LOCAL ANAESTHETIC TECHNIQUES IN PAEDIATRIC SURGERY

D. S. ARTHUR AND L. R. McNICOL

At a time when the agent of choice for paediatric anaesthesia was chloroform, the introduction of spinal anaesthesia (Bainbridge, 1900; Gray, 1909a,b, 1910) produced a considerable reduction in morbidity and mortality (Farr, 1920). Other advantages of note were limitation of anaesthesia to the part to be operated on, muscular relaxation and avoidance of the over-distended gut but, more significantly, during the postoperative period there was an almost total absence of vomiting, with an associated rapid return to normal feeding. Gray was also impressed by the long duration of postoperative analgesia and the commensurate reduction in the use of opioids.

Local anaesthesia continued to remain popular for use in children into the 1940s and Leigh and Belton (1948) reported that 10% of all anaesthetics at their hospital were spinal blocks, even for lobectomy and pneumonectomy.

The introduction of neuromuscular blocking agents to paediatric anaesthetic practice (Rees, 1950), followed by halothane, coincided with a growing controversy over the use of techniques such as spinal anaesthesia in children. Some authors continued to extol the technique: "Spinal anaesthesia is an excellent method for children" (Berkowitz and Greene, 1951), while others contended that "Spinal anaesthesia in children has been and still is frowned upon by the majority of anaesthetists and surgeons" (Slater and Stephen, 1950). Following the Woolley and Roe case, it was proposed that all forms of local anaesthesia for major surgery should give place to general anaesthesia (Armstrong Davison, 1965).

PHARMACOLOGY AND PHARMACOKINETICS

Detailed discussion of these aspects of local anaesthetics appear elsewhere in this issue. There are significant differences in the way in which drugs are distributed and metabolized in the very young compared with the adult.

Plasma protein concentrations are lower in the plasma of the neonate; both albumin and globulin concentrations are lower and, in particular, the concentration of alpha1-acidglycoprotein, responsible for the binding of lignocaine, is three times lower in the neonate. This enables more of the drug to remain active (Boreus, 1982). Neonates have been found to be affected neurologically by a blood concentration of lignocaine of 2.5 µg ml⁻¹, whereas toxicity in the adult is unlikely to occur below 5 µg ml⁻¹ (Ralston and Schnider, 1978).

Plasma protein binding does not approach adult levels until after the first year of life.

Plasma pseudocholinesterase concentrations are also low in the newborn and therefore excessive doses of procaine cannot be metabolized, particularly if red cell true cholinesterase is low, as may occur with the normal anaemia experienced around 2–3 months of age (Zigismond and Downs, 1971).

Metabolism of local anaesthetics, particularly by microsomal enzyme systems, is greatly reduced in the neonate and up to 90% of the local anaesthetic agent, in the case of mepivacaine, is excreted unchanged in the urine. Meffin, Long and Thomas (1973) suggested that forced diuresis might be the appropriate treatment of the neonate depressed at birth because of local anaesthetic toxicity.

After the first few months of life, children eliminate drugs at a greater rate than adults. This accounts for low blood concentrations of bupivacaine 1.87 µg ml⁻¹ following intercostal block after a total dose of 4 mg/kg body weight (Rothstein et al., 1982). Using bupivacaine 3 mg kg⁻¹ for caudal analgesia, Eyres and others (1983) found peak blood concentrations in the 1-year-old of 1.55 µg ml⁻¹. Ecoffey and others (1984), using lignocaine 5 mg kg⁻¹, achieved maximum blood concentrations between 1.6 and 2.5 µg ml⁻¹, well
below the toxic concentration of 5 μg ml⁻¹. The greater elimination of local anaesthetics in older children may result partly from the fact that the liver is relatively much larger in children as a percentage of body weight (Rylance, 1981) and also contains more metabolic sites for the breakdown of local anaesthetics and other drugs (Boreus, 1982).

The more rapid increase to peak blood concentrations following intercostal, topical (Eyres et al., 1978; Eyres, Bishop and Brown, 1983) and more particularly caudal analgesia in children, observed in the studies of Rothstein and colleagues (1982) and Ecoffey and colleagues (1984), probably represent the relatively greater cardiac output in children. Peak plasma concentrations following caudal anaesthesia occurred around 15 min as opposed to 30 min following extradural analgesia in adults.

Ecoffey and colleagues (1984) noted, however, that the elimination half-time was considerably longer; this is unlikely to be the result of slow elimination in older children for reasons already mentioned, but is more likely to be related to the larger volume of distribution in children (Boreus, 1982), a factor largely related to the difference in body composition that occurs not only with age, but also with sex differences, particularly up to and around puberty (Widdowson, 1981).

Potentially toxic concentrations of local anaesthetics do not cause overt signs in children. For instance, topically applied lignocaine 4 mg kg⁻¹ may produce concentrations of 8 μg ml⁻¹, well in excess of the toxic value of 5.3 μg ml⁻¹ (Foldes et al., 1960), and bupivacaine 4 mg kg⁻¹ injected intercostally may result in blood concentrations of 1.87 μg ml⁻¹ which exceed the toxic concentration of 1.6 μg ml⁻¹ (Tucker and Mather, 1975). This must relate to modifying factors, particularly general anaesthesia and premedication with agents such as diazepam. Diazepam has been shown to have a protective influence on the toxicity of local anaesthetics (Moore, Balfour and Fitzgibbon, 1979) and general anaesthesia doubles the blood concentration at which toxic signs appear, to 10 μg ml⁻¹ for lignocaine (Bromage and Robson, 1961). Respiratory alkalosis, a frequent accompaniment of IPPV in children, also increases the toxic threshold, which has been shown to be reduced by acidosis (Moore, Thompson and Crawford, 1982) and hyperkalaemia (Avery et al., 1981).

