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# Pediatric Neuraxial Blockade

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*Regional anesthetic techniques for children have recently enjoyed a justified resurgence in popularity. Intraoperative blockade of the neuraxis, whether by the spinal or epidural route, provides excellent analgesia with minimal physiologic alteration and, with an indwelling catheter, can provide continuous pain relief for many days postoperatively. As a supplement to general anesthesia, local anesthetic blockade of the neuraxis decreases the total amount of general anesthetic required for surgery, hastens emergence, and allows for a better postoperative experience by providing a pain-free emergence from general anesthesia. Although some practitioners contend that a regional block on an already anesthetized child adds to the risk of the general anesthetic itself, in experienced hands the risks are negligible and the benefits dramatic.*

*In this review of caudal and lumbar epidural and subarachnoid blockade in infants and children, anatomy, physiologic alterations, and pharmacology pertinent to the three types of neuraxial blockade are described, with the aim of providing the practicing anesthesiologist with the foundation needed to perform these blocks with relative confidence.*

**Keywords:** Anesthesia—neurosurgical, pediatric, regional; neuraxis—blockade.

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## Historical Perspective

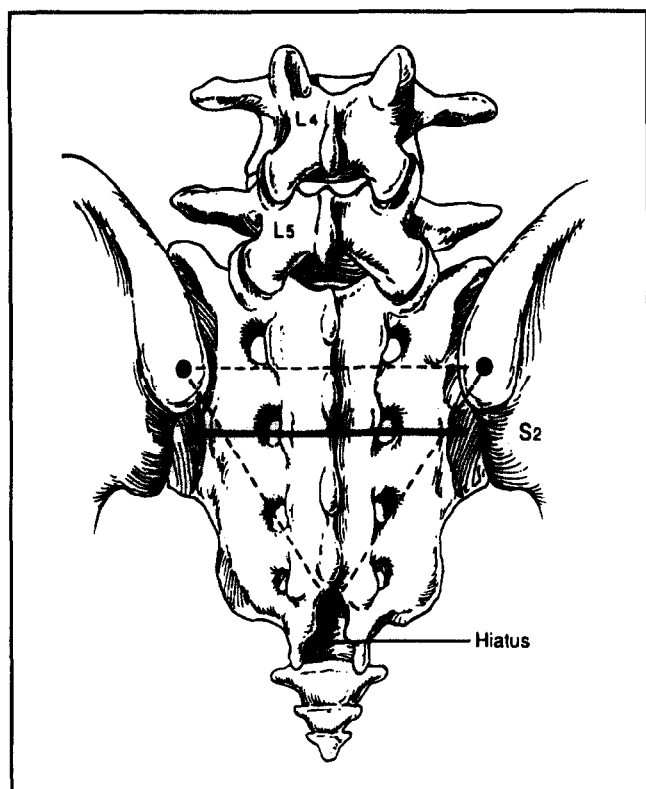
August Bier's investigation of spinal anesthesia in Germany<sup>1</sup> and Siccard's<sup>2</sup> and Cathelin's<sup>3</sup> studies of caudal epidural anesthesia in France introduced to the late 19th-century medical world the novel concept of anesthesia for selected regions of the human body. Ten years after Bier's 1899 paper on the subarachnoid injection of cocaine,<sup>1</sup> regional anesthesia was described in children.

Tyrrell-Gray<sup>4</sup> published his experience with spinal anesthesia in 300 infants and children in *Lancet* in 1909 and followed this initial report with an extension of his series a year later.<sup>5</sup> Pediatric spinal anesthesia continued to be popular well into the 1940s. Indeed, Leigh and Belton, in their 1948 *Textbook of Pediatric Anesthesia*, noted that 10% of all anesthetics performed in children at Vancouver General Hospital were spinal anesthetics.<sup>6</sup>

However, with the introduction of neuromuscular blocking drugs in the 1940s and modern volatile anesthetics in the late 1950s and 1960s, regional anesthesia for children was almost forgotten. In the early 1970s, papers on regional anesthetic techniques in children again began to appear in the literature,<sup>7,8</sup> and interest in pediatric regional techniques has grown steadily since. Safer local anesthetic drugs are now available, and their pharmacologic and physiologic effects are well documented. Technical difficulties have been overcome with the introduction of regional equipment specifically designed for infants and children. Widespread acceptance of the concept that general and regional anesthetics in children are complementary, along with an appreciation that regional techniques have minimal hemodynamic effects, also have helped spur a resurgence of interest in this field.

## Anatomic Considerations

In the fetus, the notocord develops along the entire length of the spinal canal. At about the midpoint of fetal life, the growth of the canal begins to outstrip the growth of the developing cord so that the tip of the spinal cord at birth lies at the level of L<sub>3</sub>. By about 1 year of age,



**Figure 1.** Sacral Surface Anatomy. Reproduced with permission from: Ecoffey C, McIlvaine WB: Techniques of regional anesthesia in children. In: Raj PP (ed): *Clinical Practice of Regional Anesthesia*. New York: Churchill Livingstone, 1991: 369.

the tip of the spinal cord reaches its permanent position at L<sub>1</sub>. The lower end of the dural sac is generally at the S<sub>1</sub>-S<sub>2</sub> intervertebral foramen. Whereas the epidural space in an adult is characterized by densely packed fat lobules and fibrous strands, the epidural fat of neonates and young children is spongy in nature, with discrete spaces between the individual fat lobules.<sup>9</sup>

A clinician wishing to perform a caudal epidural block in a young child will find that the sacral hiatus is easily identified. Drawing an equilateral triangle on the skin with the base connecting the two posterior superior iliac spines usually locates the sacral hiatus at the apex. Palpation of the sacral hiatus at the apex of this inverted triangle should identify the puncture site bounded by the two sacral cornua (Figure 1).

The clinician wishing to do a lumbar epidural block needs to be aware that the distance from the skin to the lumbar epidural space in small children is much shorter than in adults, with an increased risk of an inadvertent spinal tap. In the neonate, the distance from the skin to epidural space is only about 1 cm.

