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REVIEW ARTICLE

# Epidural anesthesia and analgesia in the neonate: a review of current evidences

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**Abstract** The role of single shot spinal anesthesia has been established in ex-premature infants at risk of apnea. However, use of epidural anesthesia in neonates is on the rise. In this systematic analysis, we have reviewed the current evidence on the safety and efficacy of the use of single shot and continuous epidural anesthesia/analgesia in neonates. Current clinical practice is guided by evidence based mostly on non-randomized studies, prospective/retrospective case series and surveys. Single shot caudal blockade as a sole technique has been used in neonates mainly for inguinal hernia repair and circumcision. Use of continuous epidural anesthesia through the caudal route or caudo-thoracic advancement of the catheter for major thoracic and abdominal surgery offers good perioperative analgesia. Other observed benefits are early extubation, attenuation of stress response, early return of bowel function and reduction of general anesthesia-related postoperative complications. However, risk of procedure-related and drug-related complications to the developing neural structure remains a serious concern.

**Keywords** Epidural anesthesia · Epidural analgesia · Neonate

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## Introduction

Inadequate pain relief in neonates in the perioperative period and in the intensive care unit may have long-term physiological consequences, such as altered sensory processing and response to future painful stimuli [1, 2]. Moreover, adequate perioperative analgesia in newborns has been linked to better postoperative outcomes [3]. Although intravenous analgesia is effective, there may be increased postoperative systemic complications. Moreover, neonates feel more pain than their older counterparts. In addition, systemic analgesic use in the neonates may have long-term consequences. Recent preclinical studies have demonstrated that use of inhalational agents, benzodiazepines, and *N*-methyl-D-aspartate antagonists may be associated with increased perinatal neuronal apoptosis and long-term behavioral changes in animal models [4]. Use of neuraxial block techniques may, therefore, find more acceptability in neonates by minimizing use of systemic analgesic.

In 1984, spinal anesthesia was advocated as the technique of choice to avoid postoperative apnea [5], and many studies reported benefits of spinal anesthesia for postoperative outcome in neonates and infants [6–9]. However, benefits of caudal or epidural anesthesia with/without general anesthesia in neonates undergoing major surgery are still not clear [10, 11]. Therefore, effects of various adjuvant drugs (opioids, alpha-2 adrenergic agents, ketamine, benzodiazepine and neostigmine) with neuraxial block agents in the neonate are of recent concern [12, 13].

In this systematic review, we have summarized the current evidence on the use of single shot caudal and continuous epidural anesthesia and analgesia techniques, and tried to determine the safety and efficacy of these techniques in neonates.

## Methods

### Protocol and registration

A protocol of this systematic review has not been registered.

### Eligibility criteria

We included published prospective or retrospective human clinical trials, observational studies and case series where caudal or intervertebral epidural technique was used either as a sole anesthetic technique or as a supplementation for intraoperative or postoperative analgesia in both term and preterm neonates. No language barrier was imposed in the search strategy.

### Information sources and search

We did an electronic search of MEDLINE, PUBMED, EMBASE and CENTRAL Database for published clinical trials, observational studies and case series on caudal/epidural anesthesia and analgesia in neonates until 31 July 2013, with the following key words: "neonate", "caudal", "epidural", "regional", "epidural analgesia", "epidural anaesthesia" and "regional anaesthesia". Relevant references from the primary search results were also manually searched. The PUBMED search strategy is mentioned in the "Appendix". The flow chart of study selection has been provided in Fig. 1.

### Data collection

We qualitatively extracted data from the trials that used caudal/epidural anesthesia technique as a supplement with general anesthesia or as a sole anesthetic technique in the neonatal age group. As a majority of the available clinical studies were observational and comprised of a heterogeneous group of neonates undergoing various surgeries, a quantitative analysis was not possible. Apart from clinical studies, retrospective reports, case series where epidural anesthesia/analgesia was used in neonates were also included in this review. However, we did not search for any unpublished data. Preclinical studies and animal studies were excluded from this review.

We manually searched the articles that were to potentially be included in this review. The following data were independently collected from each article by two authors (SM and DKB): name of the first author, year of publication, study population, intervention and control group, outcome and reported complications. The primary aim of this article is to find the potential benefits and risks of epidural anesthesia and analgesia in neonates.

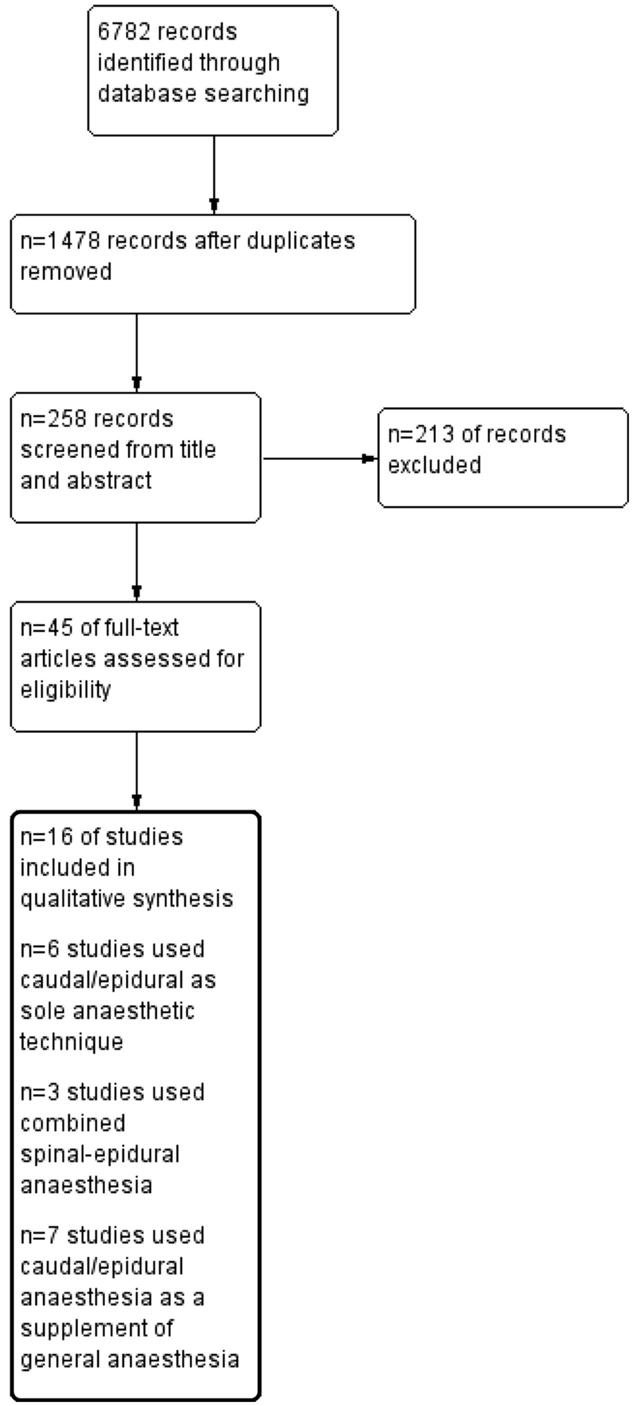


**Fig. 1** Flow chart of study selection

## Results

### Epidural anesthesia as a sole technique

Epidural anesthesia can be used as a sole anesthetic technique or as a supplement to general anesthesia; it can be a "single shot caudal", a "caudal catheter technique", or an

