

Workshop: Pediatric Epidurals

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Introduction

Epidural blockade in children continues to grow in popularity with increasing applications in the operating room and beyond. In infants and children, epidural anesthesia is most commonly performed in conjunction with general anesthesia as a means of providing postoperative analgesia or as a combined general-regional anesthetic technique to limit the requirements for general anesthetic agents. However, epidural blockade may also be the sole surgical anesthetic in various clinical scenarios such as the former premature infant at high risk for post-anesthetic apnea, in patients with concurrent medical conditions that increase the potential risks of general anesthesia, or in cooperative older pediatric patients who chose a regional anesthetic technique over general anesthesia. When performed preemptively prior to surgical incision, epidural blockade may ablate the surgical stress response, decrease postoperative analgesia requirements, and improve the postoperative course. Epidural anesthesia has also found increasing roles in the management of acute and chronic pain outside of the perioperative period. Additionally, the sympathetic blockade that can be induced by epidural anesthesia is occasionally used as a therapeutic tool to improve regional blood flow in various clinical scenarios with associated vascular insufficiency. This workshop will review local anesthetic agents, opioids, and adjuvant agents commonly used for pediatric epidural anesthesia/analgesia and discuss the practical aspects of these techniques. Additionally, specific issues as they pertain to the use of these techniques in neonates will be reviewed.

Caudal epidural blockade

The most commonly performed pediatric epidural technique is the caudal epidural block. First described for pediatric use in 1933³⁵, caudal epidural analgesia involves accessing the epidural space through the sacrococcygeal ligament via the sacral hiatus at the base of the sacrum. The technique is relatively easy to perform and combines a high success rate with a low risk of complications. It is particularly popular in pediatric practice because of the ability to obtain analgesia extending to the mid-thoracic dermatomes when volumes of 1.3-1.5 mL/kg are used in infants and young children while approaching the epidural space below the level of the spinal cord. It may be considered for any procedure or process below the umbilicus. Caudal block in children is most commonly performed in combination with a general anesthetic, but may be the sole technique in former premature infants at high risk for post-anesthetic apnea. Caudal block is performed with the patient in lateral or prone position.

The sacral hiatus is identified above the coccyx, at or near the superior aspect of the gluteal crease, by palpation of the two sacral cornua. The sacral cornua represent the posterior bony elements of the S₅ vertebral body. Using appropriate sterile technique, a needle is inserted midway between and slightly inferior to the two sacral cornua at a 45° angle to the skin. The needle angle may be decreased immediately after passing through the skin or after encountering bone,

representing the posterior wall of the ventral sacral elements. The needle is advanced, readjusting the angle as needed, until a characteristic "pop" indicating passage through the sacrococcygeal membrane is appreciated. Potential sites of improper needle placement include intraosseous, subdural, in an epidural vein, and under the sacral ligament.

Controversy has been raised regarding the type of needle used: standard or stylet. Advocates of a stylet needle voice concern regarding coring or the removal of a tissue plug which theoretically could be carried into the epidural space and develop into an epidermoid tumor. Goldscheider and Broman demonstrated residual material in 54% of cases when a non-stylet needle was used. In 33% of the cases, the core included epidermal tissue. This issue remains to be resolved as many institutions continue to use standard, short bevel, non-stylet needles while others use stylet needles such as a standard spinal needle.

The sacrococcygeal membrane represents the most inferior aspect of the ligamentum flavum surrounding the spinal epidural space. After negative aspiration for blood or CSF, the same process as outlined above for dosing an epidural block at the lumbar or thoracic level is followed including the use of a test dose and fractionating the entire dose of local anesthetic solution. The volume administered depends upon the desired area level of analgesia. Bupivacaine (0.125-0.25%), levobupivacaine (0.125-0.25%), and ropivacaine (0.2%) are the local anesthetics most commonly used for bolus caudal epidural administration. Bupivacaine, levobupivacaine, and ropivacaine when used in concentrations of 0.2-0.25% will provide surgical anesthesia for 60-120 minutes with persistent analgesia for up to 6-12 hours thereafter. Analgesia at more distant sites or for longer periods may be achieved by addition of opioid and/or adjuvant agents.

Although caudal block is most commonly performed as a "single shot" bolus technique, postoperative analgesia can be provided by a continuous caudal infusion following placement of a caudal epidural catheter as is performed for lumbar or thoracic epidural analgesia. Several commercially prepared kits are available for caudal anesthesia or standard epidural kits may be used with a Crawford or other end-hole needle. Alternatively, a standard 20-gauge epidural catheter may be threaded through an 18-gauge intravenous catheter that has been placed into the caudal epidural space. In neonates and small infants, it may be feasible to pass a catheter from the caudal area to the thoracic dermatomes to provide analgesia for thoracic and upper abdominal procedures.