### Physiologic Effects

The cardiovascular effects of neuraxial blocks are much less pronounced in children than in adults. The reason

for this is poorly understood but has been attributed to the lower systemic vascular resistance (SVR) found in the young.<sup>10</sup> Caudal and lumbar epidural blockade in healthy infants and children cause clinically insignificant hemodynamic alterations.<sup>8</sup> Epidural blockade to the T<sub>7</sub> dermatome results in only a modest drop in heart rate (HR) and systolic blood pressure, and left ventricular function, as measured by echocardiography, is unaffected.<sup>11</sup> Similarly, there have been no reports of clinically significant hypotension with spinal anesthesia in children less than 5 years of age.<sup>12</sup> As a consequence, fluid loading is usually unnecessary in these pediatric patients.<sup>13</sup>

Although there is a dearth of information on the effect of neuraxial blockade on respiratory function in children, it seems that it has no adverse effect on respiratory function in children as long as the level of the motor block, usually a few segments below the sensory level, remains low enough to spare most of the intercostal muscles. Yu<sup>14</sup> found that if a spontaneously breathing child received a caudal block high enough to achieve a T<sub>2</sub> sensory level (and, therefore, a mid-thoracic motor level), atelectasis with hypoxemia could occur. In the case of spinal anesthesia, Pascucci *et al.*<sup>15</sup> found that a sensory level at T<sub>2</sub>-T<sub>4</sub> decreased the normal outward movement of the rib cage during inspiration and often induced a paradoxical inward movement during inspiration. Notably, they did not find any deterioration in oxygen saturation in their infants as a result of this change in respiratory dynamics.

Regional anesthetic techniques can ablate the metabolic and stress responses of children to surgery and prevent the increase in catecholamine and blood glucose concentrations that is commonly seen with general anesthesia. Some authors even suggest that children who have had a caudal or lumbar epidural block should have a glucose-containing solution running during surgery.<sup>16</sup> Our preference is to monitor blood glucose levels in the operating room (OR) and give glucose-containing solutions only as indicated.

### Pharmacologic Considerations

The volume of distribution of local anesthetics is larger in children due to age-related differences in fluid compartments. Rates of elimination of local anesthetics, however, may be lower due to a reduction in the efficiency of clearance pathways (amide local anesthetic drugs) or a reduction in plasma cholinesterase activity (ester local anesthetics) in infants younger than 6 months of age. Decreased concentrations of albumin and  $\alpha$ -1 acid glycoprotein may result in decreased protein binding of amide local anesthetics, thereby resulting in an increase in the free fraction of the drug. Acidosis, both metabolic and respiratory, can increase the free fraction of lidocaine and bupivacaine and may be a consideration when sedation or general anesthesia with spontaneous ventilation is contemplated.

plated.<sup>17,\*</sup> Elevations in bilirubin likewise may result in a decrease in available albumin for amide local anesthetic drugs and an increase in the free fraction available.

Although some of the above findings seem contradictory, clinical experience shows that larger doses of local anesthetics are usually required to achieve the same dermatomal level of epidural blockade in children as in adults and that the duration of the blockade in children is generally shorter.

Infants and children weighing less than 15 kg have a higher total volume of cerebrospinal fluid (CSF) than adults (4 ml/kg *vs.* 2ml/kg) and for this reason require significantly higher doses of local anesthetic for subarachnoid blockade.<sup>18</sup> The rates of CSF production and absorption also are higher, partially explaining the shorter duration of subarachnoid blockade commonly seen in infants and young children.<sup>19</sup>

### Contraindications to Any Pediatric Neuraxial Block

#### Absolute

1. Patient or parental refusal
2. Uncorrected hypovolemia
3. Untreated clotting abnormalities
4. Infection at the injection site
5. Raised intracranial pressure

#### Relative

1. Septicemia
2. Abnormal sacral neuroanatomy, such as myelomeningocele
3. Preexisting neurologic disease

The presence of a congenital lumbosacral anomaly is not itself an absolute contraindication to safe neuraxial blockade. However, radiologic investigation of the vertebral column is essential prior to insertion of an epidural catheter at a level of normal vertebral anatomy. Also, local anesthetic volume requirements may be unpredictable in these patients.<sup>20</sup>

There are no objective data to support the supposition that preexisting neurologic diseases constitute a contraindication to regional anesthesia.<sup>21</sup> Abnormal nervous tissue has not been shown to be more susceptible to the toxic effects of local anesthetic drugs. However, spinal anesthesia should be avoided in patients with progressive disease involving the cord lest progression of the disease be blamed on the spinal anesthetic. Cancer patients with metastases to the lumbar vertebrae, however, may benefit from spinal anesthesia if their neurologic status is stable.

\*Denson DD, Coyle D, Thompson G, Myers J: Alpha-1 acid glycoprotein and albumin in human serum bupivacaine binding [Abstract]. *Clin Pharmacol Ther* 1984;35:409.

### Counseling and Acceptance of Neuraxial Blockade

Both child and parents need to be counseled and prepared for the subjective sensations to be experienced postoperatively. Numbness and motor weakness may be unpleasant, annoying, or even terrifying, depending on the cognitive capacity of the child and the explanations given by the parents and physicians prior to the surgical procedure. A child's fear of injections must be managed with patience and understanding, but answers to the key question, "Will I get a shot?," should be given in a forthright manner.

Recruitment of positive role models, such as other children who have already experienced the benefit of regional blockade or mothers who have had epidural analgesia for childbirth, may be very helpful. Most important, when parents or patients ask questions about the management of postoperative pain, continuous-block techniques should be carefully explained, and the commitment of the anesthesia pain service to check and maintain the child's analgesia postoperatively should be emphasized.

Anesthesiologists should appreciate that surgeons have their relationships already established with patients either by their reputation or by contact with the patient and family prior to the child's surgery. When a surgeon reinforces the benefits of regional anesthesia, the family usually takes the surgeon's attitudes to heart. Similarly, when the OR and ward nursing staff support the idea of neuraxial blockade for perioperative pain relief and provide testimony to patient comfort, the family is much more accepting.

There are some situations in which neuraxial blockade may be of significant benefit:

1. The child who is morbidly fearful of unconsciousness. Frequently this patient is an adolescent or child who has had numerous surgical procedures in the past.
2. The child with a family history or a personal history of malignant hyperthermia.
3. The child with a neuromuscular disease whose respiratory reserve would potentially be adversely affected by the administration of a general anesthetic.
4. The premature or ex-premature infant with a history of abnormal ventilatory control who is at risk of postoperative apnea.
5. The child with chronic pulmonary disease such as cystic fibrosis or severe asthma for whom airway manipulation may pose a significant risk.
6. The emergency patient with a full stomach.

