Chapter 3

Spinal Anaesthetic Management in Paediatric Surgery

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Additional information is available at the end of the chapter

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Abstract

The first paediatric cases involving the use of spinal anaesthesia were published at the end of the nineteenth century. However, the technique did not receive much interest in paediatric anaesthesia until the 1980s. In the last three decades, paediatric spinal anaesthesia has received widespread approval as an alternative technique to general anaesthesia in school-/preschool-aged children, particularly in term and preterm neonates with high risk associated with general anaesthesia. The development of new and safer local anaesthetics mainly through better understanding of the pharmacokinetics and dynamics and dedicated paediatric tools are the keys to this success. Paediatric spinal anaesthesia is an easy and effective technique, and its high efficiency and safety are supported by the presence of numerous publications from the medical literature. However, it remains limited to situations in which general anaesthesia poses a major risk. Despite these advances, it is important to understand the correct technique and the anatomy of children at different ages. Also, the appropriate equipment, the pharmacokinetics and toxicities of local anaesthetics and the indications and complications of paediatric regional blocks should be well known. The goal of this chapter is to review and discuss some of these topics of paediatric spinal anaesthesia for paediatric surgery.

Keywords: paediatrics, anaesthetic techniques, regional anaesthesia, paediatric spinal anaesthesia, complications, anaesthetic management

1. Introduction

1.1. History of paediatric spinal anaesthesia

The use of paediatric regional anaesthesia began in the first half of the 1900s. In 1898, Bier [1] performed the first spinal anaesthetic, and two of his patients were children. Bier's publications were followed by reports by Donitz in Europe [2]. In addition, in 1909–1910, two detailed articles about more than 100 children with spinal anaesthesia were published by Gray [3, 4] in the Lancet.

With the development of general anaesthesia, there was little interest in paediatric spinal anaesthesia until the 1950s. Since then, paediatric spinal anaesthesia has become a more popular technique for the anaesthesiologist, and during the last three decades, the spinal anaesthetic approach has increased dramatically in children. This technique has been used safely in premature and ex-premature infants with a high risk of apnoea associated with general anaesthesia [5–8]. Also, spinal anaesthesia is an uncomplicated and effective technique that provides a rapid onset and exceedingly effective analgesia, sympathetic and motor block in the lower part of the body [9].

Despite the increased prevalence of spinal anaesthesia in children, it is still not practised everywhere owing to the use of conventional general anaesthesia.

2. Spinal anaesthetic approach: anatomical and physiological differences in paediatric patients

2.1. Anatomical structure of and differences in vertebral column

The anatomical structure of the spinal column in children differs from that of adults. In premature infants (approximately 90%), the spinal cord terminates between the L2–L3 vertebra [10]. In newborns, the spinal cord extends down to the level of the L3 lumbar vertebra, compared with the L1 lumbar vertebra in adults (**Figure 1**) [11–13].

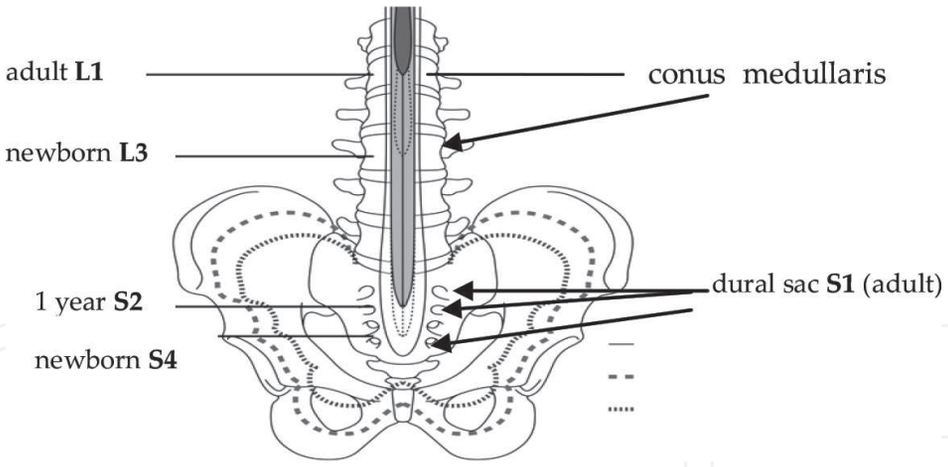

Figure 1. Anatomical structure and differences between paediatric and adult invertebral column (Remodified from Frawley and Ingelmo [13]).

The dural sac ends at the L4 vertebra at birth but reaches S2 by the end of the first year of life (**Figure 1**) [13]. Shin et al. confirmed that the end of the dural sac was at a median level of the upper S2 in children aged less than 36 months of age [14].