Regional anesthesia, either spinal or caudal block, with the patient awake is occasionally performed for surgical procedures below the umbilicus in children at high risk for post-anesthetic apnea, particularly former premature infants. Avoidance of general anesthesia may decrease the likelihood of postoperative respiratory complications including apnea. Awake regional anesthesia generally uses only local anesthetic agents as the addition of neuraxial opioid and/or adjuvant agent may confer the same risk for post-anesthetic apnea as does general anesthesia. Either caudal epidural or spinal anesthesia may be used. Topical anesthesia is provided by skin infiltration or local anesthetic cream before block placement. Numerous regimens have been suggested for awake caudal anesthesia with volumes ranging from 1 to 1.5 mL/kg of bupivacaine in concentrations varying from 0.2%-0.375%. For these techniques, a higher volume is needed to provide high thoracic block while a higher concentration (0.2-0.375% bupivacaine) of local anesthetic is needed to improve surgical anesthesia. Limitations of these techniques include incomplete motor block with resultant unfavorable surgical conditions and duration of anesthesia less than 90 minutes. Additionally, the combination of a high volume and a higher concentration of local anesthetic agent approaches or in some suggested regimens exceeds the recommended

doses of bupivacaine. These concerns and the need to prolong anesthesia beyond 90 minutes in some cases has resulted in the use of 3% chloroprocaine by continuous infusion. Successful anesthesia can be provided for 2-3 hours in the awake neonate using a regimen of 1.5-2 mL/kg of 3% chloroprocaine as the initial bolus followed by an infusion of 1.5-2.0 mL/kg/hr. Despite the high volume and high concentration of local anesthetic agent, serum concentrations have been shown to be insignificant even in the neonatal population. This technique has also been shown to be effective as a combined technique with general anesthesia for abdominal surgical procedures in neonates thereby allowing for immediate tracheal extubation by avoiding high concentrations of an inhalational anesthetic agent and eliminating the need for parenteral opioids.

Since neuraxial blockade in children is most commonly performed under general anesthesia, neurologic toxicity may not manifest itself leaving cardiotoxicity as the first sign of systemic toxicity. Although local anesthetic toxicity may occur during continuous infusion techniques, particularly if the dose is not appropriately adjusted for patient age, most adverse reactions occur with bolus administration, given the greater likelihood of rapidly reaching toxic serum levels. Local anesthetic toxicity may also result from unrecognized intravascular or intraosseous injection. Before the epidural administration of local anesthetic, aspiration for blood should be performed. Negative aspiration reduces, but does not eliminate the risk of inadvertent intravascular injection as inadvertent intraosseous injection may occur (generally during caudal epidural blockade) given the cartilaginous nature of the lumbar and sacral vertebral bodies in neonates and infants. Following negative aspiration, a test dose of epinephrine-containing local anesthetic is injected (0.5-1 µg/kg of epinephrine, or 0.1-0.2 mL/kg of a solution containing epinephrine 1:200,000 or 5 µg/mL) with 30-60 seconds of observation for hemodynamic changes suggestive of intravascular injection (ST segment or T wave changes, increased heart rate or hypertension) before injection is continued. Even if no hemodynamic changes are noted, many practitioners administer the remainder of the dose slowly and in fractionated fashion, with repeated aspiration and observation after each subsequent dose. The reader is referred to the reference list for a review article concerning the history and current status of test dosing.

Pediatric epidural anesthesia: equipment, technique, and complications

Pediatric epidural anesthesia represents a potentially valuable technique in perioperative care of children. A review of the historical background of pediatric epidural anesthesia provides greater understanding of its development, underscores possible applications, and reinforces potential complications and contraindications. Successful pediatric epidural anesthesia requires careful planning and skillful execution, with the goal of providing optimal analgesia. The analgesia provided is at least equivalent, and at times may be superior, to that afforded by other modalities. Particularly when performed pre-emptively, regional anesthesia has been shown to attenuate the surgical stress response, although the significance of this in pediatric patients is unclear. Regional anesthetic techniques should provide analgesia while minimizing respiratory depression and other side effects of systemic opioid therapy, although this has been difficult to demonstrate in clinical practice. Regional anesthetic techniques permit lighter planes of intraoperative general anesthesia, facilitating emergence and expediting recovery, and in some cases may allow avoidance of general anesthesia. There are also roles for epidural anesthesia in pediatric pain management, in the perioperative setting and outside the operating room.