### Caudal Epidural Blockade

The most common regional block performed in the pediatric centers of North America is the caudal epidural block. Its popularity over the past decade is due to its technical simplicity, its applicability to many pediatric surgical procedures, and the significant duration of analgesia that can be achieved with a single injection. In

children, it is technically an easy block to perform and is less invasive than the subarachnoid block. The success rate in one series of 750 consecutive children having caudal blocks was found to be as high as 96%.<sup>22</sup>

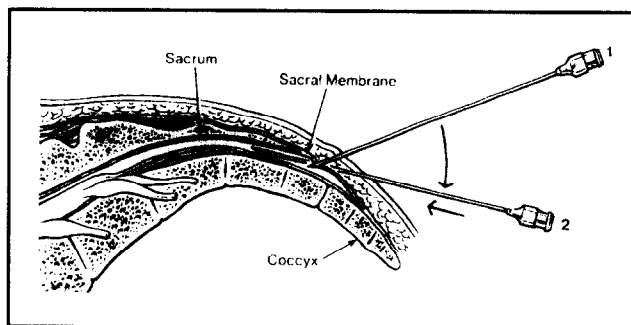
Caudal epidural blocks are usually performed in children who have already been anesthetized, because small children are often distressed by parental separation and will not lie still in the OR for any length of time, despite having adequate regional analgesia for their procedure. There are several advantages to placing the caudal block after the induction of general anesthesia but prior to the onset of surgery. Administration of a caudal epidural block before surgery allows the anesthesiologist to administer less anesthetic during the procedure. The few extra minutes needed to perform the block are recouped at the end of the case with faster emergence and room turnover. In children having perineal procedures, the caudal block reduces the risk of reflex laryngeal spasm. If a single-shot caudal appears unsuccessful, the anesthesiologist can elect to repeat the block at the end of surgery, ensuring adequate postoperative analgesia for virtually all patients. Finally, caudal blocks when used with general anesthesia decrease postoperative opioid requirements<sup>23</sup> and result in a suppression of the endocrine responses to surgery.<sup>16</sup>

If a general anesthetic should be avoided in a particular case, ketamine or midazolam may be used for monitored, conscious sedation with a caudal block. An important exception to this is the infant with a history of central apnea, for whom sedation of any type should be avoided. For this patient, a caudal block may be used successfully as the sole method of analgesia as long as a concentration of at least 0.25% bupivacaine is used.<sup>24</sup>

### Technique

Following induction of general anesthesia, the child is turned to the lateral position. The location of the sacral hiatus is determined by palpation, keeping in mind the aspects of sacral surface anatomy described earlier. The anesthesiologist prepares the puncture site with sterile gauze soaked with povidone iodine. While the iodine solution is setting, the anesthesiologist dons sterile gloves and aseptically accepts a sterile over-the-needle cannula with stylet such as Angiocath® and a syringe and needle from an assistant. The anesthesiologist wipes off the excess iodine solution and proceeds with the block using either the over-the-needle cannula with stylet or a blunt needle, according to personal preference.

Puncture of the sacrococcygeal ligament occurs at an initial angle of about 30 degrees relative to the skin. A distinct loss of resistance is often felt as the cannula enters the epidural space via the sacral hiatus. The angle of the over-the-needle cannula is immediately reduced to about 15 degrees to the skin, and the cannula is advanced about 0.5 cm over its stylet (Figure 2). The stylet is removed, and the anesthesiologist then accepts a syringe containing the premeasured volume of local anesthetic from the assistant. The syringe, held by the no-longer-sterile hand, is attached to the cannula, held by the still-sterile hand.



**Figure 2.** Sagittal section of the Sacrum. After puncture of the sacrococcygeal membrane, the needle is angled down from position 1 to position 2 to align with the axis of the sacral canal. Reproduced with permission from Willis RJ: Technique of caudal block. In: Cousins MJ, Bridenbaugh PO (eds): *Neural Blockade in Clinical Anesthesia and Management of Pain*, 2nd Ed. Philadelphia: J.B. Lippincott, 1988: 373.

Following a negative aspiration for blood or CSF, the local anesthetic is slowly injected into the caudal epidural space. This technique requires little time and a minimum of equipment, but it maintains sterility at the puncture site.

To eliminate the need for sterile surgical gloves, a "no touch" technique has been advocated in which the anesthesiologist performs the puncture without further palpation of the sacral hiatus after the puncture site is prepared with antiseptic solution.\* The main disadvantage of this technique is that further palpation to relocate the sacral hiatus is not possible.

Easy advancement of an over-the-needle cannula off its stylet is indicative of correct tip placement in the epidural space. Using a blunt-tipped, over-the-needle cannula may reduce the chance of an inadvertent dural puncture. For these reasons, we prefer using an over-the-needle cannula to locate the caudal epidural space.

The resistance to injection for a caudal epidural should be the same as that perceived during a lumbar epidural, and there should be no subcutaneous swelling with injection. If a blunt needle is selected, some anesthesiologists recommend that while the needle is advanced through the sacrococcygeal ligament, the bevel should face anteriorly to reduce the chance of piercing the anterior sacral wall.<sup>25</sup> Inadvertent puncture of the anterior sacral wall may lead to an intraosseous injection of local anesthetic, with high blood levels.

Desparmet *et al.* demonstrated in halothane-anesthetized children<sup>26</sup> and lambs<sup>27</sup> that "test dosing" with an epinephrine-containing solution (0.5 µg/kg) will not reliably produce a tachycardia that would warn of an inadvertent intravascular injection unless preceded by

\*Broadman LM: Regional anesthesia in children. Cleveland, OH: International Anesthesia Research Society Review Course Lectures, 1992:68-74.

intravenous (IV) atropine 10 $\mu$ g/kg. Because of this unreliability, many clinicians do not bother with a test dose, relying instead on good puncture technique, watching for blood or CSF on aspiration, and slowly injecting the local anesthetic to minimize the risk of an intravascular injection.

A 20-gauge epidural catheter may be threaded through an 18-gauge Jelco® (but not an 18-gauge Angiocath®) or through an 18-gauge Tuohy needle that has punctured the sacrococcygeal membrane, and the catheter may be left in situ postoperatively for repeated injections or a continuous infusion of a local anesthetic solution. Proper placement of the catheter tip can be confirmed radiologically by injection of 0.5 ml of a radio-contrast dye such as iohexyl (Omnipaque). Bošenberg *et al.*<sup>28</sup> found that the ease with which one is able to thread an epidural catheter cephalad from the sacral hiatus varies inversely with the age of the patient. Infants have a sponginess to their epidural space, with distinct spaces between the individual fat lobules allowing easy catheter passage.<sup>9</sup> With age, the fat lobules become more tightly packed, and this sponginess disappears. If resistance to cephalad spread is encountered, it is usually due to the presence of an obstructing nerve root. In most cases, minor resistance to the cephalad passage of an epidural catheter can be overcome by simple flexion or extension of the infant's vertebral column.<sup>29</sup> If this maneuver fails to overcome resistance to catheter passage, no attempt should be made to advance the catheter farther because this may cause bleeding or cause the catheter to curl up and double back into the epidural space.

In contrast to the 20-gauge epidural catheters, thinner 23-gauge epidural catheters have been shown to cause catheter misplacement in 20% of cases when used in preterm infants. van-Niekerk *et al.*<sup>29</sup> concluded that in these very young patients, an epidurogram was necessary to confirm correct placement when the thinner catheters were advanced rostrally from the sacral hiatus. The thinner epidural catheters also impart a high resistance to injection, which may make the use of some programmable syringe pumps or other infusion devices problematic.