**Table 1** Studies that used caudal/epidural as the sole anesthetic

| References | Years | Population | Technique | Benefits | Risk |
|---|---|---|---|---|---|
| Gunter et al. [14] | 1991 | Twenty premature or high-risk infants posted for inguinal herniorrhaphy, orchiopexy, and circumcision | Single injection caudal anesthesia, performed with 1 ml/kg of 0.375 % bupivacaine | Successful in 19/20 neonates<br>Acceptable anesthesia technique | No postoperative complications were observed |
| Henderson et al. [15] | 1993 | Ten former preterm infants (35–49.5 weeks), ASA PS II and III, for inguinal hernia repair | Caudal anesthesia by indwelling catheter: a loading dose of 1 ml/kg (30 mg/kg) of 3 % 2-chloroprocaine, incremental doses of 0.3 ml/kg (9 mg/kg) to achieve a level of T4 to T2. Maintenance: minimum infusion rate of 30 mg/kg/h (1 ml/kg/h) of the same local anesthetic solution | | No reported complication |
| Peutrell et al. [16] | 1993 | Caudal epidural anesthesia in 9 awake ex-premature babies who were having inguinal herniotomy | Epidural anesthesia by caudal catheter technique | Excellent analgesia in 6 neonates | No postoperative complication |
| Webster et al. [17] | 1993 | Lumbar epidural anesthesia in 18 low-birth-weight, preterm neonate undergoing hernia surgery | Loss of resistance to saline by 20G epidural needle.<br>Bupivacaine 0.25 %, 0.75–1.0 ml/kg | Good operating condition in 15 cases by epidural alone | Intraoperative periodic breathing = 7<br>Desaturation = 6<br>Post op apnea = 3<br>No hemodynamic adverse effects<br>No neurological complication |
| Bouchut et al. [18] | 2001 | Caudal anesthesia in 25 consecutive conscious ex-premature infants for inguinal herniotomy | 0.5 ml/kg of lidocaine 1 % (5 mg/kg) and 0.5 ml/kg of bupivacaine 0.5 % (2.5 mg/kg) was given | Satisfactory surgical condition in 22 cases | Spinal anesthesia = 1<br>Transient pain = 2<br>Desaturation = 2<br>Insufficient duration = 1<br>Postoperative apnea = 2 |
| Geze et al. [19] | 2011 | Caudal anesthesia in 15 conscious low-birth-weight infants for inguinal herniotomy | 0.2 % levobupivacaine at a dose of 1–1.5 ml/kg (2.5 mg/kg) and sedated with intravenous 0.1 mg midazolam and 0.5 mg/kg ketamine | Satisfactory surgical anesthesia in all patients | No reported intraoperative or postoperative complications |

"intervertebral epidural catheter". Six clinical studies [14–19] reported the use of either single shot or continuous caudal anesthesia in awake preterm neonates (Table 1).

Most of the studies used caudal technique for inguinal hernia repair and other inguinal surgeries. Only one study used a caudal catheter technique to achieve a mid-thoracic dermatome anesthesia for inguinal hernia repair. None of the studies reported any serious neurological complications; however, two studies reported intraoperative periodic breathing, postoperative apnea and desaturation in quite significant numbers. It is worth mentioning that Webster et al. reported intraoperative periodic breathing in seven out of 18, desaturation in six out of 18, and postoperative apnea in three out of 18 low-birth-weight preterm neonates.

A retrospective study [20] published in 2011 was aimed at finding the safety and efficacy of caudal block in preterm and ex-preterm infants undergoing herniotomy combined with light general anesthesia. They performed caudal block by means of a short catheter of 22G or 24G and used 1 ml/kg of 0.25 % bupivacaine or 0.2 % ropivacaine or 0.25 % levobupivacaine with epinephrine (5 mcg/ml). The authors found caudal anesthesia proved successful at first attempt in 69 % of the infants (term or premature). Three attempts were needed in 8 % of the infants born at term and 2 % of the infants born prematurely. One failure was recorded. Seven patients presented one episode of perioperative apnea.

Combined spinal-epidural technique

Three studies reported the use combined spinal-epidural technique in elective major gastrointestinal surgery (Table 2). However, only one study was a controlled trial that compared with general anesthesia.

In 2007, Somri et al. [21] used combined spinal-epidural anesthesia in 28 neonates and infants with isobaric bupivacaine 0.5 %, 1 mg/kg, followed by placement of a caudal epidural catheter to thoracic spinal segments. Four infants required being converted to general anesthesia (one due to failure of spinal anesthesia, two due to failure of epidural catheter insertion, and one infant due to repeated apnea), and respiratory and hemodynamic variables were stable throughout the surgery. However, 20 infants required intravenous midazolam sedation, and two infants in the intraoperative period and two others required positive pressure ventilation. Epidural analgesia was effective in 22 infants in the first 48 h postoperative period. In 2011, Somri et al. [22], in a small, randomized controlled trial (RCT), compared the benefits of combined spinal-epidural anesthesia with general anesthesia in neonates undergoing gastrointestinal surgery. The total number of postoperative respiratory adverse events (16 vs. 6, $p = 0.0001$) and the number of infants (11 vs. 3, RR = 2.5, 95 % CI 1.2–5.3) who experienced at least one respiratory adverse event were statistically more in patients receiving general anesthesia than in infants who received combined spinal-epidural anesthesia. There were significantly more cardiovascular adverse events (tachycardia, tachycardia and hypotension, tachycardia and hypertension, bradycardia, ventricular premature beats) in the general anesthesia infants than in the combined spinal-epidural anesthesia infants (20 vs. 11, $p = 0.005$). However, there were no statistically significant differences found between each specific cardiovascular adverse event. But, these adverse cardiovascular events were also more resistant to treatment in the infants receiving general anesthesia than those receiving combined spinal-epidural anesthesia (9 vs. 0, $p = 0.001$). In another RCT [23] performed in small infants undergoing elective intestinal surgery, the authors reported that combined spinal-epidural anesthesia was associated with faster recovery (onset of stool passage in $< 5$ days) of intestinal function (19/23 vs. 4/23), and a lower frequency of postoperative abdominal distension (7/23 vs. 14/23, $p = 0.038$) and pneumonia (0/23 vs. 3/23, $p = 0.038$). Seven infants in the general anesthesia group required mechanical ventilation after surgery, whereas no infants in the combined spinal-epidural group required postoperative respiratory support.