The iliac crest (intercristal line—Tuffier's line) can be used to determine safe puncture levels for children in the same way as in adults. In infants, the intercristal line passes through the

vertebral column at the L4–5 or L5–S1 interspace, well below the termination of the spinal cord [13]. Therefore, the L4–5 or L5–S1 intervertebral space should be used for needle placement in children.

Studies related to vertebral anatomy in children demonstrated that the distance between the skin and the subarachnoid space at the level of the L4–5 interspace is 6 mm at birth and 10–12 mm at 1 year of age [15]. Ecoffey et al. [16] reported that the distance between the skin and the subarachnoid space was 10–18 mm in the lumbar region and 7–14 mm in the thoracic region in children less than 3 years of age.

The pelvis has a more rounded structure in infants, and the iliac crest is lower than in adults. Another anatomical difference in paediatric patients is the flexibility of a child's spine and intervertebral spaces, which are easily palpated [13]. In addition to these characteristics, ossification of the vertebral lamina is incomplete, and the spinal needle can readily enter the bone. The lumbar spinal canal differs in the paediatric age group too; the interpedicular diameter of the spinal canal at the lumbar level is quite wide and is 70% of the adult size at birth [9, 17].

All these anatomical differences between children and adult scan facilitate dural puncture in children, but paediatric spinal anaesthesia is a specialised technique, and these anatomical characteristics must be taken into consideration in order not to cause complications when performing the spinal technique.

2.2. Physiological differences between adult and paediatric patients

In neonates, insufficient myelinisation and a weak endoneurium provide an ineffective barrier to drug diffusion. These anatomical and physiological characteristics mean the rapid onset and offset of block [12, 18].

Vascularisation of the pia mater is relatively high in neonates. Cardiac output is also higher in children than in adults. Because of these two factors, local anaesthetic reabsorption is rapid, and the duration of block is shorter. Compared to adults, the total cerebrospinal fluid (CSF) volume is higher in children (neonates, 10 ml kg^{-1}; infants and toddlers, 4 ml kg^{-1}), and because the ligament density is low, the feeling of loss of resistance is less marked than in adults.

In infants, the lack of lumbar lordosis and increased limits of spinal flexibility can predispose to high spinal blockade with differences in positioning compared with older children [12, 13].

3. Benefits of spinal anaesthesia in children

3.1. Effective pain control

Spinal anaesthesia provides effective analgesia with minimal physiological changes or adverse effects and is an alternative to systemic analgesics (such as opioid and non-opioid analgesics) [19]. This feature provides a significant advantage in cases where systemic opioid use is contraindicated, especially in children at risk of opioid-induced adverse effects.

Effective analgesia also creates ideal physiological conditions for the recovery period for children and their families. An awake, cooperative and painless child adjusts more easily to the postoperative period. Additionally, efficient pain control reduces adverse effects due to the neuroendocrine stress response.

3.2. The effects of anaesthetics on neuronal development

In recent years, many important studies and preclinical data have been reported that describe how general anaesthesia affects neurodevelopmental outcome in young animals [20]. Changes in brain development include dose-dependent neuronal apoptosis, impairment of neuronal differentiation, synaptogenesis and changes to dendritic morphology [21].

The neurodegenerative effect seems to be both time and dose dependent. In animal studies, anaesthetic drugs (these act through the NMDA and GABA receptors) played a role in neurodegeneration.

In young animals, long-term cognitive and behavioural changes associated with general anaesthetics have been shown in several studies, but these findings must be supported by human studies and clinical data.

In recent years, various reviews, cohort studies and two meta-analyses have established that there is an association between anaesthesia in childhood and neurodevelopmental outcome [22].

In a randomised clinical trial, Davidson et al. compared the neurodevelopmental outcome in children who received either awake regional anaesthesia or sevorane-based general anaesthesia for inguinal herniorrhaphy in early infancy (the general anaesthesia compared to spinal anaesthesia (GAS) trial) [23]. The authors found that exposure to just less than 1 h sevoflurane general anaesthesia in infancy did not increase the risk of adverse neurodevelopmental outcome at 2 years of age. Nonetheless, reducing exposure to general anaesthesia especially in premature infants is important so as to reduce the deleterious effects of inhalational anaesthesia.

4. Physiological effects and advantages of spinal anaesthesia

4.1. Respiratory effects

Spinal anaesthesia has been correlated with minimal respiratory changes and ensures continuity of spontaneous breathing during surgery. This advantage is important in high-risk children in whom the anaesthetist wishes to avoid tracheal intubation and mechanical ventilation.