Pediatric epidural anesthesia does require time and effort on the part of the anesthesia provider, as well as patience on the part of surgical and nursing colleagues; depending on

technique, specialized equipment may be required. Any regional anesthetic may fail, or be only partially effective. Intravascular injection is possible, as are vascular injury and bleeding including epidural hematoma. Infection including epidural abscess is uncommon with single injection techniques, but may be encountered with indwelling catheters. Concern persists over the potential for regional anesthetic techniques to mask potentially serious surgical conditions, in particular compartment syndrome of the distal lower extremity. Intra-neural injection and nerve injury are theoretically possible and have been described, but fortunately are quite rare in children. Coagulopathy, infectious process, patient or parent refusal, and anatomic deformity are all relative contraindications, although risks and benefits must be weighed in each patient and for each procedure.

Successful pediatric epidural anesthesia requires careful planning and skillful execution. Administration of anesthetic at or near the midpoint of the dermatomal area over which analgesia is desired is probably the single most important determinant of analgesia. Anesthetic may be injected or a catheter placed directly at the desired vertebral level; in infants and young children, catheters may be placed caudally and threaded distally. Anesthetic injection or catheter placement may be undertaken by paramedian or midline approaches. Early pediatric practice entailed paramedian approach, primarily because of historical precedent in adults, but for most pediatric patients midline approach will be successful. Anesthetic may be administered as a single injection, or by repeated injection or continuous infusion through an indwelling catheter. Catheters may be placed conventionally for use over several days, or tunneled for use over weeks to months. Pediatric epidural anesthesia is most commonly performed with the patient under general anesthesia, although awake placement may be attempted in particularly cooperative older children. The primary role for awake regional anesthesia in the pediatric patient is in the former premature infant at risk for apnea following general anesthesia. Clinical studies in humans have demonstrated little or no difference in timing of pediatric regional anesthesia before or after a variety of surgical procedures.

Pediatric epidural anesthesia has great historical precedent, and represents a potentially valuable technique in perioperative care of children. Serious complications and absolute contraindications are rare; analgesia is at least equivalent, and at times may be superior, to that afforded by other modalities. Careful planning and skilled execution increase likelihood of optimal analgesia.

Pediatric epidural anesthesia: Medications and pharmacology

Local anesthetics form the backbone of regional anesthesia and analgesia practice. As used in children they have a narrow therapeutic window for serious complication yet are used with a high degree of safety. Their efficacy of analgesia is accompanied by an acceptable rate of side effects. The epidural route of local anesthetics and adjuvant drugs is typically utilized for postoperative analgesia as part of a balanced general anesthetic technique. Only rarely will epidural anesthesia be the sole anesthetic for infants and children. Local anesthetics share a structural-activity relationship. A tertiary amine is linked by an intermediate chain to an unsaturated aromatic. This produces a molecule with both water solubility and lipophilicity. The local anesthetic must bind the sodium channel in the interior of the cell to block gate opening, preventing the formation or transmission of an action potential. Local anesthetics do not alter the resting membrane potential or alter the metabolic activity of the cell otherwise. Successful blockade of a single nerve's transmission requires a sufficient concentration (Cm)

of the local anesthetic to be present over a sufficiently long section of nerve. C_m is a function of drug and nerve type. The practical clinical required concentration is typically 10 fold greater than the *in vitro* C_m . The unmyelinated C fibers and smaller myelinated A-delta fibers carry nociceptive information have a lower C_m than the more heavily myelinated motor fibers.

Peak local anesthetic blood levels are largely a function of total dose administered. The rate of absorption and time to the peak blood level differs for the location of injection. Increasing absorption rate follows this general pattern: subcutaneous, distal blocks, brachial plexus, caudal, epidural, intercostal, intratracheal, intravenous. Vasoconstrictors may slightly decrease the peak levels obtained. Peak levels and lower effective therapeutic indices result from the dose scaling in children. Comparable size nerves require similar total doses of local anesthetic to effect blockade, yet the volume of distribution for the disposition of the local anesthetic varies more proportionately with the weight of the patient. Producing a similar nerve block in an infant therefore requires a substantially greater dose for body weight than for adults.