Caudal/epidural analgesia as supplement to general anesthesia

Several studies [13, 24–30] addressed the safety and efficacy of caudal/epidural analgesia as a supplement of general anesthesia in neonates (Table 3).

Murrell et al. [24] in 1993 reported the use of lumbar epidural analgesia in neonates and ex-premature infants as a supplement to general anesthesia. The quality of

**Table 2** Studies that reported the use of combined spinal-epidural anesthesia

| References | Years | Population | Technique | Results |
|---|---|---|---|---|
| Somri et al. [21] | 2007 | CSEA in neonates and infants undergoing elective major upper abdominal surgery | Spinal anesthesia was performed in 28 neonates and infants with isobaric bupivacaine 0.5 %, 1 mg/kg, followed by placement of a caudal epidural catheter to thoracic spinal segments | Satisfactory surgical anesthesia was achieved in 24 neonates and infants |
| Somri et al. [22] | 2011 | Fifty infants undergoing elective primary gastrointestinal surgery: GA (25 patients) and CSEA (25 patients) | GA: induction with propofol-fentanyl-rocoronium and maintenance with air-oxygen-isoflurane.<br>CSEA: spinal—0.8 ml/kg 0.5 % bupivacaine at L3–4/L4–5 intervertebral space<br>Epidural—20G epidural catheter to thoracic level by caudal approach, bolus dose of 0.5 ml/kg 0.25 % bupivacaine followed by 0.1 % bupivacaine infusion at a rate of 0.2–0.3 ml/kg/h | Total number of postoperative respiratory adverse events and the number of infants who experienced at least one respiratory adverse event were more in general anesthesia than in combined spinal-epidural anesthesia; [($p < 0.0001$), (RR = 2.5; 95 % CI 1.2–5.3)] |
| Somri et al. [23] | 2012 | Fifty young infants undergoing elective intestinal surgery | 50 young infants were randomly allocated to two groups of 25 patients each, a general anesthesia group and a CSEA group | Recovery of intestinal function was faster ($p < 0.0001$) |

*GA* general anesthesia, *CSEA* combined spinal-epidural anesthesia

**Table 3** Studies assessing caudal/epidural analgesia as supplement to general anesthesia

| References | Years | Population | Technique | Benefits | Complications |
|---|---|---|---|---|---|
| Murrell et al. [24] | 1993 | Fourteen newborn infants (32–40 weeks gestation) aged 4 h to 35 days undergoing major surgery, and six ex-preterm (25–29 weeks gestation) infants aged 2–5 months at time of surgery | Epidural at L3–4 or L4–5 interspace.<br>0.25 % bupivacaine with 1:200,000 adrenalin with 1–2 mcg/kg fentanyl up to 0.8 ml/kg | Effective analgesia was achieved for up to 69 h without complication<br>All infants were awake and extubated | None of the infants developed respiratory depression or prolonged apnea |
| Tobius et al. [25] | 1996 | Twenty-five neonates ranging in age from 1 to 28 days and in weight from 2.2 to 4.9 kg, continuous caudal epidural by catheter | Bolus dose of chloroprocaine 3 % (1 or 1.5 ml/kg)<br>Followed by a continuous infusion of 1 or 1.5 ml/kg/h | Adequate intraoperative anesthesia was achieved in all 25 neonates<br>No episodes of hemodynamic instability<br>Twenty-three of 25 of the neonates' tracheas were extubated immediately | No reported complication |
| Bosenberg et al. [26] | 1998 | Epidural analgesia in 240 neonates weighing between 0.9 and 5.8 kg in major abdominal/thoracic surgery | Lumbar/thoracic epidural anesthesia by loss of resistance to air technique.<br>Initial dose: 0.7 ml/kg (lumbar) or 0.5 ml/kg (thoracic) 0.25 % bupivacaine increments of 0.1 ml/kg 0.25 % bupivacaine when hemodynamic response to surgical incision<br>Postoperatively: intermittent boluses of 0.2 % bupivacaine or by continuous infusion of 0.2 % bupivacaine at 0.1 ml/kg/h | Effective analgesia was established intraoperatively in all patients<br>No additional muscle relaxant or opioid required | Dural puncture ($n = 1$), convulsion ($n = 1$) intravascular migration of catheter ($n = 1$)<br>Bradycardia below 100 ($n = 15$) |
| Vas et al. [27] | 1999 | Continuous lumbar epidural analgesia in 20 neonates for various major surgical procedures | Epidural catheter insertion through lumbar route, postoperative analgesia for 72 h | 19/20 babies could be extubated in the operating theater.<br>They were awake but comfortable at the time of extubation | Catheter insertion failure through lumbar route = 2/20 |
| Shenkman et al. [28] | 2009 | Use of continuous lumbar/thoracic epidural anesthetics<br>in low-weight infants undergoing major surgery in 40 consecutive patients | Bupivacaine 0.125–0.2 % at a dose of up to 2 mg kg-1 with sodium bicarbonate<br>0.0336 % at a volume of 0.06–<br>1 ml/kg per segment to be blocked<br>Maintenance: bupivacaine<br>0.15–0.2 mg/kg/h every 1.5–2 h at a volume similar<br>to the loading volume<br>Epidural fentanyl 1 lg/kg in the same volume was added in the event of inadequate analgesia | Good intraoperative and postoperative analgesia was achieved in all patients.<br>Tracheal extubation was performed in the theater after 40 procedures | Intraoperative complications: hemodynamic instability ($n = 1$) vascular catheter placement ($n = 5$). Postoperative complications: meningitis ($n = 1$), insertion site erythema ($n = 7$),<br>apnea ($n = 6$; four premature and two full-term infants) tracheal re-intubation ($n = 6$) |