### Dosage

The most cephalad extent of analgesia depends primarily on the volume of local anesthetic injected through the sacrococcygeal membrane and not the concentration of the local anesthetic used.<sup>30-32</sup> Rather, the concentration of the local anesthetic determines the quality of the block. Many dosage formulas have been used to determine the optimal volume of local anesthetic for a single-shot caudal, but one should appreciate that the final upper limit of sensory blockade can vary widely from patient to patient, especially in older children.<sup>24</sup> No mathematic formula can predict with a high degree of accuracy the rostral limit of analgesia in any individual case.<sup>24</sup>

Regardless of the formula used to determine the volume of bupivacaine needed for a caudal block, the maximum dose of bupivacaine with epinephrine that we use is 3 mg/kg. Eyres *et al.*<sup>33</sup> established the safety of this dose

when they demonstrated that plasma levels with it were well below the generally accepted toxic limit of 4  $\mu$ g/ml.

We have used the following three formulas in our clinical practice with probably equal success:

1. Armitage's formula<sup>34</sup> gives good clinical results and has the distinct advantage over the other two of being easy to remember:

Volume of local anesthetic needed for:

Areas supplied by sacral-lumbar nerves 0.5 ml/kg

Areas supplied by lumbar-thoracic nerves 1.0

2. Takasaki's formula: The volume of drug determined by this formula is calculated as 0.056 ml/kg/segment. This formula was derived from Takasaki *et al.*'s<sup>35</sup> early experience with 250 children, 163 of whom were younger than 2 years of age.
3. Proportioning the injected volume according to body surface area (BSA), discussed later in the lumbar epidural section (*Table 1*).

Larger volumes of caudally injected bupivacaine have a higher frequency of complications. Dalens, in a later study, found that the administration of 1.25 ml/kg of 0.25% bupivacaine in the caudal space resulted in an excessive spread of analgesia in 30% of his pediatric patients.<sup>22</sup> In the same study, he also noted that in almost 50% of the children studied, the level of analgesia was 1 to 2 dermatomes higher on the side that was dependent during the performance of the block.<sup>22</sup> Thus, gravity can have a minor influence on the extent of cephalad spread of analgesia.

In the formulas mentioned, the injection of local anesthetic takes place through the sacrococcygeal membrane at the level of the sacral hiatus (about S<sub>4</sub>). However, if a caudally inserted epidural catheter is threaded to the mid-thoracic level, the larger volumes determined by the formulas may cause an inadvertently high level of anesthesia, with possible respiratory embarrassment. Thus, if one elects to thread an epidural catheter from the sacral hiatus to the mid-thoracic level, one should reduce the loading dose to 0.5 ml/kg of 0.25% bupivacaine with epinephrine.

Our preferred bupivacaine concentration for caudal blockade remains 0.25% with 1:200,000 epinephrine despite recent reports that analgesia from a 0.125% solution is equally efficacious.<sup>36,37</sup> A 0.25% concentration of bupivacaine will reliably provide adequate surgical analgesia when used not only in conjunction with a light general anesthetic but even in the awake, unsedated pediatric patient.<sup>37</sup> When a less profound motor block is desirable, as in the ambulatory care center, we use 0.125% bupivacaine. When used alone, 0.125% bupivacaine was found by Wolf *et al.*<sup>37</sup> to be the minimally effective concentration that provided adequate sensory anesthesia for penoscrotal procedures while causing only a minimal degree of motor blockade.

If it is necessary to maintain the sensory level of analgesia for hours or days postoperatively, one may, imme-

**Table 1.** Volume (ml) of Local Anesthetic Required per Spinal Segment\*

	Adult	1-Month-Old	1-Year-Old	2-Year-Old	3-Year-Old	4-Year-Old
Segmental level						
Sacral	2.5	0.37	0.59	0.74	0.88	1.1
Lumbar	2.5	0.37	0.59	0.74	0.88	1.1
Thoracic	2.0	0.29	0.47	0.59	0.71	0.88
Cervical	1.5	0.22	0.35	0.44	0.53	0.66
Total ml required for T <sub>10</sub> block	31	4.6	7.3	9.2	10.9	13.6

Note: Volume of local anesthetic required per spinal segment = pediatric BSA/adult BSA × value in Adult column.

\*The following approximate weights and body surface areas are assumed: adult, 70 kg, 1.7 m<sup>2</sup>; 1-month-old, 4 kg, 0.25 m<sup>2</sup>; 1-year-old, 9 kg, 0.4 m<sup>2</sup>; 2-year-old, 12 kg, 0.5 m<sup>2</sup>; 3-year-old, 15 kg, 0.6 m<sup>2</sup>; 4-year-old, 18 kg, 0.75 m<sup>2</sup>.

diately after administering the initial loading dose, start an infusion of 0.1% plain bupivacaine containing 2 µg/ml of fentanyl. A convenient way of preparing this maintenance solution in a 50 ml syringe is to aspirate 10 ml of 0.5% plain bupivacaine, 38 ml of saline, and 2 ml of fentanyl (50 µg/ml). The rate of this maintenance infusion is determined, in part, by the location of the catheter tip. If the tip resides in the low, capacious sacral epidural space, an initial infusion rate of 0.4 ml/kg/hr is usually adequate to maintain the level of analgesia established by the loading dose. The continuous infusion of this solution is not associated with toxic accumulation of either fentanyl or bupivacaine. If the catheter tip resides in the less voluminous thoracic epidural space, one needs only an initial infusion rate of 0.2 to 0.3 ml/kg/hr to maintain a level of analgesia.

Berde,<sup>38</sup> in a study funded by the Anesthesia Patient Safety Foundation, surveyed 15 institutions, examining the results of more than 20,000 pediatric regional anesthetics. He concluded that children are probably not more resistant to local anesthetic toxicity than adults and that premonitory symptoms and signs of local anesthetic toxicity may not be reliably elicited. For these reasons, he recommended that conventional doses or infusion rates (such as those mentioned in this review) should not be exceeded.

#### Duration of Action

It is our experience that the duration of action of a single-shot caudal for penile or saddle area surgery is about 4 to 6 hours when 0.25% bupivacaine with epinephrine is used. This is consistent with the findings of Wolf *et al.*<sup>39</sup> but is at considerable variance with the findings of Warner *et al.*,<sup>40</sup> who found that a much longer duration of analgesia was achieved in the younger age-groups and that the addition of epinephrine consistently prolonged the duration of analgesia.