In summary, the respiratory benefits of spinal anaesthesia are as follows: effective analgesia without respiratory depression, improved respiratory performance and enhanced ventilatory response to hypercapnia with bupivacaine (possible mechanism is a direct stimulating effect of bupivacaine on the respiratory centre) [24].

In the neonatal period, the risk of opioid-related respiratory depression and sensitivity to muscle relaxant is more pronounced. However, spinal anaesthesia decreases the requirement for anaesthetic agents, muscle relaxants and opioids during surgery. These effects are especially

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important for reducing the risk of postoperative apnoea in high-risk infants that require surgery in this period [25].

4.2. Haemodynamic properties

Spinal anaesthesia in infants and young children is characterised by remarkable haemodynamic stability [15, 19, 26]. This physiological feature can be expressed clinically as the lack of significant decreases in blood pressure and the reduced need for volume preloading or vasoconstrictor use. This property is important especially in the neonatal period. The neonatal heart is immature immediately after birth and in the first month of life. Myocardial compliance and contractility are lower than in adults. This means that the ability to cope with stress with afterload is also reduced [27]. Therefore, especially in infants with congenital cardiac disease, spinal anaesthesia should be the preferred anaesthetic approach as it has minimum cardio-depressant effects.

Haemodynamic stability during spinal anaesthesia in infants can be considered as one of the advantages of spinal anaesthesia [28, 29]. Because of this feature, awake spinal anaesthesia is usually regarded as safe in high-risk infants [15].

4.3. Neuroendocrine stress response

Neuroendocrine stress responses associated with surgical trauma cause some hormonal changes in plasma. Increased levels of plasma cortisol and suppression of anabolic hormones, such as insulin, cause harmful effects during the perioperative period [30]. As a result, postoperative pain associated with surgical trauma may cause instability in haemodynamic parameters, behavioural changes and neuroendocrine stress responses [31, 32].

Regional anaesthesia can reduce the stress response associated with surgical trauma (6–10). Many studies have confirmed this [30, 33]. Wolf et al. [34] reported that, in infants undergoing major surgery, central block with epidural anaesthesia was more efficacious than high-dose opioid in suppressing cardiovascular and stress responses. The same authors also pointed out that high spinal anaesthesia is more effective than intermittently delivered epidural anaesthesia to reduce stress responses to surgery [35].

The neuroendocrine stress response is a phenomenon induced by surgical trauma. Severe stress may be pathological and may increase postoperative morbidity and mortality. Spinal anaesthesia is an effective method for attenuating the surgical stress response and may be considered an alternative to general anaesthesia especially in immunocompromised or malnourished paediatric patients [26].

4.4. Gastrointestinal function

Expected effects of opioid drugs are increased intestinal muscle tone and a slowdown in peristalsis [36]. This situation is particularly undesirable in necrotising enterocolitis and gastroschisis surgery in the neonatal period, because it may lead to anastomotic leak after surgery. However, spinal anaesthesia is associated with earlier return of gastrointestinal function. The vasodilator effect of autonomic blockade increases splanchnic perfusion and peristalsis. Early recovery of bowel movements favours early recovery of appetite, eating and discharge from hospital.

5. Indications and contraindications of spinal anaesthesia

5.1. Indications

Operations associated with the lower part of the body include abdominal (e.g. exploratory laparotomy, pyloromyotomy, omphalocele and gastroschisis and inguinal hernia repair), urological (hypospadias, orchiopexy and circumcision) and orthopaedic surgery and constitute the main indications for spinal anaesthesia (**Table 1**) [9, 37].

General surgical procedures

Abdominal pathologies

- Gastroschisis
- Omphalocele
- Exploratory laparotomy
- Colostomy
- Appendectomy
- Pyloromyotomy

Inguinal and umbilical herniorrhaphy

Lower extremity procedures and orthopaedic surgery

- Club foot repair
- Open and closed reduction of hip
- Tumour resection
- Amputation
- Muscle biopsy

Urological surgery

- Circumcision
- Orchidopexy
- Cystoscopy
- Hydrocelectomy
- Hypospadias repair
- Vesicostomy
- Urethral reconstructive surgery

Other procedures

- Cardiothoracic procedures: noninvasive and invasive techniques (atrial/ventricular septal defect closure, patent ductus arteriosus ligation, etc.)
- Neurosurgical procedure: meningomyelocele operation
- Outpatient procedure: radiation oncological processes

Table 1. Indications of paediatric spinal anaesthesia.

Paediatric patients, especially premature and ex-premature infants, may require surgical interventions for several reasons in early stages of their life. In the past 30–40 years, spinal anaesthesia has been introduced to the modern surgical era as an important and suitable technique for selected surgery in high-risk premature and ex-premature infants (**Figure 2**). The use of the spinal anaesthetic approach is supported by studies in high-risk infants published by Abajian et al. [38] in 1984.