The lung has an important role in absorbing up to 80% of an i.v. bolus of local anaesthetic during first passage, but in the case of right to left shunting (which is relatively more common as a result of congenital heart disease in the young) this effect can be bypassed, leading to potential CNS toxicity (Bokescb et al., 1985).

A distinction must therefore be made between patients younger than 1 year of age, particularly neonates, and older children. Great care should be exercised with the very young, and low doses of local anaesthetics should be used. Abajian and others (1984) have suggested that, in the very young, the small doses of local anaesthetic associated with spinal anaesthesia are much safer than subcutaneous infiltration with larger doses, particularly as the neonate has little subcutaneous fat. The older child is very tolerant of high doses of local anaesthesia. Bupivacaine 4 mg kg⁻¹ has been used safely for intercostal block (Rothstein et al., 1982) and lignocaine 11 mg kg⁻¹ was used by Takasaki (1984) for caudal anaesthesia without apparent side effects, although blood concentrations were not measured until 15 min after injection and therefore peak concentrations may have been missed.

Various parameters have been suggested for calculating doses in children, for example surface area, height and age. Every child in hospital, however sick, should be weighed, and we have found this to be the simplest and safest factor on which to base doses without complex calculations which are always open to error. A guide to maximum doses of local anaesthetics is shown in table I.

**INDICATION FOR LOCAL ANAESTHESIA IN CHILDREN**

**Sole anaesthetic**

Many children will accept a regional technique as the sole anaesthetic regimen. Caudal extradural

<table>
<thead>
<tr>
<th>Agent</th>
<th>Proprietary name</th>
<th>*Maximum safe dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignocaine</td>
<td>Lidothesin</td>
<td>7 mg kg⁻¹</td>
</tr>
<tr>
<td></td>
<td>Xylocaine</td>
<td></td>
</tr>
<tr>
<td>Prilocaine</td>
<td>Citanest</td>
<td>8 mg kg⁻¹</td>
</tr>
<tr>
<td>Bupivacaine</td>
<td>Marcain</td>
<td>2 mg kg⁻¹</td>
</tr>
<tr>
<td>Cinchocaine</td>
<td>Nupercaine</td>
<td>0.4 mg kg⁻¹</td>
</tr>
<tr>
<td>Etidocaine</td>
<td>Duranest</td>
<td>4 mg kg⁻¹</td>
</tr>
</tbody>
</table>

* These maximum safe doses are for plain solutions only; the addition of vasoconstrictor such as adrenaline may increase the permissible dose. Toxic symptoms may arise with small doses with intravascular injection or injection to a vascular area.
anaesthesia has been used in conscious neonates for ano-perineal procedures (Touloukian et al., 1971; Arthur, 1980b). Lumbar extradural and spinal anaesthesia have also been used in awake children, with up to 95% success (Serlo and Haapanemi, 1985). Upper limb blocks such as axillary block (Clayton and Turner, 1959; Dales et al., 1960; Eriksson, 1965) and i.v. regional anaesthesia (Carell and Eyring, 1971; Fitzgerald, 1976) have also been used effectively in unanaesthetized children.

**Combined local analgesia and sedation**

This is a most useful method of producing good operative conditions when formal general anaesthesia is contraindicated or unavailable. Melman, Penuelas and Marrufo (1975) sedated 200 patients with ketamine 1–2 mg kg⁻¹ i.v. before administering caudal extradural analgesia, following which most patients required no further sedation. Cardiac catheterization may be performed in children under a combination of local analgesia and sedation. This provides a quiet steady state with minimal changes in cardiopulmonary function. Eather (1975) described 1500 patients who had an axillary brachial plexus block combined with various forms of i.v. sedation. McGown (1982) described 500 African children who had caudal analgesia performed as the sole intra-operative analgesic, supplemented by heavy sedation which consisted of i.v. thiopentone titrated against the child’s movements. However, this was not always a satisfactory technique for upper abdominal surgery and this author now uses caudal analgesia combined with general anaesthesia with the trachea intubated. Aisenberg (1972) supplemented local anaesthesia of the extremities with nitrous oxide.

**Postoperative pain relief**

This is undoubtedly the most frequent indication for a local technique in paediatric anaesthetic practice. The problems associated with postoperative analgesia in general were highlighted in an Editorial (1975) which advocated the more frequent use of “single shot” local analgesia. Mather and Mackie (1983) drew attention to the particular problem of postoperative analgesia in children when they reported on the incidence of postoperative pain in children in two Australian hospitals. Sixteen per cent of children had no postoperative analgesia prescribed, and 30% of those who were prescribed opioid analgesia failed to receive any. Only 25% of children were pain free on the day of surgery and 17% reported severe pain on the first day after operation.

The two main groups at risk from receiving inadequate parenteral analgesia are neonates and infants (because of fear of overdose) and outpatients (because of fear of delaying ambulation and discharge from hospital). Local analgesia administered after induction of general anaesthesia can overcome these problems and provide a smoother postoperative course than is seen with opioid analgesia, although the few comparative studies performed to date do not unanimously favour local analgesia (table II).

The confidence placed in the beneficial effects of local analgesia compared with other methods is reflected by the number of recent publications comparing a regional technique with no analgesia (Goulding, 1981; Meignier, Sauron and Le Neel, 1983; Carlsson and Svensson, 1984; McNicol, 1985, 1986), different types of block (White et al., 1983; Yeoman, Cooke and Hain, 1983; Hannallah et al., 1984; Hatch, Hulse and Lindahl, 1984; Vater and Wandless, 1985) or different analgesic agents (Jensen, 1981; Jones et al., 1984).

**Preoperative pain relief**

Many acutely painful conditions, especially of the limbs, may be relieved by the use of a suitable regional block. The pain from a fractured shaft of femur can be abolished by a block of the femoral nerve, which relieves periosteal pain and reduces spasm of the quadriceps muscles (Grossbard and Love, 1979). Painful conditions of the fingers or hand can be eased by digital or metacarpal blocks. These techniques reduce the need for pre- and intra-operative opioid analgesia and allow time for the patient to be prepared for surgery, under general anaesthesia if necessary.