Bupivacaine is the most commonly administered local anesthetic for routine intraoperative and postoperative analgesia in children. At concentrations appropriate for postoperative analgesia it produces differential blockade that permits good muscle strength with the possibility for assisted ambulation with lumbar epidural and especially with thoracic level epidural. Metabolism for amide local anesthetics is decreased in neonates and care must be taken to avoid excessive infusions. Larsson followed blood levels in neonates with epidural infusions at 0.2 mg/kg/hour, finding a wide range in blood levels, with some exceeding 3 $\mu\text{g/ml}$ without showing evidence for plateau at 48 hours. This would suggest that dosing beyond this or for longer periods in neonates could be of concern. Levobupivacaine is a single enantiomer of the racemic bupivacaine. Levobupivacaine may have an improved therapeutic index with respect to the racemic mixture suggested by *in vitro* studies. In clinical use it appears similar in potency and differential blockade to bupivacaine. There is insufficient clinical evidence for reduced toxicity yet to suggest higher permissible doses of Levobupivacaine as compared to racemic bupivacaine. Ropivacaine has *in vitro* cardiac effects similar to levobupivacaine. Comparative trials suggest that it is slightly less potent than bupivacaine. Because it appears to have a greater differential blockade, it might be useful in situations where minimal motor block is desired. Chloroprocaine is the most rapidly metabolized local anesthetic, degraded by plasma esterases with a half-life of 45 seconds in neonates and 25 seconds in adults. Systemic reactions have still been reported, especially as rapid boluses can saturate the limited esterase capacity of infants. This drug is most useful for testing the functionality of an epidural catheter for which the proper positioning might be in question. It has also been utilized as a continuous infusion for surgical anesthesia in neonates.

Utility of mixtures of local anesthetics may present hypothetical benefits. It may be possible to produce faster onset with longer block by mixing, for example, lidocaine with bupivacaine. The specific advantages of these admixtures have had only limited assessment. One difficulty for comparison is determining exactly what would be a comparable dose of a single agent. Two percent lidocaine mixed at equal volumes with 0.25 % bupivacaine will result in 1% lidocaine and 0.125% bupivacaine concentrations. A rational concentration and dose of a single agent for comparison is not intuitively obvious. For purposes of avoiding toxicity, the fraction of maximal dose of each should be summed (e.g. half the permissible lidocaine dose with half the permissible bupivacaine dose is the limit to be administered).

There has been no suggestion of benefit for admixing local anesthetics for use with continuous postoperative administration.

Toxicities in infants can occur at lower doses compared with children and adults because of decreased protein binding of the local anesthetic agent. Metabolism of the amide local anesthetics is significantly slower through age 12 to 18 months and consideration of this must be made for repeated doses or continuous infusions of local anesthetic. Toxicity typically produces CNS symptoms before cardiovascular effects occur. Agitation, restlessness, and myoclonic movements indicative of CNS excitement could be confused for unrelieved pain. CNS symptoms generally precede cardiovascular complications except with bupivacaine. Bupivacaine has a narrower therapeutic index and cardiac symptoms may coincide or precede CNS symptoms. The dysrhythmias described may produce difficult to resuscitate conditions. All local anesthetics directly depress cardiac contractility. By altering sodium channel conduction the propagation of contraction occurs more slowly creating the situation where reentrant dysrhythmias may occur. Bupivacaine differs from the other amide anesthetics having increased lipid solubility and a more avid binding to the sodium channel. Cardiac dysrhythmias precipitated by bupivacaine under the conditions of hypoxia and hypercarbia are probably best managed with amiodarone in addition to support of ventilation and circulation. Isoproterenol has been demonstrated to reverse the electrocardiac effects of bupivacaine toxicity and might be useful also in resuscitation. In summary: For bupivacaine, maximum infusion rate for neonates is 0.2 mg/kg/hour. Over age 6 months through adult, 0.4 mg/kg/hour.

General considerations for the use of adjuvant drugs for epidural anesthesia and analgesia include: (1) children often tolerate opiates quite well and can often achieve adequate analgesia utilizing opiates and NSAIDs. Therefore, epidural safety must at least meet the already high safety profile of IV opiates. (2) Dose ranging in children is often incomplete or absent. (3) Most experience is from single dose (typically caudal epidural) use. (4) Drug additives and preservatives may be present in adjuvant drugs, and have less often been safety tested for epidural and spinal use. (5) Because of the probability for unintended intrathecal administration, drugs considered for epidural use should be established as safe for intrathecal use.