**Table 3** continued

| References | Years | Population | Technique | Benefits | Complications |
|---|---|---|---|---|---|
| Bozza et al. [29] | 2012 | Seventeen newborns/infants necessitating colorectal surgery | Intravenous vs. epidural analgesia | Epidural analgesia is more effective in attenuating stress response | Not reported |
| Gomez-Chacon et al. [30] | 2012 | Matched case–control (2:1) study of patients undergoing neonatal major surgery who received intraoperative and postoperative epidural anesthesia and controls with conventional general anesthesia | Levobupivacaine was selected as anesthetic drug | Significantly less time to extubation (95 % CI OR 12 1.99–72.35; Mann *U* Whitney $p = 0.013$) and intestinal transit time (Mann–Whitney *U* $p < 0.001$, 100 OR, 95 % CI 8.06–12. 39) | No reported complication |

analgesia was very good. They were able to extubate all patients at the end of surgery and did not report any complication. Bösenberg [26] in 1998 reported use of lumbar/thoracic epidural analgesia in major neonatal surgery. He reported that epidural analgesia can be considered for neonates undergoing major surgery with a low risk of complication, with advantages of the reduced need for muscle relaxants, opioid analgesics and postoperative ventilatory support [13]. In 2009, Shenkman et al. [28] reported safe use of continuous epidural analgesia in small infants (1,400–4,300 g) in major surgery. The advantages were good perioperative analgesia and early tracheal extubation in the operating room. However, 15 % neonates required reintubation due to postoperative apnea. In a matched case–control study, Gomez-Chacon et al. [30] reported that intraoperative and postoperative epidural analgesia is associated with significant reduction in time to extubation and intestinal transit time in major neonatal surgery. There were no complications from epidural analgesia.

## Epidural analgesia/anesthesia: physiological benefits

Bösenberg et al. [31] reported that neuraxial blockade is not associated with hypotension in neonates, and the hemodynamic stability is remarkable, even in neonates with congenital heart disease. Stability of hemodynamic variables during caudal anesthesia with bupivacaine and with epinephrine-added bupivacaine in newborn infants has been previously reported in clinical study [32]. Regional analgesia is associated with reduced perioperative opioid use, and may have some respiratory stimulant action at least in healthy children of 3–8 years age [33]. This physiological benefit may be reflected in clinical practice as reduced need for mechanical ventilation. Moreover, surgical stress response is more effectively mitigated by regional anesthesia in comparison to systemic opioids. Regional anesthesia is free of respiratory depressant and immunosuppressive effects of opioid [34, 35]. In neonates, epidural anesthesia may attenuate surgical stress responses better than intravenous anesthesia [29].

As the neonates remained awake, the complications that may arise from general anesthesia, positive pressure ventilation and airway management could be avoided. It may provide good postoperative analgesia as well. Epidural analgesia by various routes has been described as a supplement to general anesthesia in major surgeries in neonates.

## Epidural catheter insertion: which approach?

Though thoracic epidural catheters are described in neonates in one report [36], their routine use cannot be advocated at this moment because of serious concern about injury to the growing spinal cord. However, relative fluidity of the epidural fat in neonates and young infants allows the anesthesiologist to advance the thoracic catheter inserted through the caudal or lumbar route. Bösenberg et al. [37] described the successful placement of an 18G epidural catheter up to a thoracic or cervical level via the caudal approach. Advancement to the thoracic or upper abdominal level may be easier with relatively large bore catheters; thinner (19G vs. 23G) catheters are more difficult to thread and malposition is common [38, 39]. Epidurography was recommended as a technique of confirmation for catheter placement when epidural catheter was advanced from the lumbar/caudal route to the thoracic level, because of the high possibility of catheter malposition [38, 40]. Other techniques for confirming epidural catheter position, such as electrocardiography [41], ultrasonography [42] and trans-esophageal echocardiography [43], have also been described. Amongst these techniques, ultrasonography is the most practical technique, as the cartilaginous nature of the neonatal vertebral column and the fluid nature of the epidural fat will provide a very good visualization of the epidural space. Tsui et al. [44] reported use of electrical nerve stimulation through the epidural catheter to delineate the exact level of tip of catheter.

A single study found an 85 % success rate of blind 24G stylated epidural catheter advancement from the caudal to thoracic region, and the authors mentioned that radiographic confirmation is not required [45]. A Crawford epidural needle or a simple intravenous needle [45] is preferable to a Tuhoy needle during catheter threading in the caudal space in small children [37].

Lumbar epidural anesthesia has been used in neonates for inguinal hernia repair [16] and major thoraco-abdominal surgery [26]. However, there are reports of paraplegia due to intraspinal hematoma during attempted lumbar epidural block [46], and this route is less preferred in neonates [26, 45]. The advent of ultrasound may be especially useful in neonates, as the ossification of the vertebral column is less and the cord structures are well visualized [47].

## Local anesthetic in neonate: safety issues

The physiological differences between neonates and older children make neonates vulnerable to various local anesthetic toxicities. Neonates are at risk of bupivacaine and other amino amide local anesthetic (LA) toxicities, due to low serum levels of α1 acid glycoprotein (AAG), albumin and bicarbonate reserve [47]. AAG has high affinity but low capacity for binding with LA, and the opposite is true for albumin. Clinical presentations of LA toxicity may be different in these patients; cardiac dysrhythmia and respiratory arrest may be the initial manifestation and convulsion is uncommon [48].

To minimize the LA requirement and for better analgesia, the tip of the epidural catheter should be situated at an intraspinal level that corresponds to the dermatome center of the surgical procedure. Bösenberg et al. [49] reported that a caudal bolus injection of 3 mg/kg of ropivacaine or a continuous epidural infusion of 0.2–0.4 mg/kg/h of the same drug was clinically effective and did not result in excessive plasma levels of the drug. In an Anesthesia Patient Safety Foundation sponsored study, all children who had systemic toxicity had infusion rates in excess of 0.5 mg/kg/h of racemic bupivacaine [50]. In a recent review, authors recommend a maximum bolus dosage of 1.5–2.0 mg/kg followed by an infusion of 0.2 mg/kg/h, and it should only be continued beyond 48 h when considerable benefits exist [51]. Ropivacaine may be a better choice where an infusion is needed, because plasma concentration of unbound ropivacaine does not depend upon the duration of infusion, and a duration of 48–72 h is usually safe with an infusion rate of 0.2–0.4 mg/kg/h [52].

In a questionnaire survey [53] done among French-speaking pediatric anesthesiologists, (Association of Anesthésistes—Réanimateurs Pédiatriques d'Expression Française; ADARPEF), a total of 24,005 regional procedures were reviewed. The number of accidents without long-term effects was 108 (0.45 %). There is also report of five serious accidents (0.02 %). All serious accidents were reported in small children less than 3 months of age and were associated with central nervous system injury.

## Epidural anesthesia techniques

From a technical standpoint, caudal anesthesia is the simplest and easiest to learn [54]. Use of real-time ultrasound guidance will provide direct visualization of drug spread in the epidural space, and may increase the safety profile of the procedure [55]. Though no clinical study has been conducted in neonates to find out the proper volume of drug required for a particular level of block, adherence to the Armitage rule [56] is widely practiced. Limiting the dose of local anesthetic below the maximum recommended limit is essential to avoid toxicity.

