Chapter 2: Literature review

2.1) Paediatric caudal epidural block

2.1.1 Introduction

Caudal epidural blocks are the most widely used regional anaesthetic technique for any procedure on the lower part of the abdomen and lower limbs, especially in neonates, infants, and certain high-risk children (Dalens, 1995). The popularity of this procedure seems to be due to the presence of clearly defined anatomical landmarks, safety, ease of performance, and availability of data on doses and pharmacokinetics of local anaesthetics in infants and older children (Fortuna, 1967; Kay, 1974; Lloyd-Thomas, 1990; Dalens & Mansoor, 1994; Dalens, 1995; Giaufre *et al.,* 1996; Berde, 1996; Ivani *et al.,* 2000; Markakis, 2000).

A similar situation exists in South Africa where 63.75% of the participants in a survey on paediatric regional anaesthesia stated that they performed caudal epidural blocks in their anaesthesiology practice. The participants also felt that an adequate knowledge of anatomy is important to minimise complications and difficulties and improve the confidence levels of the anaesthesiologist performing the caudal epidural block (van Schoor, 2004).

2.1.1.1 History of caudal epidural blocks

Although Cathelin (1901) was the first to describe the caudal epidural block in adults, it is thought that Campbell (1933) was the first to perform caudal epidural blocks on children. He reported 83 cases of endoscopic interventions for bladder and urethral procedures. Campbell claimed no post-operative complications with a very high success rate of 90%.

Three decades later Fortuna (1963) reported 38 instances of poor-risk paediatric patients managed under caudal analgesia, without any complications, or failed analgesia. His results demonstrated that the technique had many advantages and started a trend that, during the next two decades, spread throughout the entire world. Today caudal epidural blocks have surpassed all others to become the most performed procedure in paediatric regional anaesthesia (Gunter, 1991; Giaufre *et al.,* 1996).

Spiegel (1962) performed 128 caudal blocks in children; all scheduled for infra-umbilical operations and had a failure rate of 23.2% in obtaining satisfactory analgesia. He used height as a guide to the dose required to obtain a level above T10. The formula was:

$$V = 4 + \frac{(D - 15)}{2}$$

V is the volume in ml and D is the distance between C7 and the sacral hiatus in cm.

Fortuna (1967) published the results of 170 caudal blocks in paediatric patients. In this series, 91.7% obtained adequate analgesia. There were two patients who experienced convulsions due to an overdose of the local anaesthetic solution, two bloody punctures and one accidental total spinal. All were treated immediately and did not develop any permanent sequelae.

The use of caudal anaesthesia for post-operative pain control in children was first proposed by Kay (1974). In this study, performed caudal epidural blocks for 300 cases of circumcisions. He claimed good results and advised that this approach is a safe, effective and reliable method for pain management after paediatric surgery. There was no mention of any transitory residual motor block in these children, which would have forced them to stay longer in the post-operative unit.

Melman (1975) published 200 cases of regional anaesthesia in children, most of them caudal epidural blocks, without any significant complications. McGown (1982) related his experience of performing 500 caudal epidural blocks on children. Although he praised the technique, he reported four deaths and four cardiac arrests. In the same article, he attributed the high index of complications on the fact that those were the first patients on whom he had carried out the procedure. He also commented that the following series of 400 caudal blocks did not produce any serious sequelae and achieved an overall success rate of 97.2%.

Later, Broadman and co-workers (1987) described 1154 caudal epidural blocks performed on children without the occurrence of any deaths or neurological sequelae. In 1988, Silva (1988) reported his experiences of performing 4416 caudal epidural blocks at the International Symposium of Regional Anaesthesia (ISRA) in Williamsburg, United States of America. He concluded that, although there were a few complications, there were no deaths.

Currently caudal and lumbar epidural blocks are considered to be safe and easy to perform. This statement is based on information obtained in 1996 when the French Paediatric Society of Anaesthesia (ADARPEF) presented an analysis of 84 412 anaesthetic procedures, of which 24,409 had been managed with local anaesthesia or by regional block procedures. Fifty per cent of the latter were caudal epidural blocks, followed by lumbar, thoracic epidurals and spinal anaesthesia. The only complications reported were eight cases of dural perforation with four accidental spinals, two occurrences of convulsions (due to inadvertent vascular injection) and one of rectal penetration. The other complications were minor. The main feature in this large number of patients was that no neurological sequelae were observed and no deaths occurred (Giaufre *et al.,* 1996).

Similar results were obtained by Gunter (1991), who reported a survey of 158 229 caudal epidural procedures carried out in 192 different hospitals in the USA. He also found that no deaths could be related to the procedure in this large group. Adverse events were registered in 16 subjects, represented by two total spinals, two syringe swaps, two rectal penetrations, two dysrhythmias, six incidences of hypotension, two convulsions and one cardiac arrest. No epidural haematoma or infection was observed.

Needles, with stylets, are now preferred for conducting caudal epidural blocks. Some prefer using an IV needle with a plastic cannula, which allow easy introduction of catheters and decreases the incidence of bloody punctures. At the same time, epidermal cells are not carried into the epidural space that could subsequently produce an epidermal tumour related to the technique – a risk present when simple hypodermic needles are used for the injection (Dalens & Hasnasqui, 1989)

2.1.1.2 Advantages of paediatric vs. *adult caudal epidural blocks*

There are a number of inherent advantages that caudal epidural blocks, performed on paediatric patients, have over performing the same procedure on adults.