Clonidine is FDA approved for epidural use in adults with chronic pain. It is available in a preservative free preparation at 100 µg/ml and 500 µg/ml. Clonidine acts as a presynaptic α_2 -adrenergic agonist at the interneurons of the dorsal horn mimicking the activation of descending noradrenergic pathways and inhibiting neurotransmitter release. Typical side effects of clonidine include sedation, bradycardia, orthostatic hypotension and dry mouth. Alterations in intraoperative or postoperative blood pressure are minimal in children. Respiratory depression is minimal, with resting carbon dioxide levels normal, but ventilatory response to CO₂ challenge somewhat blunted. Numerous studies have evaluated the efficacy of single dose clonidine via the caudal route as an adjuvant with local anesthetics for procedures below the umbilicus, most finding benefit with doses from 1-2 µg/kg. A dose response study evaluated three concentrations of clonidine finding improved pain scores without change in sedation scores in children with continuously infusion epidural catheters. The authors concluded that clonidine 0.08 to 0.12 µg/kg/hr added to ropivacaine was superior to ropivacaine plain or with 0.04 µg/kg/hr. In children undergoing major abdominal surgery clonidine alone at 0.2 µg/kg/hr as epidural infusion may be sufficient for a majority of patients.

A reasonable role for clonidine in postoperative management would be to supplant the use of an opiate, thus reducing the complications from PONV and pruritus and respiratory depression. The spinal administration of clonidine has been shown to produce antihyperalgesia persisting months after surgery and anesthesia, suggesting that clonidine might have some preemptive analgesic benefit (that has been elusive in clinical trials for opiates.)

Ketamine is available as a preservative free drug, but is not labeled for epidural or spinal use. Ketamine acts through the blockade of NMDA receptors in the substantial gelatinosa, and also binds mu opioid receptors. These receptors are located throughout the CNS and play an important role in central pain and neural plasticity in the spinal cord. Numerous studies in children mostly for hernia and genitourinary surgery has demonstrated efficacy for prolonging analgesia for bupivacaine caudals. Dose ranging for single dose administration suggests that 0.25-0.5 mg/kg is optimal; larger dosing was associated with urinary retention and behavioral effects.

Neostigmine is available only with preservative (methylparaben, propylparaben, or even phenol outside the U.S.) and is not labeled for epidural or spinal administration. The paraben preservatives utilized in the U.S appears safe in animal studies. Muscarinic receptors are present in lamina 2 and 3 of the spinal cord and are responsible for the analgesics effects. Epidural and intrathecal neostigmine is associated with significantly increased rates of PONV. Hemodynamics are stable, and blood pressure is supported more near normal as compared to controls without neostigmine administration. Dose ranging studies in children have shown dose independence over a range 2-4 µg/kg neostigmine with bupivacaine versus bupivacaine only controls, yet a similar study exploring the range 10-50 µg/kg using neostigmine as the sole analgesic found that analgesia was dose dependent throughout this range, but PONV was increased with doses over 30 µg/kg. Evidently, neostigmine requires substantially larger doses without the presence of a local anesthetic. It usefully prolongs the duration of conventional caudal block with local anesthetic but has poor efficacy as a sole analgesic. PONV and sedation are problematic at higher doses. Continuous infusion has not been explored for continuous epidural infusion.

Midazolam is available as a preservative free drug, but is not labeled for epidural or spinal use. Action is through GABA-A receptors in the spinal cord in lamina II of the dorsal horn. Dose ranging is extrapolated from adult upper abdominal surgery, finding 50 µg/kg optimally providing analgesia, with higher doses associated with excessive sedation. Kumar recently compared effects of midazolam, ketamine, and neostigmine co-administered with bupivacaine. Time to first analgesic was longest for the midazolam and neostigmine groups, with the ketamine group having 2 of 20 patients experience hallucinations. Midazolam has had relatively little study to determine the optimal dose range in children, or evaluate for unanticipated side effects. Further study is warranted before widespread routine use is instituted.

Morphine is labeled for epidural and spinal use. It is known to produce a dose and concentration dependent local tissue inflammation inducing tissue granuloma at the site of intrathecal infusion. This is not an issue with the concentration or duration associated with acute perioperative analgesia use. Side effects include PONV, urinary retention, pruritus, and hypoventilation and apnea. The principle concern with the use of neuraxial opiates is for respiratory depression. This CNS effect can occur as a result of direct action upon the brainstem through CSF circulation or through systemic absorption with effect similar to IV

administration. Morphine has a peak effect for respiratory depression at 4 hours following administration but cases have occurred up to 12 hours later. This time can often coincide with circadian sleep, change of staff, and waning staff vigilance to produce critical respiratory depression if not monitored for and treated. The more lipophilic drugs fentanyl and sufentanil are more rapidly absorbed from the CSF, making rostral spread less likely; concerns for delayed respiratory depressions from single doses seems to be less likely than for morphine. Such safety cannot be assumed if these drugs are utilized as continuous infusions, and all opiate infusions should receive equivalent postoperative monitoring.