During identification of the epidural space in lumbar/thoracic technique, loss of resistance to saline is desirable, as injection of air in the epidural space in a small child may cause air embolism and even neurological injury [57].

## Which drug to choose? Local anesthetics or opioids or combinations?

Local anesthetics are most commonly used in the epidural route. As we previously discussed, the altered

Table 4 Local anesthetic doing recommendation in neonate

| Drug | Bolus dosing (mg/kg) | Infusion dosing (mg/kg/h) |
|---|---|---|
| Bupivacaine [51] | 1.5–2.0 | 0.2 |
| Ropivacaine [52] | 2.0 | 0.2–0.4 |

pharmacokinetics of LAs in neonates is the most important concern here. Apart from this, a limited duration of analgesia with the single injection technique is also an important consideration. The maximum dosage recommendation of local anesthetic is mentioned in Table 4.

Opioid analgesics administered through the epidural route hve been shown to increase the duration of analgesia at a dose much less than in systemic dosing. However, no study has been done in neonates to find out the optimum dose of epidurally administered opioids and their safety and efficacy. In older children, caudal morphine at a dose of 10–30 mcg/kg has been shown to increase the duration of analgesia [58–60]. However, increasing the dose from 10 to 30 mcg/kg does not significantly increase the duration of analgesia [61].

A retrospective review of caudal morphine use at a dose of 70 mcg/kg in infants and children found that clinically significant respiratory depression occurred in 8 % cases, and most of the patients were younger than 1 year age. However, it provided excellent to fair analgesia in 88 % cases [62].

Clonidine also prolongs the duration of caudal/epidural analgesia and perhaps more than morphine [58]; there are important safety concerns that are mentioned later.

### Safety data

Complications from epidural anesthesia in the neonate can be due to the drug toxicity, intravascular/intrathecal injection, catheter-related complications (e.g. intravascular/intrathecal catheter migration, infection etc.) and neurological complications (e.g. cauda equine syndrome, paraplegia etc.), which may be as severe as injury to the developing cord. Though clonidine when used in caudal block prolonged duration of analgesia in children [63], there are case reports [64, 65] of intraoperative and postoperative apnea with the use of caudal clonidine in neonates. However, no definite cause-effect relationship has been established [66].

Local anesthetic toxicity may be devastating in neonates; despite negative aspiration, real-time US use cardiac arrest has been reported in a neonate who received 0.25 % bupivacaine at a dose of 1 ml/kg [67].

The most important risk consideration in central neuraxial block in neonates is the possibility of inadvertent injury to the developing spinal cord. Serious complications including neurologic injury have been reported in neonates [65]. Many authors [20, 25] have recommended that only experienced pediatric anesthesiologist should perform a central neuraxial block in a neonate. Neural injury following local anesthetic use via the epidural route may also cause persistent hiccups [68].

In 1996, a survey [69] by the French-Language Society of Pediatric Anesthesiologists involving 24,409 regional anesthetics found that the caudal block was the most commonly performed regional anesthetic technique in all age groups of children, including neonates. However, the rate of complications from regional anesthesia in this age group is low, and they found that the overall complication rate of regional anesthesia was 0.9 per 1,000. Yet, all the complications occurred with central neuraxial blocks. The complication rate of central blocks is 1.5 per 1,000, with significant variations in different age groups. Another 1-year prospective survey [41] found that a caudal epidural block followed by a lumbar epidural is the most commonly performed regional anesthetic technique in neonates. They also found that complications due to regional anesthesia in neonate range between 0.8 and 1.0 %, but none resulted in serious long-term consequences. A large prospective observational study [70] found that single injection neuraxial techniques are very safe, and serious complications with long-term consequences are uncommon. There were no deaths or complications with long-term consequences lasting > 3 months, but short-term complications such as catheter-related problems (dislodgement or kinking), accidental dural puncture (0.9 %), intravascular injection (2 %) and local site inflammation/infection (11 %) were observed. However, the authors mentioned that detection of minor neurological complications like paresthesia in pre-verbal age group children is impossible. Another recent retrospective analysis [71] has mentioned that caudo-thoracic epidural is increasingly being used in neonates, despitea greater chance of complications in neonates with caudal epidural analgesia than in their older counterparts.

## Discussion

Epidural anesthesia has been used in the neonate as a sole anesthetic technique or as a supplementation of analgesia along with general or spinal anesthesia [14–19]. When used as a sole anesthetic technique, mostly inguinal surgeries have been done under caudal epidural anesthesia with a reasonable success rate. Though the most important benefit of a sole regional technique in neonates is the avoidance of sedative/narcotics and subsequently elimination the risk of postoperative apnea, two studies [17, 18] reported a high incidence of intraoperative periodic breathing, apnea, desaturation and postoperative apnea. However, no neurological complications or hemodynamic compromise have been reported. It is worth mentioning that none of the studies had a control group, so comparison with general anesthesia or other anesthesia techniques has not been possible. Moreover, all the studies were small in sample size and used caudal/epidural anesthesia for relatively minor surgical procedures. Use of epidural anesthesia as a sole anesthetic technique may eliminate the need of opioid analgesic; however, incidences of apnea and desaturation have been reported for opioid free regional technique—hence, regional anesthesia does not eliminate the need for a vigilant anesthesiologist! Another limitation of the single injection caudal block is the finite duration of analgesia.

A combined spinal-epidural technique has been compared with general anesthesia in neonates undergoing elective abdominal surgery [21–23]. It was found to be associated with fewer adverse respiratory effects and early return of gastro-intestinal function. However, neither mortality benefit nor any serious neurological complications were reported. In one study, intravenous sedation was used in most of the babies; however, safety of intravenous sedation in these vulnerable infants exists, and the authors aptly concluded that combined spinal-epidural anesthesia could be considered as an effective anesthetic technique for elective major upper abdominal surgery in awake or sedated neonates and infants, and could be used cautiously by a "pediatric anesthesiologist" as an alternative to general anesthesia in high-risk neonates and infants undergoing upper gastrointestinal surgery.

Caudal/epidural analgesia has been used as a supplementary analgesic technique with general anesthesia. Though no randomized controlled trial has been conducted and only one matched case control study has been published, all the authors reported extubation immediately after completion of surgery in most of the neonates. Four studies did not report any complications. Reported intraoperative complications from the three other studies included intravascular catheter placement, bradycardia, convulsion; postoperative complications were postoperative apnea, re-intubation, local site erythema and meningitis. General anesthesia administered through a face mask without opiates or neuromuscular blocking agents, maintaining the infant's spontaneous breathing and combined with a caudal anesthesia, could be a safe and effective alternative [19].