The use of epidural opioids in children is beyond the scope of this review. However, if it is important for the duration of analgesia to exceed 6 hours, we either start a continuous infusion of bupivacaine and fentanyl (de-

scribed previously) or administer 0.03 mg/kg of preservative-free morphine through the epidural catheter about 45 minutes before the end of the procedure.

#### Complications

1. Inadvertent dural puncture with resultant "total spinal"
2. Motor blockade
3. Hematoma formation
4. Urinary retention
5. Infection

Inadvertent dural puncture has been known to occur, especially if the cannula (or needle) is advanced too far up the sacral hiatus. If, during administration of a caudal block, the cannula enters the subarachnoid space, it should be removed and the caudal block abandoned. One should not perform a caudal block in a patient who has had a recent subarachnoid puncture, as caudally injected local anesthetics can pass through the rent in the dura and into the subarachnoid space, causing a "total spinal."<sup>41</sup>

Motor blockade can occur both intraoperatively and postoperatively but is essentially absent when a concentration of bupivacaine less than 0.125% is used.

Hematomas can occur occasionally but are clinically inconsequential.

Urinary retention appears to be more of a theoretic possibility than a practical problem. In Broadman *et al.*'s\* series of 1,154 single-shot caudals, only two patients developed urinary retention, and neither patient required catheterization. Another recent study by Malviya *et al.*,<sup>42</sup> comparing 0.5 ml/kg of 0.125% bupivacaine with 1.0 ml/kg of the same drug, found that no patient required

\*Broadman LM, Hannallah RS, Norden JM, McGill WA: "Kiddie caudals": experience with 1,154 consecutive cases without complications [Abstract]. *Anesth Analg* 1987;66:S18.

catheterization for urinary retention. Urinary retention becomes more of a concern if a continuous infusion of bupivacaine is used over a number of days.

Infection caused by a one-shot caudal block is essentially unheard of. In an ongoing prospective study that now encompasses more than 3,500 patients, Broadman *et al.*\*,† did not find a single instance of infection at the injection site as a result of a one-shot caudal block. The frequency of infection as a result of the presence of a caudal catheter is unknown, but some practitioners have expressed concern, as the caudal catheter may be soiled by feces if it is not adequately protected by an adhesive barrier. It is our practice to leave a caudal catheter in situ no longer than 72 hours. If we feel that an epidural catheter would be advantageous for a longer period, we usually insert a catheter into the epidural space in the lumbar region.

### Safety

In Broadman *et al.*'s\* report of 1,154 consecutive cases ranging from 1 month to 18 years, bupivacaine to a maximum of 3 mg/kg was used. No intravascular injections, toxic drug reactions, hypotension, or other perioperative complications were detected in any patient in this series during either the immediate or late postoperative period. Epinephrine was not routinely administered, and test dosing was not used.

Ex-premature infants receiving caudal anesthesia may develop severe apneas as a result of perioperative hypothermia, anemia, or sepsis. For this reason, apnea and oxygen saturation monitoring should be used postoperatively.<sup>43</sup>

### Lumbar Epidural Blockade

Interest in, and experience with, lumbar epidural blockade has been more limited than for caudal epidural blockade partly because caudal blocks are so easy to perform. Nevertheless, the lumbar approach to the epidural space is becoming increasingly popular now that specially designed pediatric epidural kits are available. In a young child requiring a high sensory level of anesthesia, epidural puncture at the lumbar level with threading of the catheter cephalad is usually so easily accomplished that the thoracic approach to the epidural space is seldom necessary.

### Technique

For lumbar epidurals in children 5 years of age or older, we prefer a standard adult epidural kit containing an

18-gauge Tuohy needle and a 20-gauge epidural catheter. In younger children, we prefer a special continuous-epidural kit manufactured by Abbott Laboratories (Abbott, North Chicago, IL). This kit contains a 20-gauge 3.5-inch Tuohy needle with a modified Huber point through which a 22-gauge catheter can be passed. Another epidural kit (Portex Ltd, Hythe Kent, UK) contains a 19-gauge Scott-Tuohy needle with stylet; a winged hub and a short, round bevel; and a 21-gauge nylon catheter graduated every 0.5 cm.

Because children are generally unable to deal with the psychological distress of being awake for their surgery, a light general anesthetic is usually used in conjunction with the block. Following anesthetic induction, the child is allowed to resume spontaneous ventilation with nitrous oxide in oxygen and halothane or isoflurane and is placed in the lateral decubitus position. Having the patient breathe spontaneously during injection of the epidural test dose is a useful exercise, as a sudden cessation of spontaneous breathing suggests an inadvertent subarachnoid injection. Pancuronium may mask the tachycardia caused by an inadvertent intravascular injection of an epinephrine-containing test dose, and paralysis of the patient during the test dose injection robs the clinician of a useful clinical sign suggesting an inadvertent subarachnoid block.

The puncture technique is essentially the same as for adults and requires a well-lubricated, saline-filled glass syringe to locate the epidural space. Using continuous pressure on the barrel of the advancing syringe, the epidural space is easily located using the standard backhanded "Bromage" grip.

Air should not be used in the advancing syringe because air injected into the epidural space of a small child may cause venous air embolism. In adults, the use of air to locate the epidural space has been implicated as a cause of an inadequate, or "patchy," block.<sup>44</sup>

While observing the patient's HR, blood pressure (BP), and ventilation, a test dose of 1.5% lidocaine containing 5 µg/ml of epinephrine is injected through the catheter. If subarachnoid injection occurs, BP and HR may fall, and the patient may stop breathing. In contrast, an intravascular injection of this epinephrine-containing solution may cause a prompt increase in HR and BP.

Once the anesthesiologist is satisfied that the test dose has not caused a change in BP or HR or a cessation of breathing, the child may then be relaxed with a nondepolarizing drug and mechanically ventilated or be allowed to breathe spontaneously, according to the anesthesiologist's preference.

### Dosage

Dosage formulas cannot predict with 100% reliability the level of epidural blockade that can be achieved in infants and children because of the variability in patient age and size and the highest dermatomal level at which surgery is performed. Nevertheless, for mid- or lower abdominal surgery, we recommend using 0.25% bupivacaine with

\*Broadman LM, Hannallah RS, Norden JM, McGill WA: "Kiddie caudals": experience with 1,154 consecutive cases without complications [Abstract]. *Anesth Analg* 1987;66:S18.

†Broadman LM: Regional anesthesia in children. Cleveland, OH: International Anesthesia Research Society Review Course Lectures, 1992:68-74.