Jankovic & Wells (2001) contended that, the anatomical landmarks are easier to locate in children, which makes for easier orientation by the anaesthesiologist, thus decreasing time required for puncture. Also, perforation of the sacrococcygeal membrane (or ligament) is more clearly palpable (Eather, 1975; Jankovic & Wells, 2001) and there is a better distribution of the injected local anaesthetic solution than in adults (Busoni & Andreuccetti, 1989). It is easier to advance the epidural catheter in children than in adults, which allows for higher positioning of the catheter. This was demonstrated by Bosenberg and co-workers (1988) who successfully threaded an epidural catheter via the caudal route to the thoracic level of children undergoing biliary duct surgery. They believe that this technique could be used as a safe alternative route of access to the thoracic and upper lumbar epidural spaces in small infants.

Bosenberg (1998) reported that the recovery phase after anaesthesia is very rapid, because only light supplementary general anaesthesia is needed and no muscle relaxants are used. This reduces the need for opioids and therefore the occurrence of side effects such as nausea, vomiting and/or urinary retention.

With experience, caudal epidural blocks are technically much simpler in anaesthetised children than in adults, and the blockade produced is much more predictable (McGown, 1982).

2.1.2 Indications & contraindications

2.1.2.1 Indications

Surgical indications

The caudal epidural block provides excellent intra- and postoperative analgesia for almost all surgical interventions on the lower part of the abdomen and lower limbs, especially in neonates, infants, and certain high risk children (Fortuna 1967; Eather 1975; Melman *et al.* 1975; Armitage 1979; Arthur 1980; Kester Brown & Schulte-Steinberg 1980; Bramwell *et al.* 1982; McGown 1982; Arthur & McNicol 1986; Broadman 1987; Berde 1989; Dalens & Hasnaoui 1989; Sethna & Berde, 1989; Yaster & Maxwell 1989; Lloyd-Thomas 1990; Dalens, 1995; Russell & Doyle, 1997; Markakis 2000)

In high-risk neonates, this procedure is useful for lower extremity, anorectal, and inguinal procedures. It obviates the need for general anaesthesia, endotracheal intubation and reduces the risk of postoperative apnoea (Fortuna, 1967; Spear *et al.,* 1988). Caudal epidural blocks may also be combined with general anaesthesia. This is advised since paediatric patients generally do not tolerate surgery under regional anaesthesia alone. However, in the very young, a caudal epidural block may be adequate to carry out urgent procedures such as reduction of incarcerated hernias, allowing the return of normal bowel function prior to surgical repair (Fortuna, 1967; Melman *et al.,* 1975; Dalens, 1995).

Elective procedures that caudal epidural blocks are indicated for include: Repair of inguinal or umbilical hernias, hydrocoele, orchidopexy, and hypospadias; circumcision; anorectal and genitourinary surgery in both males and females; treatment of early onset myotonic dystrophy in children

(Alexander *et al.,* 1981); surgery on the hip, the lower extremities, and the area of the coccyx; and it can also be used for muscle biopsy in undiagnosed neuromuscular disorders.

Anaesthesia can be provided for superficial operations of the lower limb such as; skin grafting and improving blood flow and reversing ischaemia in the lower limbs (Tobias *et al.,* 1989)

Caudal epidural blocks can also be used for emergency procedures such as: Testicular torsion; repair of an omphalocoele; strangulated hernia repair; and for the reduction of incarcerated hernias (Fortuna, 1967; Dalens, 1995; Jankovic & Wells, 2001)

Caudal epidural blocks can be carried out in an ambulatory or day-case setting for a range of minor and emergency procedures, e.g., circumcision and inguinal hernia repair (Kay, 1974; Lunn, 1979; Jones & Smith, 1980; Bramwell *et al.,* 1982; May *et al.,* 1982; Smith & Jones, 1982; Yeoman *et al.,* 1983; Vater & Wandless, 1985; Russell & Doyle, 1997). However, caudal epidural blocks are not recommended for minor surgery, especially if an alternative peripheral anaesthetic procedure can provide effective analgesia, i.e., a penile block for circumcision (Martin, 1982; Yeoman *et al.,* 1983; Vater & Wandless, 1985; Maxwell *et al.,* 1987; Eledjam *et al.,* 2000). In fact, Martin (1982) is of the opinion that caudal epidural blocks are not worth the time, risk and expense involved to perform on infants and neonates for circumcision and other minor surgical procedures.

Caudal epidural blocks have also been recommended for upper abdominal surgery in children for which higher doses of local anaesthetic solution is necessary to attain a higher level of analgesia. Unfortunately, this increases the risk of local anaesthetic toxicity, morbidity, or even mortality (McGown, 1982; Fortuna, 1967). Bosenberg and colleagues (1988) believe that this technique could also be used as a safe alternative route of access to the thoracic and upper lumber epidural spaces in small infants.

Continuous caudal epidural block indications

Continuous caudal epidural blocks can be used in combination with light general anaesthesia for longer operations in the upper and lower abdominal areas, urogenital area and for procedures on the lower extremities (Merguerian *et al.,* 2004).

2.1.2.2 Contraindications

General contraindications for performing regional anaesthesia have been covered in Chapter 1 (see *1.3.2: General contraindications or limitations of regional anaesthesia*). Those specific to caudal epidural blocks are discussed below.