Another important limitation of single injection caudal anesthesia is the limited duration of analgesia in neonates. The reported duration of analgesia after bupivacaine is 90–120 min. Levobupivacaine and ropivacaine may provide a shorter duration of analgesia, as well as motor block [72].

Apart from providing perioperative analgesia, regional anesthesia attenuates surgical stress response effectively, provides hemodynamic stability, and avoidance of opioid may better preserve immune functions. However, there is no evidence that these physiological benefits will be converted to a better outcome.

Due to the concern of the injury of the growing spinal cord and reports of neurological injury after lumbar epidural catheter insertion, catheter insertion through the caudal route may be most preferable. Again, there is no robust evidence on which route of the catheter is safest; the ease of catheter insertion in neonates due to the fluidity of epidural fat and absence of adult-type spinal curvature, as ewll as the usefulness of ultrasound in neonates, made the caudal route of catheter insertion most logical. However, catheter advancement from the caudal to thoracic level has its own pitfall; at times it may be impossible to insert the catheter to the desired level. The nerve routes in the epidural space may also be injured by the epidural catheter.

Patients with urogenital anomaly need special consideration, as incidence of lower spinal dysraphism is high in these children, and a pre-procedure US screening is recommended [73].

## Conclusion

Epidural anesthesia in the form of single shot caudal block, continuous epidural anesthesia with/without general anesthesia is safe in skilled hands, and offers an awake and comfortable patient at the end of surgery. Other potential benefits, such as early extubation, attenuation of stress response and early return of bowel function have been observed. Clinical evidence suggests that epidural anesthesia, when combined with spinal anesthesia, may provide a superior respiratory and gastrointestinal outcome. However, current evidence is mostly based on prospective or retrospective case series and surveys, and many of the studies are limited by small sample size. Large, well-designed RCTs focusing on outcome benefits and addressing various safety issues are required to establish a firm conclusion. But, as neonates are one of the most vulnerable populations and because of heterogeneity of the clinical conditions of neonates, these factors may preclude the feasibility of a large RCT in this population.

## Appendix

("infant, newborn"[MeSH Terms] OR ("infant"[All Fields] AND "newborn"[All Fields]) OR "newborn infant"[All Fields] OR "neonate"[All Fields]) AND caudal[All Fields]

("infant, newborn"[MeSH Terms] OR ("infant"[All Fields] AND "newborn"[All Fields]) OR "newborn infant"[All Fields] OR "neonate"[All Fields]) AND epidural[All Fields]

("infant, newborn"[MeSH Terms] OR ("infant"[All Fields] AND "newborn"[All Fields]) OR "newborn infant"[All Fields] OR "neonate"[All Fields]) AND ("epidural anaesthesia"[All Fields] OR "anesthesia, epidural"[MeSH Terms] OR ("anesthesia"[All Fields] AND "epidural"[All Fields]) OR "epidural anesthesia"[All Fields] OR ("epidural"[All Fields] AND "anesthesia"[All Fields]))

("infant, newborn"[MeSH Terms] OR ("infant"[All Fields] AND "newborn"[All Fields]) OR "newborn infant"[All Fields] OR "neonate"[All Fields]) AND ("analgesia, epidural"[MeSH Terms] OR ("analgesia"[All Fields] AND "epidural"[All Fields]) OR "epidural analgesia"[All Fields] OR ("epidural"[All Fields] AND "analgesia"[All Fields]))

("infant, newborn"[MeSH Terms] OR ("infant"[All Fields] AND "newborn"[All Fields]) OR "newborn infant"[All Fields] OR "neonate"[All Fields]) AND ("regional anaesthesia"[All Fields] OR "anesthesia, conduction"[MeSH Terms] OR ("anesthesia"[All Fields] AND "conduction"[All Fields]) OR "conduction anesthesia"[All Fields] OR ("regional"[All Fields] AND "anesthesia"[All Fields]) OR "regional anesthesia"[All Fields])