**Non-analgesic applications of regional blockade**

Kempthorne and Ratcliff (1983) and Kempthorne and Brown (1984) have described the use of tibial nerve blockade as an adjunct to physiotherapy treatment of equinus deformity in children who are recovering from severe brain damage and as a diagnostic tool in a child with an unusual gait from myotonia. Lynch and Johns (1985) have used axillary block to provide motor block in an infant to enable EMG studies to be undertaken. Sympathetic block by either stellate ganglion or brachial plexus block is of value if upper limb circulation is prejudiced following
TABLE II. Comparative studies of regional analgesia and parenteral opioid analgesia for postoperative pain relief in children

<table>
<thead>
<tr>
<th>Study</th>
<th>Block</th>
<th>Opioid</th>
<th>Surgical procedures</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lunn (1979)</td>
<td>Caudal extradural (bupivacaine)</td>
<td>Morphine</td>
<td>Circumcision</td>
<td>Better initial analgesia with caudal (1st 30 min after op.). More vomiting with caudal.</td>
</tr>
<tr>
<td>Shandling and Steward (1980)</td>
<td>Ileo-inguinal</td>
<td>Codeine phosphate</td>
<td>Hernia repair</td>
<td>Earlier mobilization and less vomiting (ns) in local group.</td>
</tr>
<tr>
<td>Bramwell, Bullen and Radford (1982)</td>
<td>Caudal extradural (bupivacaine)</td>
<td>Dihydrocodeine</td>
<td>Circumcision</td>
<td>Better initial analgesia (1st 2 h after op.) for circumcisions with caudal ($P &lt; 0.05$-$0.01$). No difference in pain relief between groups for hernia repair and orchidopexy. No difference in incidence of vomiting.</td>
</tr>
<tr>
<td>May, Wandless and James (1982)</td>
<td>Caudal extradural (bupivacaine)</td>
<td>Buprenorphine</td>
<td>Circumcision</td>
<td>Caudal better initially for pain relief (ns) and mobilization. More vomiting with narcotic group (&quot;significant&quot;); no $P$ value</td>
</tr>
<tr>
<td>Martin (1982)</td>
<td>Caudal extradural (bupivacaine)</td>
<td>Diamorphine</td>
<td>Circumcision</td>
<td>Better analgesia and mobilization, but only in first 1 h after op. ($P &lt; 0.02$-$0.01$). No difference in vomiting.</td>
</tr>
<tr>
<td>Blaise and Roy (1984b)</td>
<td>Caudal extradural (bupivacaine)</td>
<td>Codeine phosphate</td>
<td>Hypospadias repair</td>
<td>Better analgesia in local groups. No difference in vomiting.</td>
</tr>
<tr>
<td>Tree-Trakaran and Pirayavaraporn (1985)</td>
<td>Penile block (bupivacaine)</td>
<td>Morphone</td>
<td>Circumcision</td>
<td>No difference in pain relief, but better mobilization and less vomiting with local group.</td>
</tr>
</tbody>
</table>

trauma or following the creation of A-V fistulae for dialysis.

PREPARATION AND MANAGEMENT OF CHILDREN FOR LOCAL ANAESTHETIC PROCEDURES

Some older children may request a regional technique, particularly if previous experiences have been favourable (Serlo and Haapanemi, 1985) but, even if this technique is used in conjunction with general anaesthesia, a clear and detailed explanation of all that is involved must be given to the patient and, if possible, the parents, avoiding "white lies" (Pinkerton, 1981). The lack of sensation and motor blockade can cause as much distress in some children as the pain they replace.

The child should be told when to expect return of sensation and pain, which can then be treated.

A careful history should be taken and examination carried out to exclude any contraindications to local anaesthesia. These are:
- **General:**
  - Infection at the site of injection
  - Allergy to local analgesic agents
  - Bleeding disorders, including anticoagulant therapy
  - Neurological disease
- **Central blocks:**
  - Spina bifida and other spinal defects
  - Uncorrected hypovolaemia

The authors have experience of a young girl who received a brachial plexus block to improve blood
flow and provide postoperative analgesia following reduction of a 7-h old supracondylar fracture of the humerus. After operation the surgeon was unable to test for sensation and it was not until the block wore off that it was realized that a Volkmann's ischaemic contracture had developed.

**Premedication**

We recommend that patients are fasted even when a local technique is proposed, since general anaesthesia or heavy sedation may be required to supplement the block if this proves incomplete or if the patient becomes anxious or restless. Premedication may help, but should not be excessive otherwise any benefit of local as opposed to general anaesthesia may be lost. Among the more popular agents are the oral preparations of trimethobenzamide 2-4 mg kg<sup>-1</sup> or diazepam 0.4 mg kg<sup>-1</sup> in association with droperidol 0.2 mg kg<sup>-1</sup>. For more painful procedures the following are suitable: Toronto mixture (Smith, Rowe and Vlad, 1958) (that is pethidine 25 mg, promazine 6.25 mg and promethazine 6.25 mg in 1 ml) given in a dose of 0.1 ml/kg body weight or papaveretum and hyoscine given i.m. in a dose of papaveretum 1 mg and hyoscine 0.02 mg per 3 kg body weight.

Certain techniques, for example IVRA, require large volumes of local anaesthetic agents and therefore it is imperative that adequate venous access is established before the block is carried out. The same principle applies when blocks with possible cardiovascular instability (e.g. spinal, extradural) are carried out.

The surgeon and nursing staff should be aware of the technique being used, so that operating theatre care of the patient is appropriate and postoperative care also can be modified accordingly. For instance, not only will postoperative pain be relieved, but also pain from causes such as tight plaster casts. The authors have experience of one child who developed a transient sciatic nerve palsy from a hip spica pressing on the buttock, which was not detected until the caudal extradural block wore off. Figure 1 shows a similar complication.