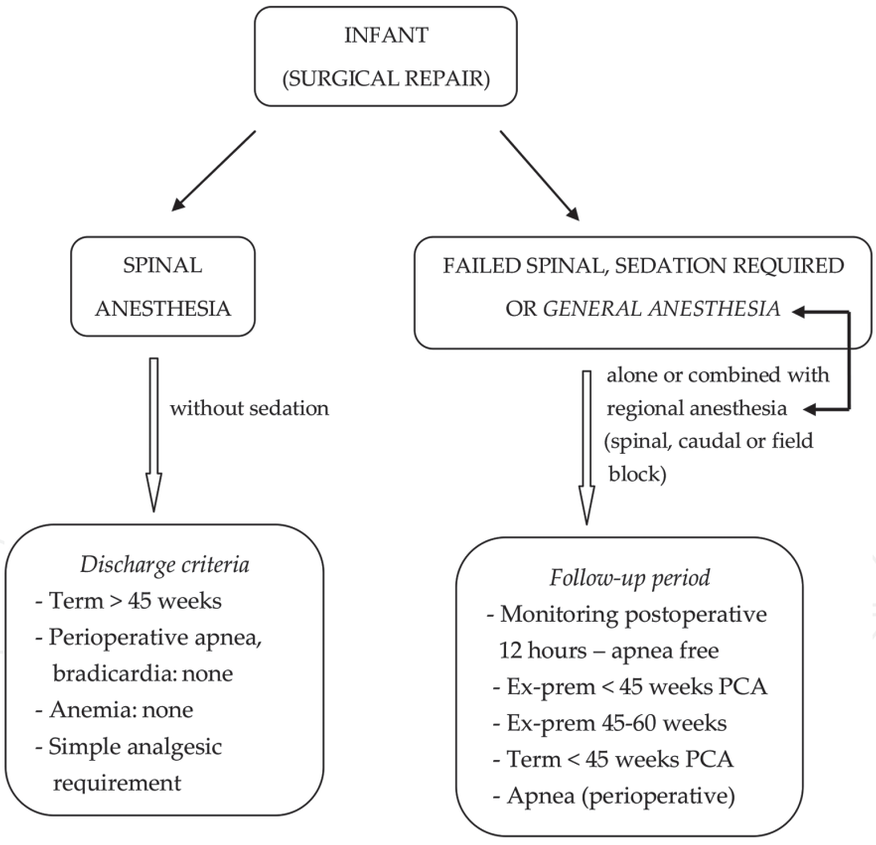

Figure 2. Chart of follow-up period after surgical intervention in infants. PCA, postconceptional age (Remodified from Frawley and Ingelmo [13] and Williams et al. [25]). Infants with pre-existing apnea and less than 45 weeks PCA are at the risk of postoperative apnea and should be kept under observation for at least postoperative 12 h.

Spinal anaesthesia is particularly important for reducing the risk of postoperative apnoea in high-risk infants and avoiding intraoperative sedation. In some specific cases, general anaesthesia may be technically difficult or associated with increased morbidity and mortality (such as in children with a known difficult airway, upper respiratory tract infection, full stomach, etc.). In such situations, spinal anaesthesia constitutes a more viable alternative for many anaesthetists.

Airway manipulation with endotracheal tube or supraglottic airway devices may not be performed in patients with a difficult airway. Likewise, in children with upper respiratory tract infection, continuous airway hyperreactivity in early stages and endotracheal intubation can cause serious respiratory complications [39]. In both cases, the spinal anaesthetic technique provides reliable airway management without endotracheal intubation and the use of a muscle relaxant. However, in such situations, if sedation is needed, special attention should be given to keeping the airway open.

Children with congenital muscular disease or respiratory muscle weakness are candidates for spinal anaesthesia. This is because general anaesthesia is thought to worsen respiratory function in the presence of muscle or pulmonary disease [11].

Spinal anaesthesia is also suitable in children with a full stomach and those who need emergency surgery, such as acute trauma patients. The risk of aspiration is less than in general anaesthesia because airway reflexes are protected during spinal anaesthesia. Nausea and vomiting are also less likely.

Paediatric patients with congenital heart disease (CHD) frequently undergo noncardiac surgical procedures for the management of both comorbidities and additional congenital anomalies [40]. Spinal anaesthesia is also used for noncardiac surgery in these paediatric patients.

Shenkman et al. and Kachko et al. [15, 41] have reported studies and experiences with spinal anaesthesia in children with congenital heart disease. Researchers consider that spinal anaesthesia is a safe and effective anaesthetic and analgesic technique in patients with CHD especially neonatal period.