1:200,000 epinephrine for the initial injection after injecting a test dose of lidocaine with 1:200,000 epinephrine to help rule out a total spinal or an intravascular injection. Usually, the 0.25% solution of bupivacaine is all that is required for effective analgesia in children, even for blockade of sacral roots. The smaller diameter of these sacral fibers and their poorer myelination may account for the effectiveness of this lower bupivacaine concentration in pediatric epidural blockade.<sup>15</sup>

In children from 0 to 8 years of age, one approach is to use a single injection of 0.75 ml/kg of 0.25% bupivacaine with 1:200,000 epinephrine. This dose injected at the L<sub>2</sub>-L<sub>3</sub> or L<sub>3</sub>-L<sub>4</sub> interspace has been shown reliably to establish a T<sub>8</sub> dermatomal level of analgesia that has a duration of action of just over 90 minutes.<sup>15</sup> A dose of 1 to 1.2 ml/kg of 0.25% bupivacaine with 1:200,000 epinephrine will establish a mid- to high-thoracic level of analgesia.

Another dosing regimen is to inject a local anesthetic epidurally by volume in proportion to BSA. Children have a greater BSA than do adults on a per kilogram basis. Their BSA can be calculated from the formula of DuBois and DuBois<sup>45</sup> or quickly estimated at the bedside by Lindahl and Okmian's<sup>46</sup> correlation between BSA and patient weight.

For patients <20 kg  $0.36 \times \text{patient weight (kg)} + 9 = \text{BSA (m}^2\text{)}$

For patients >20 kg  $0.25 \times \text{patient weight (kg)} + 33 = \text{BSA (m}^2\text{)}$

Thus, any method for calculating dose in adults can be proportionally reduced for infants and children. *Table 1* illustrates the method used by one of the authors of this publication.

After the initial loading dose is injected, an infusion of 0.1% plain bupivacaine with 2 µg/ml of fentanyl at an initial rate of 0.4 ml/kg/hr usually maintains the level of analgesia. However, because of the variability that exists in children, the maintenance infusion rate for any epidural infusion may need to be adjusted to maintain a stable sensory level of analgesia. This infusion of bupivacaine and fentanyl gives good control of both somatic and visceral pain with minimal motor block. Tachyphylaxis to a maintenance infusion of bupivacaine and fentanyl is rare.<sup>15</sup>

Another way of achieving upper abdominal or lower thoracic analgesia is for the anesthesiologist to thread the catheter cephalad from the lumbar level to a mid- or high-thoracic level. In this clinical situation, where the tip of the catheter resides in the less capacious thoracic epidural space, the loading dose of 0.25% bupivacaine should be only 0.5 ml/kg. Similarly, the maintenance infusion rate for the 0.1% bupivacaine-fentanyl solution described earlier should be started at an initial rate of only 0.2 to 0.3 ml/kg/hr.

If a thoracic or upper abdominal level of analgesia is needed and the catheter tip does not thread easily cephalad to the upper dermatomes, one must consider using 0.03 mg/kg of preservative-free morphine epidurally.

One should not expect low-placed lumbar or caudal epidural local anesthetic infusions to provide adequate postoperative analgesia after surgery involving upper abdominal or thoracic dermatomes.<sup>39</sup>

Morphine, because of its hydrophilic properties, is less segmentally confined to spinal dermatomes. Indeed, it readily travels cephalad by CSF bulk flow to give high dermatomal levels of analgesia that are unattainable with fentanyl. This same property also makes morphine more likely to cause delayed ventilatory depression if it travels far enough cephalad to reach the medullary respiratory center. For this reason, any child receiving epidural morphine should be admitted to a unit that has continuous observation and apnea monitoring. Admission to a general surgical ward is inadvisable. As a rule, if any type of epidural opioid is used, systemic opioids or sedatives should be avoided to minimize the possibility of this delayed ventilatory depression.

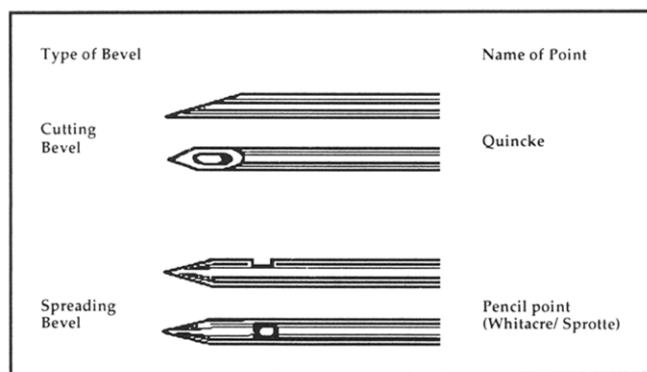
The risk of infection among pediatric patients receiving short-term postoperative epidural analgesia (0 to 8 days) is extremely low. Of 1,350 children with lumbar and caudal epidural catheters studied by Sethna *et al.*,<sup>47</sup> none experienced either local skin infection or epidural abscess.

### Subarachnoid Blockade

The subarachnoid block, or "spinal," is currently the only pediatric neuraxial block that is routinely performed on a conscious, unседated patient. Although the first series of spinal anesthetics was reported in 1909 by Tyrell-Gray<sup>5</sup> in England, it was Abajian *et al.*<sup>48</sup> in Burlington, Vermont, who reintroduced this technique in 1984 as a safe alternative to general anesthesia for high-risk premature infants. Parental concern about spinal cord damage and the prevailing medicolegal climate conspire to make subarachnoid blockade uncommon in the OR even today. Ironically, in other hospital locations, house officers perform spinal punctures on children daily.

With an increasing number of preterm infants presenting for surgery, we can expect to see subarachnoid blocks becoming more common as a safe alternative to general anesthesia. It has been established that spinal anesthesia without sedation in premature infants does not contribute to the postoperative apneas to which these patients are prone.<sup>49</sup> Furthermore, this technique does not compromise ventilation or oxygenation in high-risk infants in any way. Transcutaneous carbon dioxide (TcCO<sub>2</sub>) and SpO<sub>2</sub> studies in high-risk neonates receiving spinal anesthesia to the T<sub>4</sub> dermatome level show that these infants exhibit no deterioration of their TcCO<sub>2</sub> or SpO<sub>2</sub> values during spinal anesthesia.<sup>50</sup>

It should be stressed that single-shot spinal anesthesia imposes a time limit on the surgical team and is not a technique for slow surgeons or a surgical procedure of unpredictable duration. Adding epinephrine to tetracaine will increase the duration of a subarachnoid block by about 32% but still results in a finite duration of anesthesia of which the surgeons must be made aware.<sup>48</sup> For cases of indeterminable length where a regional tech-



**Figure 3.** Spinal needle points. Adapted from Levinson G: Spinal anesthesia. In: Benumof JL (ed): *Clinical Procedures in Anesthesia and Intensive Care*. Philadelphia: J.P. Lippincott, 1992: 649.

nique is necessary, a continuous epidural catheter is a better alternative in view of recent complications associated with continuous spinal catheters.