Patients with increased intracranial pressure (ICP)

A careful neurological examination should always precede caudal epidural blocks to check for the possibility of increased ICP. When the pressure in the spinal compartment is lowered due to piercing the dura mater, as in an accidental dural puncture, transtentorial and foramen magnum herniation may occur, resulting in immediate loss of consciousness, permanent neurological sequelae or even death (Duffy, 1969).

Accidental dural puncture in a child with increased ICP (as with a space occupying lesion) could result in herniation, immediate loss of consciousness, permanent neurological damage and even death (Saint-Maurice, 1995). In the presence of intracranial lesions with hydrocephalus and taking the problems of raised ICP in consideration, it is preferable to avoid epidural blocks and rather rely on peripheral nerve blocks (Saint-Maurice, 1995; Jankovic & Wells, 2001).

Major malformations of the lower spine or meninges

Major malformations of the lower spine are total contraindications for caudal epidural blocks, because of the unclear or impalpable anatomy (Fortuna, 1967; Dalens, 1995; Dalens, 2002). Spina bifida occulta, which is not a major sacral malformation, is a relative contraindication for caudal epidural blocks; anatomical landmarks must be clearly defined before the procedure commences. Other vertebral malformations that contraindicates the performance of caudal epidural blocks include the presence of a meningomyelocoecle (Dalens, 1995; Dalens, 2002) or patients with sacral or lumbosacral agenesis (Letts, 2003).

Active disease of the central nervous system

This includes conditions such as meningitis and poliomyelitis *(*Jankovic & Wells, 2001*)*.

Cardiovascular diseases

Specific cardiovascular diseases of myocardial, ischaemic or valvular origin, although rare in children, are specific contraindications if the planned procedure requires higher sensory spread of the anaesthetic solution (Jankovic & Wells, 2001).

Presence of a pilonidal cyst

A pilonidal cyst is a cyst at the bottom of the coccyx that can become infected and filled with pus. At this point, it is technically called a pilonidal abscess and looks like a large pimple at the bottom of the coccyx. The risk of infection after performing the caudal block is just too great and an alternative method of analgesia should be considered (Dalens, 1995; Jankovic & Wells, 2001; Chatlin, 2003).

Minor surgical procedures

Even though caudal epidural blocks have several advantages, it is vital that one should not forget the risk involved when performing this procedure. The benefits should be weighed against the risks for each individual patient before performing any central block. Minor surgery may not be an indication for caudal epidural blocks; these surgical procedures may instead be performed under a peripheral nerve block (Dalens, 1995).

2.1.3 Anatomy

2.1.3.1 The sacrum

The sacrum is a triangular bone, consisting of five fused vertebrae, with a concave anterior surface and a convex posterior surface. In the centre and on the posterior surface of the sacrum is the caudal canal, which is a continuation of the spinal canal (Standring *et al.,* 2005).

The dorsal aspect of the sacrum has several protuberances resulting from the fusion of the 1st to 5th sacral vertebrae (see Figure 2.1). These include (Standring *et al.,* 2005):

- A median sacral crest, which is a remnant of the spinous processes of the sacral vertebrae.
- Two sacral articular crests, lateral to the median sacral crest, which consist of a series of tubercles almost parallel to the median sacral crest, from which they are separated by the left and right sacral grooves. The two sacral crests originate from the fusion of the articular processes of the sacral vertebrae.
- Two sacral cornuae, which are derived from the inferior articular processes of the fifth sacral vertebra. They form the triangle shaped hiatus.