In addition, studies that compared general anaesthesia with spinal anaesthesia indicated that spinal anaesthesia is associated with a significant degree of cardiorespiratory stability, a low incidence of respiratory complications and need for postoperative ventilator support and a shorter hospital stay [42].

5.1.1. Spinal anaesthesia for day-case surgery

Nowadays, another reason for preferring regional anaesthesia is its lower cost compared with general anaesthesia. Elective surgery including lower abdominal procedures can be performed as day-case surgery in paediatric patients. Spinal anaesthesia has significant advantages in outpatient surgery. These advantages include a rapid onset and recovery after surgery, the short duration of block with a single injection, easy application in experienced

hands, the ability to eat sooner with a lower incidence of postoperative nausea and vomiting and early discharge from hospital.

Spinal anaesthesia is a suitable technique for the surgeries mentioned above in children from 6 months of age. Children can be discharged the same day after spinal anaesthesia depending on the discharge criteria (such as walking unassisted after spinal anaesthesia, no pain, tolerating clear fluids orally, no nausea and vomiting). However, syndromic infants and children with a history of apnoea or respiratory problems should not be discharged on the day of surgery.

5.2. Contraindications

As previously mentioned, paediatric spinal anaesthesia is a technique that is easily attempted in experienced hands. However, in addition to the indication for spinal anaesthesia, every anaesthesiologist dealing with paediatric spinal anaesthesia must have sufficient knowledge about the absolute and relative contraindications and limitations.

Absolute contraindications of spinal anaesthesia
• Infection at the puncture site
• Coagulation disorder
• Septicaemia and bacteraemia
• Axonal degenerative disease
• Severe hypovolemia
• Local anaesthetic allergy
Relative contraindications of spinal anaesthesia
• Major deformities of spinal column
• Long duration surgical procedures
• Minor abnormalities of the coagulation profile

Table 2. Absolute and relative contraindications of spinal anaesthesia.

Contraindications for spinal anaesthesia include absolute and relative contraindications [9, 43] and are listed in **Table 2**.

In addition to these contraindications, dermatological problems that prevent the sterilisation of the puncture site are also absolute contraindications [11].

Bleeding disorders and coagulopathy are comparatively rare in children, and drugs affecting coagulation function are rarely used in paediatric patients. Cases of neuroaxial haematomas have been reported after epidural anaesthesia and diagnostic lumbar puncture [44]. Therefore,

the patient should be questioned about the family history for major coagulation disorders before administering spinal anaesthesia.

6. Technique

As explained in the section on anatomical structure, the anatomical configuration of the vertebra and spinal canal in paediatric patients differs from that in adults, and these differences must be taken into consideration when performing spinal anaesthesia.

Spinal anaesthesia is usually performed with the patient on their side with their back flexed and neck extended (**Figure 3**).

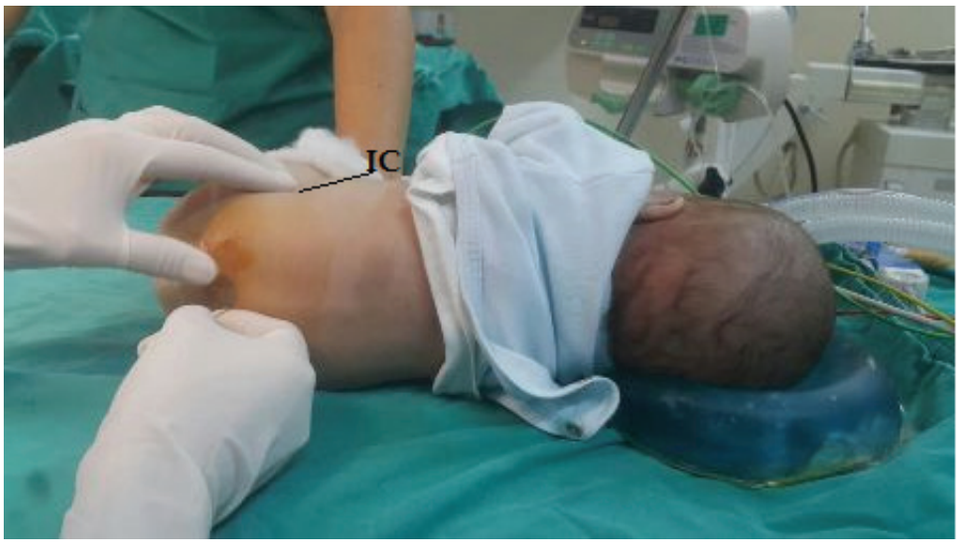

Figure 3. Lumbar puncture in the infant shown is the lateral decubitus position. In this position, puncture performed with the patient on their side with their back flexed and the neck extended for airway patency. IC, iliac crest.