Local blocks should comprise only the first step in the process of providing postoperative analgesia and it is our policy to prescribe oral analgesics 4-6 hourly as routine practice, whether or not the patient has complained, to prevent the onset of severe pain as the block wears off.

Minor analgesics such as paracetamol elixir 10-15 mg kg<sup>-1</sup> may be useful, but dihydrocodeine 0.3-0.5 mg kg<sup>-1</sup> is more dependable. Patients are also prescribed papaveretum 1 mg per 3 kg body weight i.m. if the afore-mentioned regimen proves ineffective.

**SPECIFIC TECHNIQUES**

**Central Blocks**

**Anatomical and physiological considerations**

Figure 2 illustrates important differences between a neonate and an adult. The smaller the infant, the more caudally should a lumbar puncture be performed, and it is not technically difficult to do this at the L4 or L5 space.

Infants and children weighing less than 15 kg have a relatively high volume of CSF, 4 ml/kg
Fig. 2. Age-related differences in the anatomy of the spinal cord and meninges. The tip of the spinal cord is at L3 at birth and does not assume the adult's position of the L1–2 space until approximately 1 year. The meninges remain at the S1–2 foramina throughout this period. However, there is some individual variability and both the cord and the meninges may extend further down the vertebral canal. The sacrum of the neonate is flatter and narrower than that of the adult.

Body weight, compared with adult values of 2 ml/kg body weight and, according to Gouvia (1970), this accounts for the fact that infants require proportionately more local anaesthetic than older children and adults.

Schulte-Steinberg (1980) has stated that the contents of the extradural space of the newborn and small child differ from those of the adult in that, instead of having mature densely packed fat lobules, divided by fibrous strands, they have spongy, gelatinous lobules with distinct spaces. He proposes that such juvenile extradural fat offers less resistance to longitudinal spread of injected solutions, with resultant widespread neural block.

There are important differences between small children and adults in the physiological effects of central blocks. It is a constant finding that the incidence of clinically significant hypotension following spinal or extradural anaesthesia is less than in adult patients. Slater and Stephen (1950) remarked upon this phenomenon found in 160 patients using amethocaine. There was an initial decrease in arterial pressure of 10–20 mm Hg lasting only 10 min. Berkowitz and Greene (1951) reported on 350 patients younger than 13 yr to whom they routinely administered a vasoconstrictor “even though it is usually unnecessary” and Ruston (1964) commented on the stability of the small child’s cardiovascular system following high lumbar extradural block. Arthur (1980a) confirmed this cardiovascular stability after thoracic extradural blocks. There were no valid studies dealing with age-related changes in arterial pressure associated with spinal analgesia until Dohi, Naito and Takahashi (1979) observed that children younger than 5 yr showed little or no change in arterial pressure and heart rate following sensory blockade to the T3–T5 level using amethocaine 0.3 mg kg\(^{-1}\) with phenylephrine, whereas the cardiovascular response of children older than 6 yr resembled that of adults with widely variable degrees of hypotension. They postulated not only that this resulted from immaturity of the sympathetic nervous system in small children, but also that the lower extremities in such children accounted for proportionately less volume than those in adults and, therefore, proportionately less blood was sequestered during sympathetic block. Infants and neonates may, however, be at risk from other effects of high blocks. They are more dependent on the diaphragm than older children and blocks involving the lower cervical nerve roots can result in profound respiratory depression during spontaneous respiration.

**Spinal anaesthesia**

Gouvia (1970) recommended hyperbaric 5% lignocaine in doses of 2 mg kg\(^{-1}\) decreasing to 1 mg kg\(^{-1}\) for children aged 3–10 yr, while Melman, Penuelas and Marrufo (1975) used 1.5–2 mg kg\(^{-1}\) without reference to age differences. Berkowitz and Greene (1951) used 1% amethocaine in a dose of 0.2 mg kg\(^{-1}\) or 1 mg yr\(^{-1}\), and 0.5% nupercaine 0.02 ml kg\(^{-1}\) or 0.1 ml yr\(^{-1}\), with consistent results, the solutions being made hyperbaric by the addition of an equal volume of 5% procaine hydrochloride. More recently, Abajian and others (1984) administered 1.0% amethocaine 0.2–0.3 mg kg\(^{-1}\) in 10% dextrose to small premature babies. Blaise and Roy (1984a) used isobaric 1.0% amethocaine 0.4–0.5 mg kg\(^{-1}\) for babies aged 0–12 weeks, 0.3–0.4 mg kg\(^{-1}\) for 12 weeks – 2 yr and 0.2–0.3 mg kg\(^{-1}\) for those older than 2 yr. Both these groups of workers confirmed the safety of this technique in small, high risk patients.

Intrathecal morphine has not been assessed fully in paediatric practice. Cairns (personal communication) used morphine 20 μg kg\(^{-1}\) to provide intraoperative analgesia as an adjunct to “wake up” tests during major spinal surgery, but
postoperative respiratory depression 9-10 h after administration of morphine, and an unacceptably high incidence of vomiting, caused him to adopt more conventional techniques.

Jones and others (1984) assessed the technique as a method of preventing postoperative pain in spontaneously breathing patients who were recovering from open heart surgery. A dose of 30 µg kg\(^{-1}\) was associated with unacceptable respiratory depression in 25% of the patients, while a lower dose of 20 µg kg\(^{-1}\) caused respiratory depression in 10%. Vomiting occurred in 20% of patients, but the quality and duration of analgesia were considered to be good in all patients. However the postoperative assessment was complicated by the preoperative and intraoperative use of parenteral opioid analgesics.

Extradural anaesthesia

All vertebral segments except the cervical have been used for extradural analgesia in paediatric practice.