Children often require local anesthetic doses near the maximum acceptable. The first step in planning an epidural infusion is to determine the maximal amount of acceptable local anesthetic that may be infused per hour. Written orders for the epidural infusion should include a stated maximum so that nurses can check subsequent prescribed changes for the infusion. It may be necessary to reduce the planned concentration of the local anesthetic in order to keep the total dose to an acceptable amount.

Because of variations in surgical procedure, pain perception, patient variables of anatomy and drug disposition, no fixed regimen can be sufficient for all patients. Starting doses must be adjusted based upon patient responses. Assessments in children can be quite complicated as language and understanding of pain and sensation may not convey the experience as clearly as in adults. Children often express many sensations including the tingling or pins and needles feelings of numb extremities as pain. Indeed, for many preschool age children the pulse oximeter, ECG pads and any number of non-nociceptive stimuli 'hurt' if asked. Testing cold sensation as in adults with an alcohol pad will often lead to ambiguous responses; an ice cube beginning in certainly numb areas sliding toward unblocked dermatomes may be more obvious.

Smaller patients require a nerve to experience a similar exposure to local anesthetic as adults to produce block. Children have a smaller volume of distribution and lower clearance for drugs. Because their drug doses are greater on a weight basis, smaller children will have lower therapeutic indices. The caudal space will tend to require larger volumes for the same dermatome spread compared to the lumbar or thoracic region. Body weight in clinical practice is a surrogate for volume of distribution. In the case of dosing epidurals it is utilized both for estimating the Vd and clearance rate for drugs administered, as well as for assessing the size of the epidural space. Overweight body compositions may not have larger volumes of distribution, faster clearance or larger epidural spaces than their body weight alone would suggest. For purposes of dosing an epidural and estimating maximum doses one should conservatively utilize the ideal body weight.

A SUGGESTED APPROACH TO EPIDURAL MANAGEMENT:

- 1) Calculate maximum permissible local anesthetic infusion.
- 2) Determine desired infusion rates.

Loading volume: 0.05 mL/kg/dermatome spread from catheter/needle tip. At the caudal region count from the coccyx including all sacral, lumbar and thoracic roots to be anesthetized. For lumbar catheter count segments in one direction (usually cephalad) from catheter tip.

Infusion rate: 0.2-0.4 mL/kg/hour, not to exceed typical adult infusion rates of up to 15 ml/hour. For thoracic catheters, use half the loading dose and half the infusion rate.

3) Ensure that chosen rate times concentration is an acceptable dose of local anesthetic.

4) Determine the rate for the adjuvant.

Fentanyl	1 $\mu\text{g}/\text{kg}/\text{hour}$
Hydromorphone	1 $\mu\text{g}/\text{kg}/\text{hour}$
Morphine	2.5 $\mu\text{g}/\text{kg}/\text{hour}$
Clonidine	0.2 $\mu\text{g}/\text{kg}/\text{hour}$

5) Calculate the required concentration of adjuvant in the epidural solution.

A standardized order page tailored to each institution's typical practices and patients will greatly facilitate this practice and enhance safety by preventing accidental incorrect or atypical dosing.

THE OVERNIGHT CAUDAL EPIDURAL:

Shorter postoperative hospitalizations often seem to preclude the use of epidural analgesia. In this situation, where benefit is to be gained from the use of a continuous epidural technique, the technique must adapt. Clubfoot surgery causes considerable discomfort and casting promotes tendon stretch and muscle spasm exacerbating pain. This population can be well served by the use of a continuous caudally placed epidural catheter infusing until the morning of the first postoperative day. This results in excellent patient and parent satisfaction compared with the single dose blocks with effects that, despite adjuvant drug use, still wear off in the middle of the night. Our typical regimen uses bupivacaine 0.1% with fentanyl 5 $\mu\text{g}/\text{ml}$ to infuse at 0.2 mL/kg/hr. Bupivacaine dosing is acceptable for infants. Apnea monitoring and pulse oximetry are used overnight.

PATIENT-CONTROLLED EPIDURAL ANESTHESIA (PCEA):

PCEA principles:

Demand dose administered by patient is at least minimally effective.

Demand dose administered is unlikely to produce harm.

Dosing interval is governed by the rate of onset of effect. The patient will have the opportunity to notice the effect before the lockout permits repeat dosing.