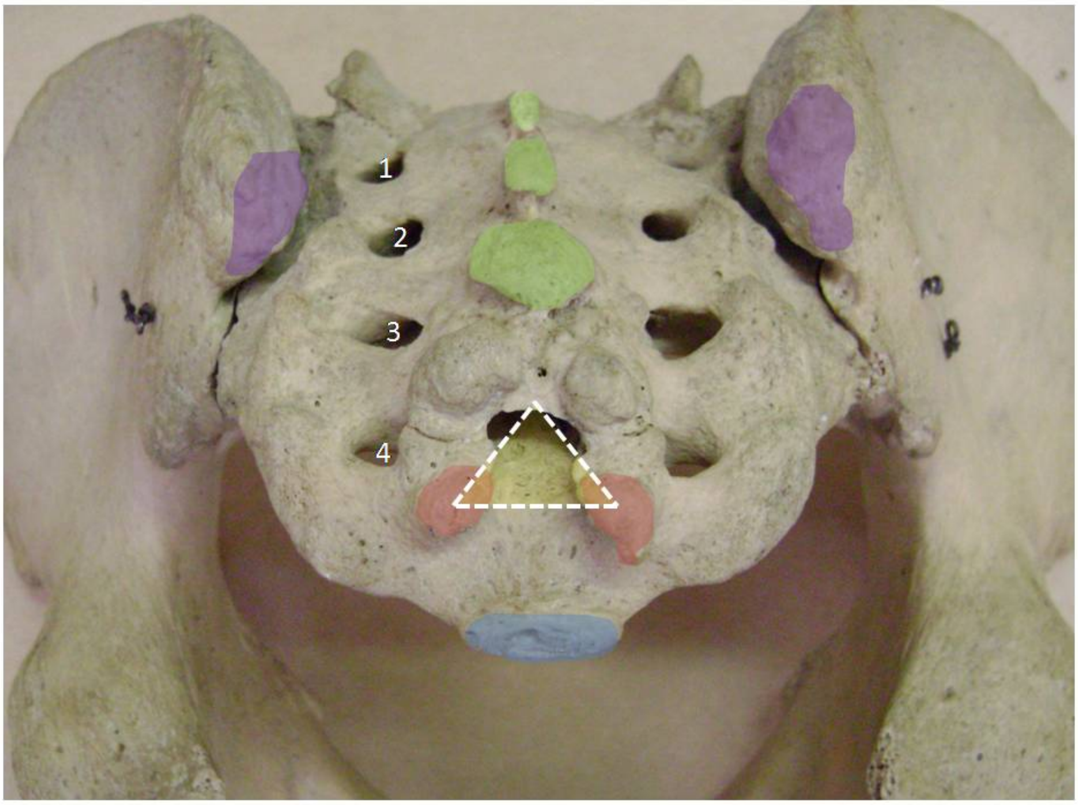

Figure 2.1: Photograph of the dorsal surface of the sacrum.

Also visible are the 1st to 4th sacral foramina (1-4), the sacrococcygeal joint (blue), posterior superior iliac spines (purple), sacral spinous processes (green) and the sacral cornuae (red). The position of the sacral hiatus is indicated by the translucent yellow triangle. The base of which lies between the two sacral cornuae with the apex directed cephalad. The triangle also indicates the surface area measurement that was taken of the sacrococcygeal membrane (see 5.1.1: Dimensions of the neonatal sacrococcygeal membrane)

2.1.3.2 Abnormalities of the sacrum

Spina Bifida

Spina bifida is a limited defect of the vertebral arch, which does not involve protrusion of the cord or membrane; it is seen as an incidental radiographic finding in up to 10% of the healthy population, mostly at the lumbosacral junction (Sadler, 2006).

Meningomyelocoecle is the severest form of spina bifida and is characterised by complex malformation of the spinal cord, nerve roots, meninges, vertebral bodies, and skin (Dalens, 1995; Dalens, 2002).

Sacral or lumbosacral agenesis

Sacral agenesis is a very rare disorder, which is characterised by the absence of variable portions of the sacrum. Patients with sacral agenesis lack motor function below the level of the normal remaining spine, while sensory function is impaired below the level of affected vertebrae. In more severe cases, part or all of the lumbar spine and even the lower thoracic spine may be absent and it is then referred to as lumbosacral agenesis *(Letts, 2003)*.

Blumel and co-workers (1959) found that in mothers with diabetes, incidence of sacral agenesis in their children was 16%. Although maternal diabetes is the risk factor most commonly associated with sacral agenesis, other less common risk factors such as, genetic mutation, teratogens and vascular anomalies (Letts, 2003) have also been shown to be possible causes for this condition. Reports have also suggested that exposure to organic solvents in early pregnancy may increase the incidence of sacral agenesis (Rojansky *et al.,* 2002).

Classification of sacral agenesis

Renshaw (1978) classified patients according to the amount of sacrum remaining and according to characteristics of the articulation between the spine and the pelvis:

- Type I is either partial or total unilateral sacral agenesis.
- Type II is partial sacral agenesis with a bilaterally symmetrical defect, a normal or hypoplastic sacral vertebra, and a stable articulation between the ilea and the first sacral vertebra.
- Type III is variable lumbar and total sacral agenesis, with the ilea articulating with the sides of the lowest vertebra present.
- Type IV is variable lumbar and total sacral agenesis, with the caudal endplate of the lowest vertebra resting above either fused ilea, or an iliac amphiarthrosis.

2.1.3.3 The sacral hiatus

The sacral hiatus is a triangular and obliquely placed defect on the lower aspect of the posterior surface of the sacrum formed by the failure of the laminae of S5 (and/or S4 in some individuals) to meet and fuse in the midline. There is a considerable variation in the anatomy of the tissues near the sacral hiatus, in particular, the bony sacrum (Pait *et al.,* 2002; Standring *et al.,* 2005).

The sacral hiatus is of considerable clinical importance since it is here that the extradural space terminates and the hiatus thus forms a portal of entry into this compartment (Standring *et al.,* 2005).

In adults, the sacral hiatus usually lies about 50mm from the tip of the coccyx and directly beneath the uppermost limit of the natal cleft. In clinical practice, it is better to locate the sacral hiatus by means of palpation of the depression that it forms between the two sacral cornuae (Dalens, 1995).

2.1.3.4 The termination of the spinal cord (conus medullaris)

In the third month of development, the spinal cord extends along the entire length of the embryo and spinal nerves pass through the intervertebral foramen at their level of origin. With increasing age, the vertebral column and the dura lengthen more rapidly than the neural tube, and the terminal end of the spinal cord gradually shifts to a higher level. At six months of foetal life, the lowest limit of the spinal cord lies at the level of S1 (Sadler, 2006). At birth the spinal cord ends at vertebral level L3 (Arthur & McNicol, 1986; Hawass *et al.,* 1987; Dalens, 1995; Sadler, 2006) and it reaches its definitive position at the L1 vertebral level at the age of 1 year (Arthur & McNicol, 1986; Dalens, 1995).