Lumbar extradural block has been used extensively and advocated enthusiastically by Ruston (1954, 1957, 1964) using, initially, a "single shot" in sedated patients, but evolving into continuous anaesthesia in selected patients ("large infants and children"). The limiting factor for deciding upon the feasibility of continuous anaesthesia has been that an 18-gauge is the smallest extradural needle able to take an indwelling catheter. However, Meignier, Souron and Le Neel (1983) have successfully performed continuous lumbar analgesia with an 18-gauge needle in a small group of high risk children whose weights varied from 4.6 to 15 kg.

Although Ruston (1957) considered that there was a linear relationship between patients' weight (lb) and volume of 1% lignocaine required to produce somatic block to consistent levels, it was Bromage (1969) who constructed the age-dose curve for patients aged from 4 to 20 yr, and he concluded that 0.1 ml yr\(^{-1}\) of 2% lignocaine with adrenaline was required to block each spinal segment.

The technique of lumbar extradural in children is similar to that in adults. The L4-5 or L3-4 spaces may be used in infants. Identification of the extradural space is best accomplished with air or, as Ruston advocates, by using the hanging drop method. We do not recommend that saline is used, since this may dilute the very small volumes of local anaesthetic used. An 18-gauge Tuohy needle is used for continuous extradural blocks, but a 22-gauge needle may be used for "single shot" anaesthesia. Although local anaesthetics are most commonly used for this block, Ecoffey, Attia and Samii (1985) produced long analgesia (19 ± 6 h) using morphine 50 µg kg\(^{-1}\) in 11 children with no major complications, although nausea, pruritus and urinary retention were noted. The same group of workers (Attia et al., 1985) have studied the pharmacokinetics following lumbar extradural morphine in five children and concluded that the long duration of analgesia, associated with a rapid decrease in morphine plasma concentration, was consistent with the action of the morphine being non-systemic, as it is with adults.

Thoracic extradural block. The authors have used this technique for postoperative analgesia in poor risk patients following thoracic and upper abdominal surgery. Arthur (1980a) described its use specifically in an attempt to prevent the increase in arterial pressure following repair of coarctation of the aorta and although the blocks produced excellent analgesia, he could not produce hypotension despite using large volumes of bupivacaine (fig. 3). Ecoffey, Attia and Samii (1985) have also used morphine for this block with good effect, but only five patients were studied.

The midline is easier than the lateral approach for this block, with the patient in the left lateral position and the spine flexed, and the 18-gauge Tuohy needle is inserted between the thoracic spines at 45° to the skin. This increases the effective depth of the extradural space available for the bevel of the needle (Massey-Dawkins and Steel, 1971). A further advantage is that the rounded part of a Tuohy needle impinges on the dura rather than the sharp end, as occurs in a lumbar extradural block when the approach is at 90° (fig. 4). The points of injection are T5-7, as in adult practice.

It should be remembered that, although the cardiovascular systems of young patients may be resistant to the hypotensive effects of local analgesics, there should be no temptation to exceed the estimated dose for the number of segments to be blocked, since upward spread of local analgesic may affect the lower cervical segments, with resultant diaphragmatic paralysis.

Caudal extradural block. This is the central block most commonly used in paediatric practice.
Campbell (1933) is credited with the first series of paediatric caudal blocks when he used it successfully in 83 children aged 5–14 yr for cystoscopy, but it was not for another 30 years that it gained popularity when Spiegel (1962) described its use in 124 consecutive operations on children varying in age from 2 days to 14 yr, this despite the fact that he reported 29 failures (23.2%). Fortuna (1967) reported on 170 children whose ages varied from 1 day to 10 yr. Anaesthesia was satisfactory in 156, but nine failed and five required supplementary heavy sedation or general anaesthesia in addition. He described caudal anaesthesia to be “a simple and safe technique in paediatric surgery” despite the fact that 5.5% of the patients in this study developed complications during the procedure, including convulsions, bloody taps, delirium, vomiting, unrecognized spinal block and transient apnoea. However, these were all treated expertly and there were no deaths. Further papers

The anaesthetic agent is injected via the sacral hiatus, which is formed by the failure of fusion of the 5th sacral vertebral arch. It is palpated easily in children as a triangular shaped depression bounded on either side by the sacral cornua. Unlike that in adults, the covering of the hiatus, the sacrococcygeal membrane, is uncalcified and is felt easily like a tight drumskin if pressed and this provides a large target. The two main reasons for failed caudal block are failure to identify the hiatus and using an insufficient volume of local anaesthetic.

There are three main methods of identifying the hiatus. With the patient in the left lateral or knee-chest position, a finger is run down the tips of the thoracic and lumbar spines towards the sacrum, where the sacral hiatus may be palpated. Figure 5 shows two other methods whereby the sacral hiatus can be detected. The sacral hiatus is found at the apex of an equilateral triangle based on a line drawn between the two posterior superior iliac spines or, alternatively, the hiatus can be found on a line drawn through the middle of the thigh with the leg flexed at a right angle. There are different views on how the needle should be inserted through the sacral hiatus. Brown and Fisk (1979) insert it at an angle of 20-40 ° to the skin. Arthur (1980b) observed that the sacral canal is narrower in the child and the sacrum is less curved. Consequently, he recommends insertion of a 23-gauge needle at 45 ° to the skin with the caveat that it should not be rotated up the canal as is the practice in performing adult caudal blocks, since the dura may end below S2. Schulte-Steinberg (1980) used a short-bevelled 21-gauge needle inserted at 65-70 ° to the skin and then turned the bevel round till it pointed caudally. After aspiration to exclude bone marrow, dural puncture or venepuncture, a test dose of 1 ml of local analgesic was given using the “bounce test”. The barrel of the syringe was bounced down rapidly and the thumb removed. If the barrel bounced back then the needle point was probably not in the sacral canal. If it remained down, injection of local anaesthetic was commenced and this should be possible without resistance to injection. The majority of early failures using this technique appear to have been because of insufficient volume of local anaesthetic used, and many formulae have been devised to overcome this problem.