The sitting position is also used in newborns and infants, but excessive flexion of the neck should be avoided [9, 45].

In children, the skin-spinal space distance is short [11]. Gupta and Saha emphasised that the depth of insertion at L4–5 level varies with age (in newborns, 10–15 mm; up to 5 years, 15–25 mm; 5–8 years, 30–40 mm) [12]. Due to the anatomical configuration of the dural sac and spinal cord in children, it is sensible to be cautious and use a low approach (L4–5 or L4–S1) (below the intercristal line) to avoid damage to the spinal cord.

To increase the success rate of the block and decrease post-puncture complications, during the puncture the spinal needle must be parallel to the dural fibre. Incorrect needle position can cause injection of local anaesthetic drug into the subdural space. This situation may give rise to an incomplete block. Before injecting local anaesthetic drug, free flow and aspiration of CSF should always be confirmed [11, 41].

After free CSF flow is observed, the needle should be forwarded by no more than 1 mm (to avoid subdural injection). Previous studies proposed that the needle be left in position for a few seconds after local anaesthetic injection. Kokki suggested that this approach would prevent the drug from tracing back into the tissues and skin puncture [38, 43]. Injection should be performed slowly over at least 20 sec.

After injecting the local anaesthetic, it is recommended that the needle should be withdrawn by reinserting a stylet. This manoeuvre reduces the formation of large hole in the dura mater. Thereby, local anaesthetic leakage is prevented at the puncture site, which is especially important in young children. Following an intrathecal injection, the lower extremity should not be moved. and the Trendelenburg position should be avoided.

Different types and lengths of spinal needle have been described for use in paediatric patients (gauge; tip design, cutting/pencil point; length, long/short). Various lengths of spinal needle are available for infants and small children, ranging from 25–50 mm [12]. A short needle allows comfortable movement and provides a minimal dead space; in infants, 25–38 mm needles are sufficiently long, and 50 mm needles are suitable in small children. In school-aged children, a standard length adult spinal needle can be used with a high success rate. In recent years, new atraumatic paediatric spinal needles have been manufactured (e.g. 26 G atraumatic needle and 27 G pencil-point needle).

The anatomical configuration of the spinal column is flatter in young children than in adults. Because of this, local anaesthetic injected into the subarachnoid space rapidly reaches the mid-thoracic level. In small children, care needs to be taken over the use of the introducer needle, because there is a short skin-spinal distance [46].

Needle type and the incidence of complications will be discussed in detail in the section on post-puncture complications. It is considered that short and thin spinal needles (e.g. 26 gauge atraumatic needle and 27 gauge pencil-point needle) significantly reduce postdural puncture complications in comparison with 22 gauge needle [11].

Kokki et al. showed that spinal puncture was successful when using cutting and pencil-point needles, with no differences between these needles in terms of post-puncture complications. Apiliogullari et al. reported that when compared with a 26 G cutting-point needle, the 27 G pencil-point needle leads to a significantly lower incidence of PDPH in children [47].

Almost half of the total CSF volume is in the spinal subarachnoid space in children. This factor plays an important role in calculating the dose of spinal blocks, with infants requiring higher volumes based on weight. The CSF in a neonate quickly dilutes the local anaesthetic after injection. This feature is one of the reasons for the use of high doses of local anaesthetic and the shorter duration of action of spinal blocks than in adults [48].

6.1. Sedation

Procedural sedation is often used in children before performing spinal anaesthesia. The aim of the sedation is to provide anxiolysis and ensure that the child remains motionless during lumbar puncture. Movement during puncture may cause injuries in neurovascular structures. Sedative drugs (such as midazolam, propofol or ketamine) may be used in small incremental

doses in children. Nevertheless, Sale reported that these sedative agents and the older inhalational anaesthetics used with spinal anaesthesia seem to be associated with apnoeic episodes in neonates [49]. Newer and short-acting inhalational agents (such as sevoflurane and desflurane) seem to be safer than older ones [11, 12].

Sedative agents should be avoided as much as possible in high-risk neonates. Abajian et al. [38] described an unsupplemented spinal anaesthesia technique in ex-premature infants undergoing herniotomy in 1984. In any case, spinal anaesthesia may be used without simultaneous sedation in this high-risk group. Further studies showed that awake spinal anaesthesia reduces the risk of apnoea in newborns [7, 25].

However, except in high-risk neonates, in many children spinal anaesthesia is performed under premedication or light sedation. In addition to the previously mentioned agents, dexmedetomidine (a potent, selective alpha-2 adrenoceptor agonist) may also be used. Dexmedetomidine provides natural sleep, anxiolysis and analgesia [50].