Barson (1970) examined the termination of the spinal cord on 252 infants during routine post-mortem examination. The infants were placed in a prone (neutral) position, the spinal cord was exposed and the level of the conus medullaris was identified. He illustrated the rate of ascent of the conus medullaris in the form of a graph (see Figure 2.2). From this it can be seen that the most rapid ascent is before the 17th week of life (or 19 weeks from the last menstrual period) when the cord ends opposite the L4 vertebra. Thereafter, the ascent continues at a much slower rate, the conus reaching the mature adult level approximately two months after birth.

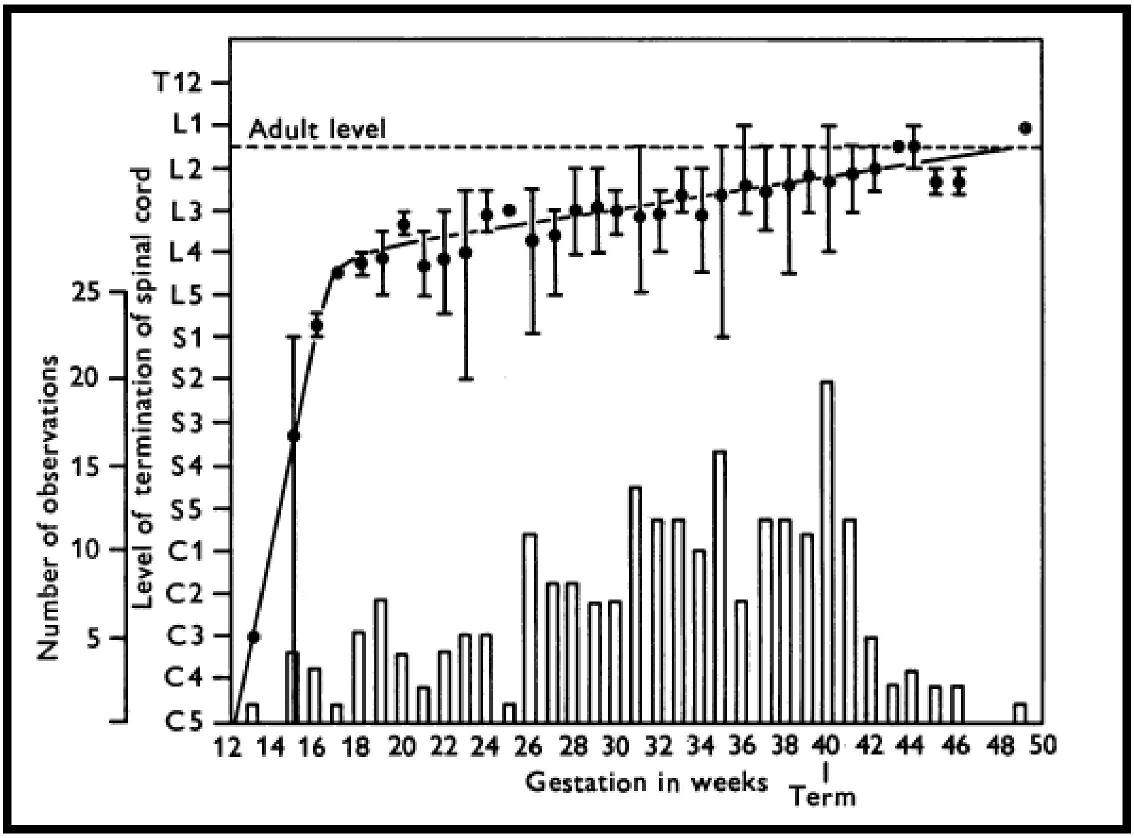

Figure 2.2: Level of termination of the spinal cord plotted against gestational age.

Ranges and mean values are indicated. The block graph represents the number of observations made in each gestational week (Barson, 1970).

Hawass and colleagues (1987) assessed the length of the spinal cord relative to the vertebral column during foetal development by performing translumbar myelograms on 146 spontaneously aborted foetuses. (76 males and 70 females; foetal age between 7-33 weeks). Significant variation in the level of spinal cord termination was found in foetuses between 12-25 weeks gestational age. In foetuses between 25-33 weeks gestational age, the cord ended at or above the level of L3.

Govender and co-workers (1989) examined the level of termination of the spinal cord in 115 autopsies of subjects ranging from a 20 week (gestational age) stillborn to an eight month-old infant. The study showed that the conus medullaris can be found at the adult level (lower border L1) at birth.

2.1.3.5 The dural sac

Along with the upward migration of the spinal cord, the dural sac also migrates from its S3-S4 level in a newborn to the S1-S2 level of the adult by the age of 1 year (Dalens, 1995). Binokay *et al.* (2006) studied the vertebral level of dural sac termination in adult males and females. They found that the dural sac terminates at the lower one third of S2 in males, while it ends at the upper one third of S2 in females (no significant difference between males and females). The mean overall level of termination for the entire sample was at the upper one third of S2.

Adewale and co-workers (2000) studied the caudal (sacral extradural) space in 41 children, ages 10 months to 18 years, using MR imaging. They determined: (a) the distance from the upper margin of the sacrococcygeal membrane to the dural sac, (b) the length of the sacrococcygeal membrane, and (c) the anterior-posterior distance of the caudal canal. Their results showed that there are great variations in the anatomy of the caudal space in children.