### Technique

Equipment needed for a neonatal subarachnoid block usually includes a standard adult spinal anesthesia tray, a 1 ml tuberculin syringe, and either a 22-gauge or a 25-gauge styleted pediatric spinal needle. Currently, the only spinal anesthesia tray produced specifically for pediatric patients with all appropriate-sized equipment included is manufactured by Preferred Medical Product of Canada (Thorold, Ontario, Canada).

The most commonly used spinal needles for infants are the 2.5 cm 25-gauge and 22-gauge short-beveled Quincke types (Becton-Dickinson, Rutherford, NJ). A short-beveled needle allows one to appreciate tissue resistance better, particularly when the needle tip pierces the dura, and the short bevel permits injection of local anesthetic into the narrow subarachnoid space.

Noncutting, pencil-point spinal needles such as the Whitacre (Becton-Dickinson, Rutherford, NJ) and the Sprotte (Pajunk, Geisingen, Germany) also are available in pediatric sizes. Such needles avoid cutting dural fibers and potentially reduce the frequency of postlumbar puncture headache. The opening is proximal to the needle tip and lies laterally (Figure 3). The only major difference between the smallest Sprotte and Whitacre needle tips is that the lateral eye is wider in the Sprotte needle (1.2 mm vs. 0.6 mm).<sup>51</sup> A wider lateral opening can potentially straddle the dura, causing the injected local anesthetic to be distributed between the subarachnoid and the epidural spaces and resulting in inadequate blockade. Both the Sprotte and Whitacre pencil-point spinal needles require more force during a spinal puncture than the cutting-tip Quincke needles. As a consequence, their shafts may bend in a struggling neonate unless needle introducers also are used.

Once the equipment is chosen, the infant is positioned in either the lateral decubitus or the sitting position after

a precordial stethoscope and electrocardiogram leads are applied. The lateral decubitus position with the operative side dependent permits some control over the distribution of a hyperbaric local anesthetic solution and allows an assistant to immobilize the infant better than does the sitting position. However, if the infant has been fasting for a long period of time, the sitting position has the advantage of reducing the chance of a "dry tap" because of the CSF hydrostatic pressure gradient that exists in the lumbar subarachnoid space. Regardless of the position chosen, the assistant should avoid neck flexion, which may result in airway obstruction. Clearly, having an experienced nurse or colleague position and restrain the infant correctly for the subarachnoid puncture is critical to its success (Figure 4).

The lumbar skin is then prepared with antiseptic and draped. If the anesthesiologist wishes to use tetracaine, he or she should mix equal volumes of 10% dextrose and 1% tetracaine in a syringe, yielding a mixture of hyperbaric solution equal to 5 mg/ml, as for an adult patient. The anesthesiologist then aspirates a small amount of 1:1,000 epinephrine into a 1 ml tuberculin syringe and slowly flushes the epinephrine out again.



**Figure 4.** Position of an infant for lumbar puncture. The authors wish to thank Dr. Navil Sethna, Children's Hospital, Boston, for the use of this photograph.

This leaves 0.04 ml (40 µg) of epinephrine behind in the dead space at the tip of the syringe. This same tuberculin syringe is used to aspirate the calculated volume of hyperbaric tetracaine or bupivacaine out of the other syringe.

Busoni and Messeri<sup>52</sup> reviewed 500 lateral and anteroposterior radiographs of the lumbar spine in infants and children and found that the intercrystal line crosses the spine at L<sub>5</sub> in children and L<sub>5</sub>-S<sub>1</sub> in infants. Since the dural sac ends at S<sub>2</sub>, the intervertebral space at the level of the intercrystal line will give safe access to the subarachnoid space. The skin is infiltrated at this level with 1% lidocaine in a 30-gauge needle, and a styleted spinal needle is then inserted through the skin wheal in the midline between the spinous processes. As with adult patients, the bevel of an advancing Quincke spinal needle should always be directed laterally until the subarachnoid space is entered to reduce the size of the rent in the ligamentum flavum and dura and to minimize the risk of postspinal puncture headache. Puncture of the ligamentum flavum, with its loss of resistance or "pop," may not be felt in infants because of the softness of their spinal structures. One should be careful not to advance the needle too far because CSF will be found at a depth of only 1 cm from the skin.<sup>53</sup> A "bloody tap" is usually due to the operator's inability to keep the spinal needle in the midline. Regardless of the type of spinal needle used, CSF return may be slow through a 25-gauge needle, and CSF may have to be aspirated to confirm subarachnoid puncture.

Once CSF appears at the hub of the spinal needle, the tuberculin syringe should be attached securely. The loss of even a small volume of local anesthetic due to improper attachment of the tuberculin syringe to the spinal needle may result in an inadequate block, so it is important to have a secure fit between spinal needle and syringe. Local anesthetic injection into the subarachnoid space should be done slowly, usually at a rate of not more than 1 ml/10 seconds to minimize cephalad spread caused by CSF turbulence. After the local anesthetic is injected, aspiration of a small amount of CSF, with its gentle reinjection (avoiding barbotage), is recommended. This confirms that the entire volume of local anesthetic, including the small volume in the hub of the syringe tip (0.04 ml), has entered the subarachnoid space. Subarachnoid injection of local anesthetic usually causes a profound motor block, with leg flaccidity appearing within 30 seconds of injection.

The level of analgesia can be extended cephalad by using the Trendelenburg position, just as in adult practice. One should be especially careful that the nurse or surgeon does not pick up the infant by the ankles to attach an electrocautery pad. This maneuver can lead to dramatic levels of spinal blockade.<sup>54,55</sup>

The IV infusion may be started in a lower extremity after the subarachnoid block, since the legs are then immobile, analgesic, and venodilated. A pulse oximeter and BP cuff also may be applied to a leg at this time. This immobile location eliminates motion artifact and minimizes discomfort for the infant.

After the subarachnoid block has been performed and the IV line and monitors have been applied, the infant

often falls asleep during the surgical procedure. Nevertheless, it is always a good idea to restrain the upper extremities to ensure an immobile patient.

