiber innervations in spinal cord is activity-dependent and can be altered by changing input at critical phases of development.^[72] Exposure to drugs that enhance inhibition may trigger excessive apoptosis. Ketamine has been shown to alter dendritic arborization of GABAergic neurons *in-vitro*, though direct *in-vivo* evaluation has not been done.^[73] On the contrary, Dexmedetomidine, a novel alpha2 agonist, has been found to have neuroprotective effects in *in-vivo* and *in-vitro* animal spinal cord preparations.^[74] Large information pertaining to neuraxial adjuvant use in human neonates and infants attests to its safety. But, it is important to realize that much of it reflects retrospective data with limited follow-up and morphological changes cannot be assessed to confirm their safety. Also, in young infants and preverbal children who are unable to report sensory symptoms and cannot walk, subtle sensory and motor symptoms may be missed. Also, underreporting because of fear of litigation cannot be ruled out.

Hence, in current scenario, a reasonable strategy would be to define therapeutic ratio of several drugs under similar condition and prefer a drug with higher ratio.^[70] Recently, it was demonstrated that therapeutic ratio in early life was >300 for morphine and clonidine, but <1 for ketamine as increased apoptosis occurred in the same dose range as analgesia.^[75-77] We should evaluate the novel and the existing spinal drugs for their safety and efficacy before their introduction into routine clinical practice.

Limitations: Despite several specific indications and advantages, this technique has some limitations:

1. Single shot technique provides mere 70-80 minutes of surgical anesthesia and shorter post-operative analgesia.

This can be overcome with judicious use of additives and CSE technique [Table 4].

2. Need for sedation and GA in some children for performance of block and despite successful block during the surgery. This, however, should not be a deterrent to use of SA because of its proven benefits and safety.^[9] In fact, there may be less risk of injury in an immobile child than in a child who is struggling during needle placement. However, sedation should be avoided in premature infants as far as possible because of the risks already mentioned.
3. Technical difficulties: Lack of co-operation and their unique anatomical features make SA in children challenging. Bloody tap and difficulty in aspiration are associated with failure of SA.^[6,13,61] Failure rates of 5-15% have been reported. However, many recent large studies have documented a good success rate.^[12-14,35] Technical difficulties and failure may thus be a matter of individual skill and experience.
4. Pediatric spinal needles are expensive and may not be freely available. Standard adult needles can be used in school-going and older children, and with due care even in younger children (6 mth-1 year).^[12,17,37]

Conclusion

Today, more than a century ahead since its inception, although firmly established as safe, SA still remains underutilized in children. Based upon extensive literature review and our own experience, we are convinced that SA is safe, cost-effective, and technically feasible technique. It has a remarkable safety record in pediatric population in the hands of an experienced anesthetist, proper patient selection, drugs, and dosages. As anesthetists become more experienced, it may well become a preferred choice either alone or as a part of balanced technique in children undergoing elective surgeries, rather than just as an alternative in the high-risk pediatric patients.

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How to cite this article: Gupta A, Usha U. Spinal anesthesia in children: A review. *J Anaesthesiol Clin Pharmacol* 2014;30:10-8.
Source of Support: Nil, **Conflict of Interest:** None declared.