2.1.3.6 The caudal canal and caudal epidural space

The caudal epidural space is the lowest portion of the epidural system and a continuation of the lumbar epidural space, below the termination of the epidural sac. The caudal epidural space can be entered via the sacral hiatus that is found on the lower portions of the sacrum (Standring, 2005).

The caudal canal contains the cauda equina, which is formed by the roots supplying the lumbar, sacral, and coccygeal plexii. The caudal canal ends caudally at the sacrococcygeal membrane that covers the sacral hiatus. The membrane may only partially cover the sacral hiatus in some individuals (Standring, 2005).

The volume of the caudal canal can vary greatly between adults (Dalens, 1995). The caudal canal contains:

- The terminal part of the dural sac, projecting at S3-S4 vertebral levels at birth and at S1-S2 level (adult level) at 1 year of age.
- The five pairs of sacral spinal nerves and one pair of coccygeal spinal nerves, which form part of the cauda equina.
- The filum terminale, the final part of the spinal cord which does not contain any nerve tissue and exits through the sacral hiatus and is attached to the back of the coccyx.
- Epidural fat, the character of which changes from a loose texture in children to a more fibrous close-meshed texture in adults. This transition occurs round about 6 or 7 years of age. This may significantly reduce the spread of the local anaesthetic solution (Schulte-Steinberg & Rahlfs, 1970; Kester Brown & Schulte-Steinberg, 1980, Bosenberg 1988). It is this difference that gives rise to the predictability of caudal local anaesthetic spread in children and its unpredictability in adults.

2.1.3.7 Vasculature of the spinal cord

Arterial supply

The spinal cord is supplied by numerous radicular arteries, which branch off from the cervical vertebral arteries, the thoracic intercostal arteries and the lumbar vertebral arteries, to form the anterior spinal artery and posterior spinal arteries. Branches of the lumbar, iliolumbar and lateral or median sacral arteries supply the cauda equina. These also supply the medullary cone. Thin pial branches run from the spinal arteries, forming a network on the surface of the spinal cord known as the arterial pial network (Standring *et al.,* 2005).

Variations of spinal blood supply

The blood supply of the spinal cord shows considerable individual and segmental variations, particularly in the so-called transitional zones. If even one of the segmental arteries that arise from the radicular arteries is injured, that particular spinal segment is very likely to undergo ischaemic necrosis (Dalens, 1995).

Venous drainage

The caudal epidural space has considerable venous drainage, thereby increasing the risk of vascular puncture during a caudal epidural block. Two venous plexii – the internal and external vertebral venous plexus – traverse the entire spinal canal and from a ring around each vertebra, freely anastomosing with one another and receiving tributary flow from the vertebrae, ligaments and spinal cord. The upper epidural veins and caudal veins have no valves and inadvertent injections into the epidural veins will result in almost instantaneous systemic distribution. These sacral epidural veins generally end at S4, but may extend throughout the caudal canal (Standring *et al.*, 2005).

2.1.4 Techniques

2.1.4.1 Safety precautions

Caudal and lumbar epidural blocks must only be performed by or under the supervision of experienced anaesthesiologists in a sterile operating theatre environment with all the monitoring and safety procedures recommended for general anaesthesia (Jankovic & Wells, 2001). Most children are fearful of needles and, if there are no contraindications, it helps to sedate the patients with a light general anaesthesia before starting the procedure (Krane *et al.*, 1998).

2.1.4.2 *Classic technique: Single-shot caudal epidural block*

With this technique, the aim is to enter the epidural space at a level not only well below the expected level of the termination of the spinal cord (L3), but also below the dural sac (S3 or S4). The choice of patient position depends on the preference of the anaesthesiologist and the degree of sedation of the patient. There are two main positions:

- *Ventral decubitis position* (prone), with the pelvis elevated with the help of a pillow or a rolled towel placed under the hips.
- *Lateral decubitis position*, with the child lying on the side with the hips and knees flexed at right angles. An assistant can hold the child in place and a pillow can be placed beneath its head to increase stability. This position is preferred in children under general anaesthesia.

Once the patient is in the correct position, the following landmarks should be palpated and then marked:

- The line of sacral spinous processes in the midline of the body
- The sacrococcygeal joint
- And the two sacral cornuae

It is important to note that the intergluteal fold is not an ideal landmark, since it is not necessarily in the midline, especially if the patient is lying in the lateral decubitis position. Palpation of the sacrococcygeal membrane, which covers the sacral hiatus, gives a characteristic feel of a membrane under tension similar to that of a fontanel. The sacral hiatus and the posterior superior iliac spines form an equilateral triangle pointing inferiorly (Senoglu *et al.,* 2005). The sacral hiatus can be located by first palpating the coccyx, and then sliding the palpating finger in a cephalad direction (towards the base of the equilateral triangle) until a depression in the skin (the sacrococcygeal membrane) is felt (see Figure 2.3)