### Dosage

Investigators have used hyperbaric 0.5% tetracaine in doses ranging from 0.4 mg/kg to 1.2 mg/kg. The lower doses are associated with a higher frequency of inadequate surgical analgesia, requiring IV or general anesthetic supplementation.<sup>56</sup> Many pediatric anesthesiologists (especially those at academic centers, where surgery often takes longer) opt for doses at the higher end of this spectrum. However, these higher doses can lead to an increased frequency of high blockade, requiring short periods of ventilatory support. A dose of 1 mg/kg of tetracaine resulted in a 3% frequency of blocks that were high enough to require short periods of assisted ventilation by bag and mask, whereas a dose of 1.2 mg/kg increased this frequency about 12%.<sup>57</sup> Despite the wide range of doses used by different investigators, there are no reports in the literature of clinically significant hypotension or bradycardia in non-volume loaded children under the age of 5 years who received spinal anesthesia.<sup>14</sup> The reason for this hemodynamic stability is unknown but is ascribed to the "immaturity" of the sympathetic nervous system. Studies in young puppies show that their SVR is low and increases progressively with age.<sup>11</sup> It is postulated that in human infants, their already low SVR causes the chemical sympathectomy of a spinal block to have less of a hemodynamic effect. Dohi *et al.*<sup>12</sup> showed that non-volume loaded children over 5 years of age who underwent spinal anesthesia exhibited the same decrease in BP as adults exhibit. Children over 5 years of age require volume loading before a subarachnoid block is administered.

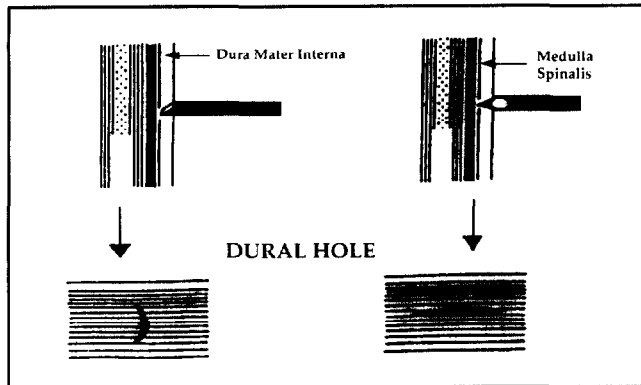
In premature infants having lower abdominal surgery such as inguinal herniorrhaphy, it is our practice to use 1 mg/kg of hyperbaric tetracaine with epinephrine to ensure that the duration of the block outlasts the duration of the surgery. This dose gives a T<sub>4</sub> sensory level in the preterm infant. In the full-term infant, we use 0.8 mg/kg, which achieves the same sensory level. For an inguinal herniorrhaphy, the duration of analgesia achieved with a single injection of 0.8 to 1.0 mg/kg of tetracaine with epinephrine varies anywhere from 90 to 177 minutes.<sup>57</sup>

Hyperbaric 0.5% bupivacaine used for infant spinals at the same doses as for tetracaine will achieve essentially the same duration and level of anesthesia.

Using 5 mg/kg of 2.5% hyperbaric lidocaine results in a shorter duration of anesthesia (about 60 to 90 minutes) and earlier recovery of motor function, with earlier discharge from the recovery room.<sup>58</sup>

### Complications

There are few reports of postlumbar puncture headache in the pediatric population.<sup>59-61</sup> Scher *et al.*<sup>59</sup> compared two age-groups of pediatric oncology patients having lumbar puncture for either diagnosis or intrathecal can-



**Figure 5.** Insertion of bevel of spinal needle parallel to and across the dural fibers. Reproduced with permission from: Mihic DN: Postspinal headache and relationship of needle bevel to longitudinal dural fibers. *Reg Anesth* 1985;10:76.

cer therapy. The frequency of postlumbar puncture headache in the 10- to 18-year-old age-group was found to be 19.2%, compared with 77.8% in adults. The frequency of headache in the 2- to 9-year-old age-group was found to be nil.<sup>59</sup> The lower frequency of postdural puncture headache in children younger than 10 years of age was thought to be due to a more elastic dura or perhaps a diminished response of the cerebral vasculature to a drop in CSF pressure. Even less is known about the frequency of postdural puncture headache in infants. Infants are unable to verbalize their discomfort and clinicians often miss the physical and behavioral changes indicative of a postdural puncture headache. However, the more elastic dura and lower CSF pressure of infants as compared to children and the inability of infants to ambulate may result in a very low frequency of postpuncture headache.<sup>60</sup>

Anesthetic technique affects the frequency of postdural puncture headache. In adults, Ready *et al.*<sup>61</sup> found a significantly lower CSF leakage rate when a 22-gauge Quincke needle was inserted parallel to the dural fibers than when it was inserted perpendicularly. It is possible (but still unproven) that performing the lumbar puncture with the bevel of the needle parallel to the dural fibers in children may reduce the frequency of postlumbar puncture headache (*Figure 5*).

Although spinal anesthesia is a safe anesthetic technique for ex-premature infants, perioperative hypothermia, anemia, or sepsis may predispose these small patients to postoperative apneas. As a consequence, postoperative apnea and SpO<sub>2</sub> monitoring are recommended.<sup>62</sup>

There is no evidence that spinal anesthesia in preterm neonates has deleterious long-term effects on the developing spinal cord. Histologic studies of neonatal rabbit spinal cords have shown that even an 8% solution of tetracaine causes no changes suggestive of long-term injury.<sup>63</sup>

Continuous spinal anesthesia with "small-bore" catheters [defined by the U.S. Food and Drug Administration

(FDA) as 27-gauge or smaller] has recently been implicated in cauda equina syndrome.<sup>64</sup> This syndrome is a prolonged and possibly permanent neurologic deficit characterized by one or more of the following: loss of bladder and/or bowel control, loss of perineal sensation, decreased sensation or mobility of the lower extremities. The FDA advises "against the use of any small-bore catheter for continuous spinal administration of any local anesthetic agent" and has taken steps to remove from the market all small-bore (27-gauge or smaller) catheters distributed for continuous spinal anesthesia.<sup>65</sup>

## Conclusion

The use of regional techniques in pediatric anesthesia practice has increased dramatically in the past decade. Recent technologic advances and new pharmacologic and physiologic insights have made it feasible to offer infants and children the psychological and physiologic benefits of regional techniques that were once available only to adults. The increased awareness of the need to provide adequate analgesia well into the postoperative period and the exceptional ability of neuraxial blockade to provide it ensure that neuraxial blockade techniques will remain an important part of the complete pediatric anesthesiologist's repertoire.

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### **Pediatric Regional Anesthesia**

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#### **Summary**

Regional anesthesia is increasingly being used in children as a component of intra- and postoperative anesthetic management and as a means to provide analgesia for both acute and chronic pain. Advantages of regional anesthesia when used intraoperatively include a reduction of general anesthetic requirements, rapid emergence from anesthesia, and early discharge from the hospital after surgery. Whether used intra- or postoperatively, regional anesthesia provides analgesia with minimal systemic side effects such as respiratory depression and hypotension. Furthermore, technical advances in equipment design and in our understanding of pediatric anatomy and pharmacology have enabled pediatric anesthesiologists to use regional anesthetic techniques in even the smallest and youngest patients. Indeed, the concept that regional blockade may be performed as an adjunct to general anesthesia rather than as an alternative has profoundly changed current pediatric anesthetic practice.

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