Total local anesthetic dose must be considered for both basal and PCEA dosing.

Patients may be relied upon to self-limit systemic opiates as they achieve comfort and somnolence, but patients using local anesthetic may fail to slow usage in a similar manner.

Tachyphylaxis for local anesthetics is promoted by allowing local anesthetic effects to wane. Repetitive small fiber stimulus produces a wind up effect within the spinal cord, sensitizing the patient to pain; effectively this is the clinical opposite of preemptive analgesia. Allowing local anesthetic effect to wane as would be expected to occur with PCEA without basal infusion might lead to this problem. Further, reestablishing the analgesia will be difficult for patients unless especially liberal pump lockouts are utilized. Thus, it is rational to utilize a basal infusion when local anesthetics are included in the analgesic regimen. Reasonable PCEA demand dose is 20% of the basal with 2 doses per hour limit, or 40% of the basal rate with one dose per hour limit. It must be assumed that the patient will receive all possible programmed doses and this must be within the acceptable limits for local anesthetic usage.

Epidural analgesia provides excellent pain control, can hasten recovery of GI function, reduce PONV, and may preemptively reduce the total pain burden by reducing spinal cord 'wind-up' effect. Successful transition from epidural may be considered once the patient is capable of consuming oral analgesics. Since the pain burden of the procedure is likely significant, having required epidural analgesia, the oral analgesia regimen should adequately address this. The oral analgesic regimen we use often consists of a basal or scheduled opiate along with a PRN dose. NSAID adjuvants will also be utilized if not relatively contraindicated by the surgical procedure. Typical dosing includes Oxycontin 0.5-0.75 mg/kg Q8-12 hours scheduled plus oxycodone 0.15-0.2 mg/kg Q2 PRN. For children who cannot swallow the Oxycontin tablets, a scheduled dose of oxycodone at 4-hour intervals could be substituted. The PRN dosing is quite short, but within 2 hours the full effect, and side effect, can sufficiently be assessed to warrant repeat dosing if discomfort persists. Intravenous opiates or reactivation of the catheter can be considered for unrelieved pain. It is uncommon to transition epidural analgesia to IV PCA; this is sometimes required for bowel procedures requiring prolonged postpone fasting.

Neonatal epidural anesthesia

There is increasing evidence that infants not only have the neuroanatomic, neurochemical, and functional ability to respond vigorously to painful stimuli, but equally as important, that early pain experiences may alter responses to pain later in life. Preterm and term neonates in the neonatal intensive care unit (NICU) are exposed to numerous sources of pain and stress following major surgical procedures. Because of the immaturity of inhibitory pathways in the central nervous system in both preterm and full term infants, tissue-damaging procedures may be particularly painful in these young infants. Untreated pain can lead to a number of adverse physiologic consequences including increased physiologic energy expenditure, increased secretion of adrenal stress hormones, altered cerebral blood flow, and disturbed sleep/wake cycles. Strategies for treating and preventing pain in the NICU and newborn nursery have recently been developed and preliminary studies have suggested that early aggressive pain control and stress reduction strategies may minimize long term effects on pain thresholds and behavior. Key in the treatment of acute postoperative pain is the use of regional anesthetic techniques including epidural anesthesia.

Epidural analgesia can provide excellent postoperative analgesia for neonates undergoing thoracic, abdominal, and lower extremity surgery. It can be particularly useful for surgeries where early resumption of spontaneous ventilation is desired to avoid barotrauma (e.g. diaphragmatic hernia repair). The use of epidural analgesia in neonates has been facilitated by the discovery that a catheter can be reliably threaded to the thoracic region from the simpler caudal approach in neonates. This technique tends to be quite reliable in infants less than 5 kg. Since proper alignment of the tip of the epidural catheter can be crucial to the success of this technique, placement should be verified by the injection of 0.5 mL of radio-opaque dye (Omnipaque 180 or Isovue 200) through the catheter followed by radiography. Radio-opaque catheters (Theracath™, Arrow International, Redding, Pennsylvania) are also available that allow determination of the level of the catheter tip with a plain radiograph. The advantage of these catheters is that placement can be easily verified throughout the duration of the infusion.