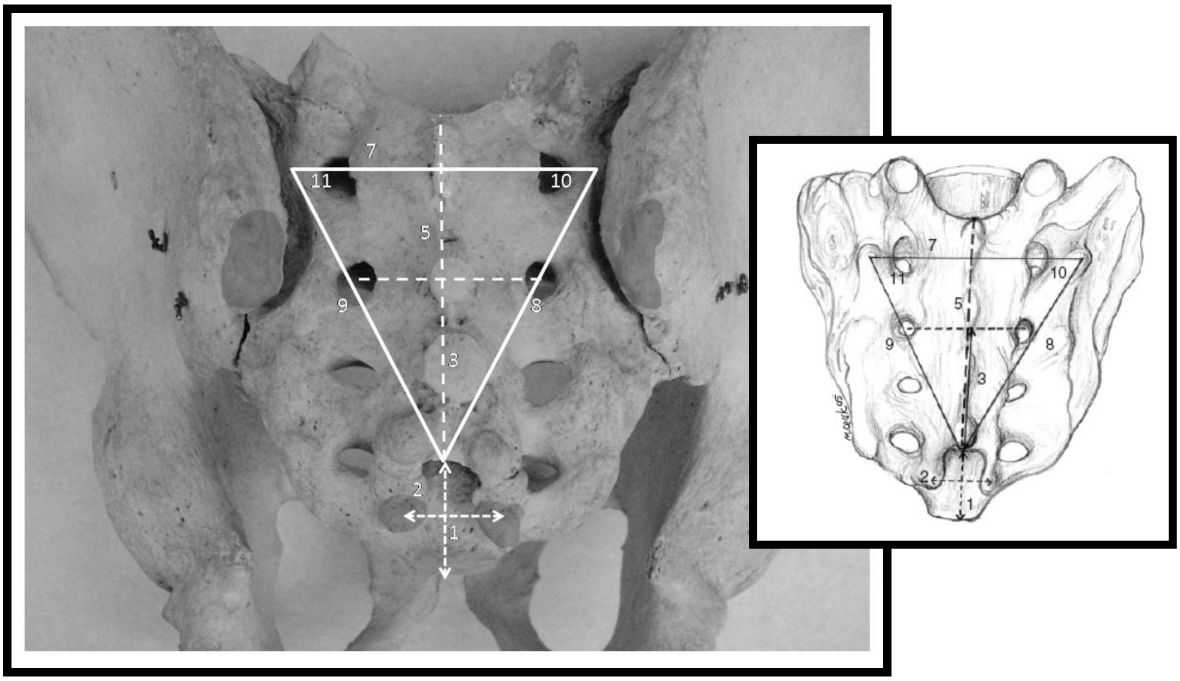

Figure 2.3: The equilateral triangle and bony landmarks described by Senoglu *et al.,* 2005.

(1) Height of sacral hiatus; (2) width of sacral hiatus at the level of sacral cornuae; (3) distance from apex of sacral hiatus to the level of S2 foramina; (4 = 1+3) distance from the base of sacrococcygeal joint to the level of S2 foramina; (5) distance between the upper border of S1 and apex of the sacral hiatus; (7) distance between the two superolateral sacral crests (the base of the triangle); (8) distance between right superolateral sacral crest and apex of the sacral hiatus; (9) distance between left superolateral sacral crest and apex of the sacral hiatus; (10) angle between the lines formed by the seventh and eighth parameters; and (11) angle between the lines formed by the seventh and ninth parameters.

As there can be a considerable degree of anatomical variation in this region, confirmation of bony landmarks is the key to success. The needle can penetrate a number of different structures mimicking the feel of entering the sacral hiatus. It is important to establish the midline of the sacrum as considerable variability occurs in the prominence of the cornuae, causing problems unless care is taken.

The needle is inserted in a cephalad direction at an angle of about 60°-70°, towards the dorsum of the sacrum with the bevel parallel to the longitudinal fibres of the sacrococcygeal membrane. A characteristic “give” will be felt as it pierces the membrane, a few millimetres before it comes into contact with the periosteum of the sacral canal (this is not ideal and should be avoided). The needle is then carefully redirected in a cephalad direction at an angle approaching the long axis of the spinal canal (about 20°-30° to the skin) (Dalens, 1995).

There are, however, many different insertion routes available in the literature (Hassan 1977). The thumb and index finger should remain on the sacral cornuae throughout the whole of the location and insertion procedure.

Care should be taken not to insert the needle too far as the dural sac may extend as far inferior as S3 or S4 in children (Dalens, 1995; Jankovic & Wells, 2001; Standring *et al.,* 2005).

An aspiration test should precede injection of any kind to check for either cerebrospinal fluid (CSF), in the case of a dural puncture, or blood, in case one of the blood vessels within the vertebral column has been punctured. After testing that the needle is indeed within the correct space, a small amount of local anaesthetic should be injected as a test dose (Dalens, 1995).

If the test dose didn't produce any side effects, then the rest of the volume of local anaesthetic solution is injected, after which the needle removed and the patient is positioned for surgery.

Schwartz and Eisenkraft (1993) oppose the use of loss of resistance to air to locate the epidural space in children and suggest that it should be avoided as reports indicate that children may develop a life-threatening venous air embolism when this technique is used.

Saberski *et al.* (1997) conducted a search of the literature for case reports of epidural complications following loss of resistance using air, spanning almost 30 years. They contend that the potential complications associated with this practice may outweigh the benefits. The use of saline to identify the epidural space may help to reduce the incidence of complications. Using air may also lead to a misinterpreted loss of resistance, especially in infants whose tissues have fewer connective fibres (Dalens & Mansoor, 1994). Further tests to confirm the correct position include gently moving the tip of the needle from side to side. When the needle is in the correct position it will feel firmly held in place.