## References


1. Peters JW, Schouw R, Anand KJ, van Dijk M, Duivenvoorden HJ, Tibboel D. Does neonatal surgery lead to increased pain sensitivity in later childhood? Pain. 2005;114:444–54.
2. Taddio A, Katz J. The effects of early pain experience in neonates on pain responses in infancy and childhood. Paediatr Drugs. 2005;7:245–57.
3. Anand KJ, Sippell WG, Aynsley-Green A. Randomised trial of fentanyl anesthesia in preterm babies undergoing surgery: effects on the stress response. Lancet. 1987;1:62–6.
4. Stratmann G. Review article: neurotoxicity of anesthetic drugs in the developing brain. Anesth Analg. 2011;113:1170–9.
5. Abajian JC, Mellish RW, Browne AF, Perkins FM, Lambert DH, Mazuzan JE Jr. Spinal anesthesia for surgery in the high-risk infant. Anesth Analg. 1984;63:359–62.
6. Coté CJ, Zaslavsky A, Downes JJ, Kurth CD, Welborn LG, Warner LO, Malviya SV. Postoperative apnea in former preterm infants after inguinal herniorrhaphy. A combined analysis. Anesthesiology. 1995;82:809–22.
7. Kim GS, Song JG, Gwak MS, Yang M. Postoperative outcome in formerly premature infants undergoing herniorrhaphy: comparison of spinal and general anesthesia. J Korean Med Sci. 2003;18:691–5.
8. Krane EJ, Haberkern CM, Jacobson LE. Postoperative apnea, bradycardia, and oxygen desaturation in formerly premature infants: prospective comparison of spinal and general anesthesia. Anesth Analg. 1995;80:7–13.
9. Somri M, Gaitini L, Vaida S, Collins G, Sabo E, Mogilner G. Postoperative outcome in high-risk infants undergoing herniorrhaphy: comparison between spinal and general anesthesia. Anesthesia. 1998;53:762–6.
10. Craven PD, Badawi N, Henderson-Smart DJ, O'Brien M. Regional (spinal, epidural, caudal) versus general anesthesia in preterm infants undergoing inguinal herniorrhaphy in early infancy. Cochrane Database Syst Rev. 2003;(3):CD003669. doi:10.1002/14651858.CD003669.
11. Kunst G, Linderkamp O, Holle R, Motsch J, Martin E. The proportion of high risk preterm infants with postoperative apnea and bradycardia is the same after general and spinal anesthesia. Can J Anaesth. 1999;46:94–5.
12. Walker SM, Yaksh TL. Neuraxial analgesia in neonates and infants: a review of clinical and preclinical strategies for the development of safety and efficacy data. Anesth Analg. 2012;115:638–62.
13. Bösenberg AT, Wiersma R, Hadley GP. Oesophageal atresia: caudo-thoracic epidural anesthesia reduces the need for post-operative ventilatory support. Pediatr Surg Int. 1992;7:289–91.
14. Gunter JB, Watcha MF, Forestner JE, Hirshberg GE, Dunn CM, Connor MT, Ternberg JL. Caudal epidural anesthesia in conscious premature and high-risk infants. J Pediatr Surg. 1991;26:9–14.
15. Henderson K, Sethna NF, Berde CB. Continuous caudal anesthesia for inguinal hernia repair in former preterm infants. J Clin Anesth. 1993;5:129–33.
16. Peutrell JM, Hughes DG. Epidural anesthesia through caudal catheters for inguinal herniotomies in awake ex-premature babies. Anesthesia. 1993;48:128–31.
17. Webster AC, McKishnie JD, Watson JT, Reid WD. Lumbar epidural anesthesia for inguinal hernia repair in low birth weight infants. Can J Anaesth. 1993;40:670–5.
18. Bouchut JC, Dubois R, Foussat C, Moussa M, Diot N, Delafosse C, Claris O, Godard J. Evaluation of caudal anesthesia performed in conscious ex-premature infants for inguinal herniotomies. Paediatr Anaesth. 2001;11:55–8.
19. Geze S, Imamoğlu M, Cekic B. Awake caudal anesthesia for inguinal hernia operations: successful use in low birth weight neonates. Anaesthesist. 2011;60:841–4.
20. Lacrosse D, Pirotte T, Veyckemans F. Caudal block and light sevoflurane mask anesthesia in high-risk infants: an audit of 98 cases. Ann Fr Anesth Reanim. 2012;31:29–33.
21. Somri M, Tome R, Yanovski B, Asfandiarov E, Carmi N, Mogilner J, David B, Gaitini LA. Combined spinal-epidural anesthesia in major abdominal surgery in high-risk neonates and infants. Paediatr Anaesth. 2007;17:1059–65.
22. Somri M, Coran AG, Mattar I, Teszler C, Shaoul R, Tomkins O, Tome R, Mogilner JG, Sukhotnik I, Gaitini L. The postoperative occurrence of cardio-respiratory adverse events in small infants undergoing gastrointestinal surgery: a prospective comparison of general anesthesia and combined spinal-epidural anesthesia. Pediatr Surg Int. 2011;27:1173–8.
23. Somri M, Matter I, Parisinos CA, Shaoul R, Mogilner JG, Bader D, Asphandiarov E, Gaitini LA. The effect of combined spinal-epidural anesthesia versus general anesthesia on the recovery time of intestinal function in young infants undergoing intestinal surgery: a randomized, prospective, controlled trial. J Clin Anesth. 2012;24:439–45.
24. Murrell D, Gibson PR, Cohen RC. Continuous epidural analgesia in newborn infants undergoing major surgery. J Pediatr Surg. 1993;28:548–52.
25. Tobias JD, Rasmussen GE, Holcomb GW 3rd, Brock JW 3rd, Morgan WM 3rd. Continuous caudal anesthesia with chloroprocaine as an adjunct to general anesthesia in neonates. Can J Anaesth. 1996;43:69–72.
26. Bösenberg AT. Epidural analgesia for major neonatal surgery. Paediatr Anaesth. 1998;8:479–83.
27. Vas L, Naregal P, Sanzgiri S, Negi A. Some vagaries of neonatal lumbar epidural anesthesia. Paediatr Anaesth. 1999;9:217–23.