Transdermal local anaesthetic (such as EMLA cream) can be used on the puncture area 45–60 min before lumbar puncture.

When under sedation, close monitoring should be performed for patient's safety. Standard parameters should be monitored (especially oxygenation with pulse oximetry, end-tidal carbon dioxide monitoring of respiratory function and electrocardiogram).

6.2. Local anaesthetic agents

The pharmacokinetics and pharmacodynamic characteristics of local anaesthetics (LA) alter with age. Local anaesthetics that primarily bind to plasma protein (such as bupivacaine and levobupivacaine) undergo enzymatic degradation in the liver [51, 52]. Local anaesthetics should be used carefully, particularly in infants less than 6 months of age, because they lack the ability to distribute the drug and have limited metabolism [51].

Ester-type local anaesthetics such as tetracaine and chloroprocaine are metabolised by plasma cholinesterase [9]. Aminobenzoic acid which metabolises to ester-type local anaesthetic is responsible for allergic reactions. However, allergic reactions are rare in amino-amide group local anaesthetics [9].

As well as the onset time and duration of action of regional block, the safety profile of an agent is among the factors that play a role in the choice of local anaesthetic. Tetracaine, bupivacaine, ropivacaine and levobupivacaine are still the most commonly used local anaesthetics in children [9, 47, 53–55].

Age and body weight form the basis for local anaesthetic dose calculation. Nowadays, obesity is a common problem in children. In clinical practice, the dose of local anaesthetics should be calculated according to the ideal body weight of the child [9]. Local anaesthetics can be used in different concentrations in paediatric patients.

Kokki et al. investigated the effects of local anaesthetic baricity on the block characteristics, comparing isobaric and hyperbaric bupivacaine in children. They found that the block characteristics were similar for both drugs.

In recent years, various studies on higher local anaesthetic doses for neonates (e.g. ropivacaine and levobupivacaine at a dose of 1.2 mg kg^{-1}) have been reported, but there are few data regarding the safety of this dose profile [53]. Recommended dosages of local anaesthetics based on weight are shown in **Table 3**.

Local anaesthetic drugs	Local anaesthetic doses according to body weight (mg kg^{-1})				Duration of anaesthesia (mean)
	<5 kg	6–10 kg	11–20 kg	>20 kg	
0.5% Bupivacaine/ levobupivacaine [9, 11, 53, 54, 59, 60]	0.3–1	0.4–0.5	0.3–0.4	0.3	65–90 min
0.5% Ropivacaine [9, 53, 56]	0.5–1	0.5	0.5	0.5	45–105 min
0.5% Tetracaine [9, 25, 55]	0.2–0.6	0.4–0.5	0.3–0.4	0.2–0.3	75–105 min

Table 3. Recommended local anaesthetic dosages for spinal anaesthesia in infants and children (Remodified from Kokki [8]).

6.3. Adjuncts to local anaesthetics in paediatric spinal anaesthesia

The relatively short duration of action and exceedingly variable characteristics between individuals (such as duration on anaesthetic, analgesic and motor block action) are among the major limitations of single-injection spinal anaesthesia.

The addition of different types of adjuvant modifies the onset time, efficacy and duration of spinal block. However, it should be noted that subarachnoidally injected drugs are in close communication with neural tissue. Therefore, potential neurotoxicity should be considered before injecting any additive drugs (such as preservatives and antioxidants) into the cerebrospinal fluid [11, 57]. The use of preservative-free additives seems to be a safe method that avoids these neurotoxic risks.

The fentanyl, clonidine and adrenaline are among the most commonly used adjuvants. Adrenalin is a vasoactive additive and can be combined with local anaesthetics to prolong the duration and intensity of block. One of the first researchers to use adrenalin was Tyrell Gray in 1909. Isobaric bupivacaine combined with adrenaline (2–5 μg kg^{-1} of body weight) prolongs the duration of analgesia by up to 50% [54].

A study by Fösel et al. found that 0.5% bupivacaine combined with 1:200,000 adrenaline prolonged the duration of analgesia from 50 to 95 min [58].

Opioids may also be used as adjunct. Low-dose intrathecal fentanyl (such as 0.2 μg kg^{-1} body weight) enhances the quality and extends the duration of spinal anaesthesia [59]. When used at high doses, fentanyl and morphine can give rise to a risk of delayed respiratory depression.

Clonidine is an alpha-2 agonist agent. Intra-spinal α2-adrenergic agonists induce analgesia by a pathway involving nitric oxide and acetylcholine release [60]. Cao et al. [61] found that 1 μg kg^{-1} of body weight preservative-free clonidine combined with bupivacaine prolonged the duration of sensory and motor blocks by 30 min and postoperative analgesia by 120 min without affecting the hemodynamic stability.