In an attempt to produce consistent anaesthesia above the level T10, Spiegel (1962) used the formula \( V = 4 + \left(\frac{D - 15}{2}\right) \), where \( V \) was the total volume of the anaesthetic agent (ml) and \( D \) was the distance (cm) between the tip of the spine of C7 and the sacral hiatus. However nine of his 29 failures were because the level of anaesthesia was below that required for surgery.

The length of the child was also used in a recent study by Satoyoshi and Kamiyama (1984), who produced anaesthesia up to the T4–5 level for upper abdominal surgery. They concluded that Spiegel’s formula could be modified to \( V = D - 13 \).

Studies by Schulte-Steinberg and Rahlfs (1970,
1977) investigated the relationship between age, weight and height of children on the effects of predicting the spread of 1% lignocaine and they found the highest correlation between age and dose, with weight next and then height, although it should be noted that all three parameters correlated well with the dose of local anaesthetic. Hain (1978) modified Schulte-Steinberg and Rahlfs' original graphs to the formula:

\[
\text{Volume of local} = \frac{\text{Age (yr)} + 2 \text{ ml per segment to be blocked}}{10}
\]

and the authors have used this scheme over the years, to good effect. Armitage (1979) took advantage of the correlation between body weight and volume of analgesic by advocating the use of 0.25% bupivacaine (plain) 0.5 mg kg\(^{-1}\) for sacral block, 1 mg kg\(^{-1}\) to block the lower thoracic nerves and 1.25 mg kg\(^{-1}\) to block up to the mid-thoracic region. If this regimen results in a volume of local analgesic in excess of 20 ml, he reduces the bupivacaine concentration to 0.19%. The addition of adrenaline 1:200000 has been shown to increase the duration of the block (Warner et al., 1985), especially in children younger than 5 yr, in whom it may increase duration by a factor of 2.

Information on extradural morphine administered caudally is scanty, but Jensen (1981) compared 0.25% bupivacaine with morphine 50 ng kg\(^{-1}\) and found that the latter produced longer analgesia with no complications. Martin (1982) found that it was not superior to bupivacaine or parenteral diamorphine.

Complications of caudal extradural block are rare, but potentially very serious. Total spinal block, convulsions and bloody taps have already been noted above. Intra-osseous injection can result in a rapid increase in plasma concentrations of local analgesic and, if the needle point is inserted beyond the ventral wall of the sacral canal, intrapelvic injection may result. Other potential complications include bleeding with haematoma formation, infection and the catastrophic complication of permanent neurological damage estimated at 1 in 20 000 (Massey-Dawkins, 1969).

Following caudal block, postoperative vomiting seems to be troublesome. In the study of Vater and Wandless (1985), 30% of patients vomited and this is in general agreement with other workers (Lunn, 1979; May, Wandless and James, 1982; Martin, 1982; Yeoman, Cooke and Hain, 1983).

Motor blockade of the bladder and limbs may be a problem. Yeoman, Cooke and Hain (1983) noted that 31% of their patients were unable to walk 6 h after receiving a caudal block using 0.5% plain bupivacaine in a dose of 1 ml yr\(^{-1}\)+2 ml. Armitage (1979) argued that this is only to be expected if 0.5% bupivacaine is used, and it is to avoid this unpleasant side effect that he used 0.25% bupivacaine. However, Vater and Wandless (1985), using 0.25% bupivacaine 0.5 ml kg\(^{-1}\) found a significantly greater number of boys who were unable to stand unaided 2 h after circumcision, compared with a similar group who had a block of the dorsal nerve of the penis. Blaise and Roy (1984b) noted that a group of children receiving caudal analgesia 1 ml yr\(^{-1}\) with 0.5% bupivacaine with adrenaline for postoperative pain relief following circumcision were able to move their legs, but they did not challenge those children by asking them to stand or walk.

Vater and Wandless (1985) and Yeoman, Cooke and Hain (1983) showed that a significantly greater number of boys in their caudal block group were unable to pass urine within 4 h of surgery. These disadvantages have encouraged us to use more peripheral nerve blocks, but caudal extradural block remains the authors' choice of analgesia for supplementing general anaesthesia and providing postoperative pain relief following circumcision were able to move their legs, but they did not challenge those children by asking them to stand or walk.

In general there are no peripheral nerve blocks that are used routinely in adults that cannot be used in children, although the techniques may differ.

**Peripheral nerve blocks**

**Upper abdomen**

Intercostal nerve block is indicated not only for postoperative pain relief, but also for the relief of pain following chest injuries. Blocking the upper six nerves provides analgesia to the chest wall and the lower six, to the abdomen. The technique of performing these blocks in children is the same as with adults, except that the needle is passed under the edge of the ribs for only 1–2 mm. They can also be performed from inside the chest at thoracotomy. The authors have used 0.5% bupivacaine + adrenaline up to 2 mg kg\(^{-1}\) for this block, but Rothstein and others (1982) found that 4 mg kg\(^{-1}\) of the same agent did not produce evidence of toxicity although peak concentrations appeared
very rapidly. It must be remembered that, if this block is used for postoperative pain relief for a midline upper abdominal incision, a bilateral block is required. The main complication is pleural puncture, and care should be taken to avoid this since even a small pneumothorax may be clinically significant in a small child.