28. Shenkman Z, Hoppenstein D, Erez I, Dolfin T, Freud E. Continuous lumbar/thoracic epidural analgesia in low-weight paediatric surgical patients: practical aspects and pitfalls. Pediatr Surg Int. 2009;25:623–34.
29. Bozza P, Morini F, Conforti A, Sgrò S, Laviani Mancinelli R, Ottino S, Bagolan P, Picardo S. Stress and ano-colorectal surgery in newborn/infant: role of anesthesia. Pediatr Surg Int. 2012;28:821–4.
30. Gómez-Chacón J, Encarnación J, Couselo M, Mangas L, Domenech A, Gutiérrez C, García Sala C. Benefits of epidural analgesia in major neonatal surgery. Cir Pediatr. 2012;25:149–54.
31. Bösenberg AT, Jöhr M, Wolf AR. Pro con debate: the use of regional vs systemic analgesia for neonatal surgery. Paediatr Anaesth. 2011;21:1247–58.
32. Deng M, Wang X, Wang L, Zheng S. The hemodynamic effects of newborn caudal anesthesia assessed by transthoracic echocardiography: a randomized, double-blind, controlled study. Paediatr Anaesth. 2008;18:1075–81.
33. von Ungern-Sternberg BS, Regli A, Frei FJ, Hammer J, Schibler A, Erb TO. The effect of caudal block on functional residual capacity and ventilation homogeneity in healthy children. Anesthesia. 2006;61:758–63.
34. Hollmann MW, Durieux ME. Local anesthetics and the inflammatory response: a new therapeutic indication? Anesthesiology. 2000;93:858–75.
35. Wolf AR, Doyle E, Thomas E. Modifying infant stress responses to major surgery: spinal vs extradural vs opioid analgesia. Paediatr Anaesth. 1998;8:305–11.
36. Ecoffey C, Lacroix F, Giaufré E, Orliaguet G, Courrèges P, Association des Anesthésistes Réanimateurs Pédiatriques d'Expression Française (ADARPEF). Epidemiology and morbidity of regional anesthesia in children: a follow-up one-year prospective survey of the French-Language Society of Paediatric Anaesthesiologists (ADARPEF). Paediatr Anaesth. 2010;20:1061–9.
37. Bosenberg AT, Bland BAR, Schulte-Steinberg O, Downing JW. Thoracic epidural via the caudal route in infants. Anesthesiology. 1988;69:265–9.
38. Baidya DK, Pawar DK, Dehran M, Gupta AK. Advancement of epidural catheter from lumbar to thoracic space in children: comparison between 18G and 23G catheters. J Anaesthesiol Clin Pharmacol. 2012;28:21–7.
39. Van Niekerk J, Bax-Vermeire BM, Geurts JW, Krammer PP. Epidurography in premature infants. Anesthesia. 1990;45:722–5.
40. Valairucha S, Seefelder C, Houck CS. Thoracic epidural catheters placed by the caudal route in infants: the importance of radiographic confirmation. Paediatr Anaesth. 2002;12:424–8.
41. Tsui BC, Seal R, Koller J. Thoracic epidural catheter placement via the caudal approach in infants by using electrocardiographic guidance. Anesth Analg. 2002;95:326–30.
42. Schwartz D, King A. Caudally threaded thoracic epidural catheter as the sole anesthetic in a premature infant and ultrasound confirmation of the catheter tip. Paediatr Anaesth. 2009;19:808–10.
43. Ueda K, Shields BE, Brennan TJ. Transesophageal echocardiography: a novel technique for guidance and placement of an epidural catheter in infants. Anesthesiology. 2013;118:219–22.
44. Tsui BC, Wagner A, Cave D, Kearney R. Thoracic and lumbar epidural analgesia via the caudal approach using electrical stimulation guidance in pediatric patients: a review of 289 patients. Anesthesiology. 2004;100:683–9.
45. Gunter JB, Eng C. Thoracic epidural anesthesia via the caudal approach in children. Anesthesiology. 1992;76:935–8.
46. Breschan C, Krumpholz R, Jost R, Likar R. Intraspinal haematoma following lumbar epidural anesthesia in a neonate. Paediatr Anaesth. 2001;11:105–8.
47. Willschke H, Bosenberg A, Marhofer P, Willschke J, Schwindt J, Weintraud M, Kapral S, Kettner S. Epidural catheter placement in neonates: sonoanatomy and feasibility of ultrasonographic guidance in term and preterm neonates. Reg Anesth Pain Med. 2007;32:34–40.
48. Eyres RL. Local anaesthetic agents in infancy. Paed Anaesth. 1995;5:213–8.
49. Bösenberg AT, Thomas J, Lopez T, Huledal G, Jeppsson L, Larsson LE. Plasma concentrations of ropivacaine following a single-shot caudal block of 1, 2 or 3 mg/kg in children. Acta Anaesthesiol Scand. 2001;45:1276–80.
50. Berde CB. Toxicity of local anesthetics in infants and children. J Pediatr. 1993;122(5 Pt 2):S14–20.
51. Lönnqvist PA. Regional anesthesia and analgesia in the neonate. Best Pract Res Clin Anaesthesiol. 2010;24:309–21.
52. Bösenberg AT, Thomas J, Cronje L, Lopez T, Crean PM, Gustafsson U, Huledal G, Larsson LE. Pharmacokinetics and efficacy of ropivacaine for continuous epidural infusion in neonates and infants. Paediatr Anaesth. 2005;15:739–49.
53. Flandin-Bléty C, Barrier G. Accidents following extradural analgesia in children. The results of a retrospective study. Paediatr Anaesth. 1995;5:41–6.
54. Schuepfer G, Konrad C, Schmeck J, Poortmans G, Staffelbach B, Jöhr M. Generating a learning curve for pediatric caudal epidural blocks: an empirical evaluation of technical skills in novice and experienced anesthetists. Reg Anesth Pain Med. 2000;25:385–8.
55. Roberts SA, Guruswamy V, Galvez I. Caudal injectate can be reliably imaged using portable ultrasound—a preliminary study. Paediatr Anaesth. 2005;15:948–52.
56. Armitage EN. Caudal blocks in children. Anaesthesia. 1979;34:396.
57. Fernandes ML, Pires KC, Tibúrcio MA, Gomez RS. Caudal bupivacaine supplemented with morphine or clonidine, or supplemented with morphine plus clonidine in children undergoing infra-umbilical urological and genital procedures: a prospective, randomized and double-blind study. J Anesth. 2012;26:213–8.
58. Singh R, Kumar N, Singh P. Randomized controlled trial comparing morphine or clonidine with bupivacaine for caudal analgesia in children undergoing upper abdominal surgery. Br J Anaesth. 2011;106:96–100.
59. Castillo-Zamora C, Castillo-Peralta LA, Nava-Ocampo AA. Dose minimization study of single-dose epidural morphine in patients undergoing hip surgery under regional anesthesia with bupivacaine. Paediatr Anaesth. 2005;15:29–36.
60. Cesur M, Alici HA, Erdem AF, Yapanoglu T, Silbir F. Effects of reduction of the caudal morphine dose in paediatric circumcision on quality of postoperative analgesia and morphine-related side-effects. Anaesth Intensive Care. 2007;35:743–7.
61. Sethna NF, Berde CB. Venous air embolism during identification of the epidural space in children. Anesth Analg. 1993;76:925–7.
62. Valley RD, Bailey AG. Caudal morphine for postoperative analgesia in infantsand children: a report of 138 cases. Anesth Analg. 1991;72:120–4.
63. Yildiz TS, Korkmaz F, Solak M, Toker K. Clonidine addition prolongs the duration of caudal analgesia. Acta Anaesthesiol Scand. 2006;504:501–4.
64. Galante D. Preoperative apnea in a preterm infant after caudal block with ropivacaine and clonidine. Paediatr Anaesth. 2005;158:708–9.
65. Bouchut JC, Dubois R, Godard J. Clonidine in preterm-infant caudal anesthesia may be responsible for postoperative apnea. Reg Anesth Pain Med. 2001;261:83–5.
66. Hussain AS, Siddiqui MS, Hamdard F, Mayhew JF. Postoperative apnoea in an ex-premature infant: is it only related to clonidine? Paediatr Anaesth. 2003;138:741.

67. Lin EP, Aronson LA. Successful resuscitation of bupivacaine-induced cardiotoxicity in a neonate. Paediatr Anaesth. 2010;20: 955–7.
68. Bagdure DN, Reiter PD, Bhoite GR, Dobyns EL, Laoprasert P. Persistent hiccups associated with epidural ropivacaine in a newborn. Ann Pharmacother. 2011;45:e35.
69. Giaufré E, Dalens B, Gombert A. Epidemiology and morbidity of regional anesthesia in children: a one-year prospective survey of the French-Language Society of Pediatric Anesthesiologists. Anesth Analg. 1996;835:904–12.
70. Polaner DM, Taenzer AH, Walker BJ, Bosenberg A, Krane EJ, Suresh S, Wolf C, Martin LD. Pediatric Regional Anesthesia Network (PRAN): a multi-institutional study of the use and incidence of complications of pediatric regional anesthesia. Anesth Analg. 2012;1156:1353–64.
71. Wong GK, Arab AA, Chew SC, Naser B, Crawford MW. Major complications related to epidural analgesia in children: a 15-year audit of 3,152 epidurals. Can J Anaesth. 2013;604:355–63.
72. Locatelli B, Ingelmo P, Sonzogni V, Zanella A, Gatti V, Spotti A, Di Marco S, Fumagalli R. Randomized, double-blind, phase III, controlled trial comparing levobupivacaine 0.25 %, ropivacaine 0.25 % and bupivacaine 0.25 % by the caudal route in children. Br J Anaesth. 2005;94:366–71.
73. Koo BN, Hong JY, Song HT, Kim JM, Kil HK. Ultrasonography reveals a high prevalence of lower spinal dysraphism in children with urogenital anomalies. Acta Anaesthesiol Scand. 2012;56:624–8.