Continuous infusions of bupivacaine, levobupivacaine, or ropivacaine can provide

excellent pain relief, but clearance of these local anesthetics can be variable in newborn infants. Bupivacaine is an amide local anesthetic requiring conjugation to inactive metabolites in the liver and excretion in the kidneys. Clearance can therefore be delayed in newborns, especially after abdominal surgery. Early pharmacokinetic studies demonstrated that, in contrast to the steady state levels seen in older infants, infants less than 4 months of age, receiving infusions of 0.1% bupivacaine can have steadily rising bupivacaine plasma levels. Subsequent studies focusing specifically on infants less than 1 month of age, demonstrated that at 48 hours of an infusion at 0.2 mg/kg/hour, rising bupivacaine levels are seen in 60% of infants. For this reason, it is recommended that infusion rates in infants less than 2 months of age should not exceed 0.2 mg/kg/hr for the initial infusion and should be lowered as tolerated during the first several days of infusion. In order to provide adequate spread of the local anesthetic and still maintain bupivacaine levels below this range, an infusion of 0.05% bupivacaine mixed with 1 µg/mL of fentanyl has been used at rates of 0.2 – 0.4 mL/kg/hour (0.1 –0.2 mg/kg/hour of bupivacaine) with good success. When the tip of the epidural catheter is properly placed, infusion rates can often be further reduced to 0.1 mg/kg/hour (0.2 mL/kg/hour) on the second or third postoperative day without significantly affecting pain relief. Lidocaine has also been used for continuous epidural infusions in newborns with the possible advantage of allowing plasma blood levels to be easily obtained during the infusion. Concerns regarding the rapid development of tolerance to this local anesthetic in laboratory animals have limited its widespread use.

To avoid these concerns regarding bupivacaine clearance, 2-chloroprocaine has been used for epidural infusions in neonates. Since 2-chloroprocaine is an ester local anesthetic, it is metabolized by plasma cholinesterases and rapidly cleared from the circulation. Theoretically, higher infusion rates can be administered with less likelihood of accumulation. Henderson and colleagues demonstrated a rapid clearance of chloroprocaine in neonates even at high infusion rates (1.0 mL/kg/hour of 3% chloroprocaine). In their cohort of patients, a continuous caudal epidural infusion was used to provide intraoperative surgical anesthesia during prolonged surgical procedures in former preterm infants as a means of avoiding the need for general anesthesia. Alternatively, the caudal epidural infusion of chloroprocaine has also been combined with general anesthesia during major intra-abdominal procedures to allow for tracheal extubation at the completion of the procedure. Further studies are needed to assess the efficacy and safety of long-term infusions of 2-chloroprocaine in newborns, since there are limited data currently available in the adult population and the studies performed to date in the pediatric population, have included intraoperative infusions with a maximum duration of 3-4 hours. With long term postoperative use, the rapid development of tachyphylaxis may limit its utility.

Summary

Interest in pediatric epidural blockade continues to grow, with increasing applications of epidural anesthesia during the perioperative period. Epidural medications generally include some combination of local anesthetic agent, opioid, and/or a variety of adjuvant agents such as ketamine or clonidine. Although the epidural space may be accessed at any vertebral level, caudal block is most common in pediatric practice. Unless a hydrophilic opioid such as morphine is used, epidural analgesia optimally requires an approach at the vertebral level corresponding to the dermatome at which maximal analgesia is desired. Epidural analgesia may entail a single bolus administration or a continuous infusion via an epidural catheter. When considering the options for prolonged analgesia (up to 24 hours), 3 basic options are available: 1) caudal epidural injection of a

hydrophilic opioid such as morphine, with butorphanol to limit the adverse effect profile for morphine; 2) lumbar intrathecal morphine which has been shown to be effective for thoracic and craniofacial procedures; or 3) an indwelling epidural catheter with a continuous infusion of a combination of the agents outlined in this chapter.

Monitoring is essential for safety. The nursing staff must be trained to understand the physiologic effects of epidural analgesia. A systematic means of assessment, focusing on the expected complications from the drug regimen chosen must be instituted for each patient. Physiologic monitors can be of benefit, but are plagued by false alarms. The SpO₂ is sensitive for hypoventilation in children breathing room air. However the use of supplemental oxygen can result in normal SpO₂ readings well into an evolving respiratory arrest. Standard epidural management orders should not generally allow supplemental oxygen administration without an additional ongoing assessment of the respiratory status such as respiratory rate or a non-invasive monitor of PaCO₂. Adverse effects from epidural morphine primarily, and other opiates also to a lesser degree, can cause significant patient distress. PONV, pruritus, respiratory depression, and urinary retention occur at lower rates for patients who receive local anesthesia alone, or in conjunction with clonidine or ketamine. Keeping epidural drug management simple, using the fewest number of drugs to achieve pain control remains the goal.

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