**Lower abdomen**

*Ileo-hypogastric and ileo-inguinal nerve blocks*. Figures 6 and 7 shows the anatomy and techniques of these blocks. They are used exclusively for postoperative pain relief following orchidopexy or inguinal hernia repair. Shandling and Steward (1980) performed 81 such blocks with three suspected failures, while McNicol (1982) reported on 50 consecutive blocks with no failures. Hannallah and others (1984) compared them with caudal analgesia for the control of post-orchidopexy pain relief and concluded that both methods produced similar analgesia. It is important to remember that these blocks are insufficient for procedures unsupplemented by general anaesthesia.
**Penile block.** There has been more discussion of penile block than any other paediatric peripheral nerve block, presumably because of the frequency of performing circumcision and the assumption that it is an exceptionally painful procedure. However, the findings by Lunn (1979), Bramwell, Bullen and Radford (1982), May, Wandless and James (1982) and Martin (1982) suggest that severe pain lasts only for the first 2–3 h after operation, hence the success of Tree-Trakaran and Pirayavaraporn (1985) with topical lignocaine applied to the penis. Goulding (1981) produced analgesia in excess of 6 h when bupivacaine was used and Yeoman, Cooke and Hain (1983) and Vater and Wandless (1985) found this block to be superior to caudal analgesia. Tozbikian, Tozbujo-kov and Roberts (1983) performed 300 blocks in association with general anaesthesia, all of which were assessed as successful with no complications. However, Blaise and Roy (1984b) found that caudal analgesia was better for hypospadias repair, but this may be because penile block provides anaesthesia only for the distal two-thirds of the penis. Bacon (1977) described the “single shot” midline block used by the authors and shown in figure 8. Soliman and Tremblay (1978) avoided the risk of potential haematoma by using a single shot lateral approach. Dosage of local analgesic for this block is shown in table III. The authors use 0.5% bupivacaine. *No adrenaline should be used for this block.* Sara and Lowry (1984) drew attention to a potential complication of this block when they described two patients with suspected reduced blood flow to the skin of the glans penis. The most common complication is haematoma formation as a result of puncturing the dorsal vein. However, this can be minimized by applying pressure on the base of the penis for a few minutes following the block.

**Lower limb blocks**

Some of the most painful operative procedures in paediatric practice are on the lower limbs and

<table>
<thead>
<tr>
<th>Age group</th>
<th>Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neonates</td>
<td>0.5 ml</td>
</tr>
<tr>
<td>1 yr</td>
<td>1.0 ml</td>
</tr>
<tr>
<td>6 yr</td>
<td>2.0 ml</td>
</tr>
<tr>
<td>12 yr</td>
<td>4.0 ml</td>
</tr>
</tbody>
</table>
although mention is made of them in paediatric text books (Brown and Fisk, 1979) there were no series of such blocks until recently. Kempthorne and Brown (1984) described in detail blocks of the tibial and common peroneal nerves in the popliteal fossa, but unfortunately failed to quote a success rate and gave no details of the patients or operative procedures.

**Sciatic nerve block—anterior approach.** McNicol (1985) described a series of 82 children who had an anterior sciatic nerve block for the control of postoperative pain following procedures on the foot and ankle, 78 of which were judged to have been successful. Great reliance was placed on the loss of resistance felt as the needle point passed through the adductor muscles into the neurovascular compartment. Bupivacaine 0.5% 0.5–1.0 mg kg\(^{-1}\) was used and there were no complications.

**Blocks of femoral and lateral cutaneous nerve of the thigh.** McNicol (1986) described combined blocks of femoral nerve and lateral cutaneous nerve of the thigh to relieve pain following surgery on the thigh, such as taking of skin for grafts for burns and major femoral surgery. Fifty blocks were performed, with two failures. The femoral artery was entered accidently on three occasions, but no haematoma developed. Other potential and rare complications of both these blocks are hypoanaesthesia or dysesthesia. The techniques are similar to those used in adult practice and the distribution of analgesia is shown in figure 9. In the same way as there seems to be a devolution from central to peripheral blocks, there is also a move away from proximal nerve blocks to distal smaller nerve blocks. Metatarsal blocks are shown in figure 10. These are useful following all forefoot surgery, including Leslie–Mitchell osteotomies, tendon transfers and removal of accessory digits. Sural nerve block is used with great effect to control the postoperative pain following calcaneal osteotomies.

**Upper limb blockade**

**Brachial plexus block.** The majority of young children will require sedation or general anaesthesia in addition to a block. Any technique which requires paraesthesia for success will be of little value in the child. The paraesthesiae associated with supraclavicular or interscalene brachial plexus block can cause extreme discomfort in adults and are certain to reduce or abolish co-operation in the young patient. The effects of accidental pneumothorax are much more profound in the young infant because of the reduced pulmonary reserve, increased closing volume to FRC ratio (Mansell, Bryan and Levison, 1972) high airways resistance and low lung compliance. Unilateral block of the phrenic nerve may also cause respiratory failure in the very young who are totally reliant on the diaphragm for ventilation, and accidental block of the recurrent laryngeal nerve may cause an undue increase in airways resistance as a result of cord paralysis (Arthur, 1983). Accidental block of these nerves is more
TECHNIQUES IN PAEDIATRIC SURGERY

FIG. 10. Metatarsal block: technique. A third metatarsal block is being performed to relieve pain following a tendon transfer to cure a curly third toe. The needle is inserted at the medial side of the base of the metatarsal bone until it is felt on the sole of the foot. Following aspiration local analgesic is injected until it is felt as a swelling on the sole. The needle is slowly withdrawn as more local analgesic is injected. The procedure is repeated on the other side of the metatarsal. Plain bupivacaine is the agent of choice.

likely using the supraclavicular approach in the small patient because of their proximity to the brachial plexus. This approach is also potentially dangerous because the cartilagenous nature of the first rib in the young patient is a less efficient landmark or barrier for the pleura (Eather, 1975).

The most satisfactory block for the arm in a child is brachial plexus block by the axillary approach. This technique does not require paraesthesia for success and so can be used in association with general anaesthesia. Prolonged analgesia can be achieved using bupivacaine which provides good postoperative pain relief for up to 8–10 h or even longer if an indwelling cannula is used to allow top-up doses. This can be of advantage if continuing motor paralysis is required following hand surgery for the correction of congenital malformation in the young infant.