7. Complications of spinal anaesthesia

Recent studies have shown that post-puncture complications in children are similar to those seen in adults after spinal anaesthesia [9]. However, evaluating the signs and symptoms of complications is more difficult in infants and young children compared with older children and adults. Babies can express their grievances with physiological changes and physical behaviours rather than verbally. Clinicians may misinterpret physical and behavioural changes as post-puncture complications.

Postdural complications and the incidence of severity are closely related to puncture technique. These complications include headache, backache, neurological complications, nausea and vomiting and cardiorespiratory and haemodynamic changes. More frequent complications are discussed below.

7.1. Headache

Headache is the most well-known complication of spinal anaesthesia [62].The incidence of headache was 3–4% with a 25–27 G spinal needle according to Kokki et al. [63]. A larger diameter needle (such as 22G) increases the incidence of post-puncture headache.

In order to decrease the risk of postdural puncture headache, small diameter atraumatic needles with a stylet were developed. These atraumatic needles are associated with a lower incidence and severity of puncture complications [64].

Indeed, headache is a common symptom in children after various surgical procedures, whatever the type of anaesthesia.

However, the symptoms mentioned below are mostly diagnostic of post-puncture headache:

- Postdural puncture headache is often bilateral.
- Develops within 24 h after lumbar puncture.
- Symptoms worsen in minutes by moving to a sitting position from their cumbent position.
- Some children may experience nausea and vomiting accompanied by symptoms such as blurred vision, vertigo and tinnitus [11].

These symptoms generally disappear spontaneously within 3–5 days, but in some children, they may continue for a few days.

Bed rest, hydration and the use of non-opioid analgesics and caffeine are mentioned in the treatment protocol.

An epidural blood patch may be required in prolonged cases and those not responding to treatment.

7.2. Backache

Backache is a common postoperative symptom. The incidence of backache after spinal anaesthesia is between 5% and 10% [9, 11, 41]. Backache may occur for various reasons such as direct trauma caused by the needle, ligamentous damage, muscular haematoma, reflex muscular spasm and uncomfortable positioning of the patient. Low back pain is the third most common pain in school-aged children. However, it is not known precisely what proportion of backache is associated with spinal anaesthesia.

7.3. Neurological complications

Looking at the overall epidemiology of neurological complications of spinal anaesthesia, they appear to be rare and transient. Improper patient selection, improper anaesthetic technique and inexperience may cause nerve damage, compressive haematoma and rarely definitive haematoma. However, these complications are rare.

The 1-year long, prospective ADARFEF study published by the French-Language Society of Paediatric Anaesthesiology in 1996 [65] evaluated complications of regional anaesthesia. Of 24,409 blocks, 60% were central blocks and 1.3% were spinal blocks. Most of the reported complications were minor (0.09%), emerged at the beginning of the process in the operating theatre, and had a short duration. Permanent neurological damage related to either spinal anaesthesia or other regional anaesthesia techniques has not been reported.

Some cases may develop transient neurological symptoms possibly because of subclinical neurotoxicity of local anaesthetic. Such symptoms occur a few hours after complete recovery from spinal anaesthesia. The incidence of symptoms following the use of bupivacaine has been reported as 3–4%. Symptoms are often mild and electropathological testing is negative [11].

Children may complain of pain radiating to lower extremities in the gluteal region and a tingling sensation in their feet. The intensity of pain ranges from mild to severe.

In recent years, ultrasound technology has offered new opportunities in the practice of regional anaesthesia, particularly in young children. Ultrasound guidance (USG) allows all relevant anatomical and neuroaxial structures to be visualised in infants up to 3 months old [66]. In experienced hands, USG may reduce the number of complications and improve the quality, safety and efficacy of neuraxial blocks in children. Therefore, the majority of paediatric anaesthesiologists are seeking to enhance their experiences in the use of USG in their routine clinical practice of paediatric spinal anaesthesia.

8. Summary

Paediatric spinal anaesthesia has made significant progress since Bier and Gray. Nevertheless, concerns about local anaesthetic toxicity, inexperience and the easy application of general

anaesthesia except in high-risk conditions, causes do not favour the use of the paediatric spinal technique by an anaesthesiologist.

Continuous progress including developments in local anaesthetics with advanced training and appropriate use of drugs, paediatric equipment and ultrasound techniques have improved safety and efficacy in paediatric patients.

As anaesthesiologists become more experienced, paediatric spinal anaesthesia will continue to be an essential part of overall care not only for high-risk patients but also for patients undergoing elective surgery.

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