The technique is well described and the single needle technique is best, using the immobile needle (Winnie, 1984). A 23-gauge butterfly type needle is suitable, although a short bevelled needle gives a better “feel” as the axillary sheath is penetrated. The absence of fibrous septae in the connective tissue within the axillary sheath allows better spread of anaesthetic agents, giving a more complete and a much higher block. It is not unusual to cause Horner’s syndrome in a child from an axillary block, particularly if the sheath is occluded distal to the site of injection by the anaesthetist’s finger, which is more effective than a tourniquet (fig. 11) and the arm is adducted to 45° or less following the injection (Winnie et al, 1979).

Several reports indicate the value of axillary block in children (Clayton and Turner, 1959; Dales et al., 1960; Eriksson, 1965). Although Winnie (1975) determines the volume of agent in relation to height, weight is an obligatory parameter in a children’s hospital and Eriksson has used weight as the basis for dose volume.

The authors have found a dose of local anaesthetic of 0.5 ml/kg of body weight to be safe and successful, care being taken not to exceed the total mg kg⁻¹ dose of drug.

In addition to analgesia, axillary block may be used as a sympathetic block to improve blood flow following fractures of the arm and also following the establishment of arterio-venous shunts for haemodialysis. It has also been used to produce motor blockade to enable electromyography to be carried out in an infant (Lynch and Johns, 1985).

Peripheral nerve blocks. Nerve blocks of the median, radial and ulnar nerves can be carried out at the wrist in children. Digital nerves can be blocked using ring blocks, but metacarpal blocks are simpler and safer, especially with small fingers.

I.v. regional anaesthesia (IVRA) has been used successfully in children (Carell and Eyring, 1971; Fitzgerald, 1976). There has been much debate concerning the use of this technique, particularly following the death of healthy patients in each of whom the drug implicated was bupivacaine (Heath, 1982; Moore, 1984). As a result, the
Committee on the Safety of Medicines (1983) recommended that this drug should no longer be used for IVRA.

Before this it was proposed that the technique should be abandoned, as a result of side effects from the use of lignocaine (Editorial, 1965; Kennedy et al., 1965). Serious side effects have not been reported following the use of 0.5% prilocaine plain and this must be regarded as the agent of choice for IVRA in a dose of 0.5 ml/kg body weight. A large volume of a potentially dangerous agent is injected to the vascular system and therefore precautions must be taken. It has been shown that, even with an intact tourniquet, toxic symptoms may be produced as a result of leakage under the tourniquet (Rosenberg et al., 1983). It is important, therefore, to have good venous access at another site. This reduces the number of young patients willing to accept the technique. The tourniquet must be tested and be seen to be working correctly and, because of the potential hazards of the use of IVRA, we cannot recommend its use in patients with full stomachs.

In the majority of the fatal cases, the blocks were administered by senior house officers in accident & emergency departments without other medical assistance. It cannot be stressed too strongly that for all local techniques the knowledge and ability to treat the complications and side effects of local anaesthetics is essential.

Other Blocks of Value in Children

Local anaesthesia can be used successfully for dental treatment in very young children, particularly using the newer 27- and even 29-gauge needles with a gentle approach and good technique.

Plastic procedures are frequently carried out on the pinna of the ear and a great auricular nerve block is of great value as ear operations appear to be associated with an inordinate amount of discomfort when compared with other procedures (Burtles, 1982). This nerve is blocked as shown in figure 12 and this will provide analgesia for 6-8 h following prominent ear surgery. If surgery is continued onto the upper one-third of the outer surface of the ear, the auriculotemporal branch of the mandibular nerve can be blocked anterior to the pinna and above the external auditory meatus (Eriksson, 1979).

The most frequently used local anaesthetic technique in children is that of local infiltration. It is important to be aware of the total doses of local anaesthetic agents and not to exceed these, which is particularly easy to do in the very young. In certain circumstances, a nerve block using a
smaller volume may be preferable or general anaesthesia should be considered as an alternative. As with dental anaesthesia, the child will have a high endogenous catecholamine concentration, so that added adrenaline should be avoided if possible but, where used, restricted to a concentration of 1:200,000. Excessive adrenaline will produce an increased incidence of tachycardia, hypertension and anxiety. Angina is unlikely in paediatric patients, but in those with congenital heart disease arrhythmias may occur.

**Adrenaline should never be used around the fingers, toes and penis.**

Topical local anaesthetic preparations have been developed to reduce the pain associated with venepuncture and setting up i.v. infusions. A mixture of lignocaine and prilocaine crystals form a Eutectic mixture of local anaesthetic (EMLA) which provides more active anaesthetic agent than emulsions of the individual local anaesthetics (Ehrenstrom Reiz and Reiz, 1982; Hallén and Uppfeldt, 1982). These proved successful but require approximately 1 h to become fully effective, thus restricting their use to elective procedures. Tree-Trakaran and Pirayavaraporn (1985) have used topical anaesthesia with lignocaine gel for circumcision and has found the resulting analgesia to be as effective as caudal anaesthesia.

**CONCLUSION**

The choice of technique for local anaesthesia in children may be governed by the addition of general anaesthesia. Techniques requiring paraesthesia for success will be of no value. Central blocks, axillary block and the anterior approach to sciatic nerve block are examples of useful blocks in paediatric practice. The authors agree with the view that, under most circumstances, peripheral blocks are preferable to central blocks (Brown, 1985). Physiological and pharmacological differences (particularly in children younger than 3 yr) must be taken into account when using local anaesthesia and great care exercised with technique to avoid overdosage. Local anaesthetic techniques are of great value in paediatric surgery, either as the sole anaesthetic or, more frequently, to provide postoperative analgesia.

**ACKNOWLEDGEMENTS**

The authors gratefully acknowledge the assistance given by the Departments of Medical Illustration at the Royal Hospital for Sick Children and Canniesburn Hospital, Glasgow, and by Miss E. Hamill and Miss S. Sandeman for secretarial services.

**REFERENCES**


Touloukian, R. J., Wugmeister, M., Pickett, L. K., and Hehre,