2.1.4.3 Classic technique: Continuous caudal epidural block

Preparing to do a continuous caudal epidural block is the same as for the single-shot technique. The landmarks used in the single-shot technique should be palpated and marked. The same point of needle insertion should be used as with the single-shot technique.

Once the point of needle insertion has been determined, a plastic IV cannula is advanced at an angle of 60° – 70° to the skin, in the direction of the sacrococcygeal membrane. After perforation of the ligament, the needle is further advanced for about 10mm into the sacral canal. The needle is then removed and the plastic cannula is advanced a further 5mm.

The appropriate length of catheter can be measured in order to advance it the correct distance within the epidural space so as to allow the desired dermatome to be blocked. In neonates, infants and small children the catheter meets hardly any resistance, so that it is easy to advance to upper lumbar or thoracic levels (Bosenberg *et al.,* 1988).

2.1.5 Complications

2.1.5.1 Dural puncture

Extreme care must be taken to avoid puncturing the dura mater, as a total spinal block will occur if the dose for a caudal epidural block is accidentally injected into the subarachnoid space. If this occurs the patient will rapidly become apnoeic and, in adults, profoundly hypotensive. Management includes control of the airway and breathing, and treatment of the blood pressure with intravenous fluids and vasopressors such as ephedrine. It usually results from inserting the needle too deeply into the sacral canal. This could be due to an inappropriate technique or anatomical variations of the sacral hiatus or the dural sac (Jankovic & Wells, 2001).

Fortuna (1967) reported that the dura was pierced in only two patients in a series of 170 children, aged between 1day and 10 years. In a study to determine the spread of caudal analgesia in children, Busoni and Andreuccetti (1986) conducted 763 caudal epidural blocks on patients aged 1 day to 12 years and reported no dural punctures. Bramwell and colleagues performed a series of 181 caudal epidural blocks and reported one case of a suspected dural puncture (Bramwell *et al.,* 1982).

Trotter (1947) showed in 53 adult cadavers that the distance between the sacral hiatus and the dura mater varies from 16 – 75mm. In the presence of certain sacral malformations, this distance might be less and the dural sac can project down to the sacral hiatus. Adewale and co-workers (2000) demonstrated in 41 children, using MR imaging, that there is great variation in the distance from the upper margin of the sacrococcygeal membrane to the dural sac (27.9mm ± 8.0mm in males and 33.2mm ± 11.5mm in females). If a dural puncture occurs the needle must be withdrawn, but another attempt may be made, provided special attention is paid to the cardio-respiratory tracings and to the speed of the injection. If a dural puncture occurs for the second time, the needle must again be withdrawn and the use of an alternative technique should strongly be considered (Dalens, 1995).

Desparmet (1990) described a case for right-sided hernia repair where a caudal epidural block was performed on a male neonate born at 27 weeks gestational age and weighing 1,07kg at birth, after a failed spinal anaesthesia. Total spinal anaesthesia occurred due to what the author describes as leakage of anaesthetic solution from the epidural space through the puncture site in the dura to the spinal canal, thereby causing a total spinal block. He therefore believes that if a dural puncture occurred, it would be wiser to abandon any further attempts as the risk of total spinal anaesthesia is too great.

2.1.5.2 Vascular puncture

Vascular puncture of the epidural veins is by no means uncommon. This accidental puncture is of no consequence if no injection was performed. The needle should simply be removed and re-inserted before administering the local anaesthetic solution (Dalens, 1995). The frequency of vascular punctures varies greatly. It has been reported by McGown (1982) to occur in 10%-15% of caudal epidural blocks performed on adults and in 7%-10% of those in children. Dalens and Hasnaoui (1989) stated that they reduced this frequency from 10% to 1.5% by replacing long bevelled needles with a short bevelled one. This strongly suggests that the frequency of vascular puncture is related in some degree to the equipment used.

2.1.5.3 Systemic toxicity

Intravascular administration, overdose and/or rapid vascular uptake of local anaesthetic solution, can quickly lead to toxic central nervous system reactions such as nystagmus, sudden vertigo, brief blackouts, and an inability to move or respond to external stimuli. Tonic-clonic seizures is a very serious complication, but if treated immediately it will not lead to cerebral injury or death (Jankovic & Wells 2001).

Inadvertent intravascular injection, even if the solution was administered within the recommended dose range, could also lead to cardiovascular toxicity. The effects of which are primarily myocardial depression and bradycardia, which may lead to cardiovascular collapse (Kapitanyan & Su, 2009).

2.1.5.4 Misplacement of the needle into soft tissue

Misplacement of the needle into the soft tissue superficial to, or surrounding the sacral hiatus, results in subcutaneous injection rather than an epidural injection of local anaesthetic solution. This inevitably leads to a failure of the block, which occurred in 4% of paediatric patients during a study done by Dalens and Hasnaoui (1989). Such misplacements decrease with experience, but cannot be completely prevented due to the frequency of malformations of the sacrum. Another puncture can be attempted, provided that the total dose does not exceed safety limits (Dalens, 1995).

2.1.5.5 Puncture of the sacral foramen

Dalens (1995) describes how one can puncture one of the sacral foramina. This occurs when the needle enters the 3rd or 4th sacral foramen due to improper identification of the anatomical landmarks, or due to incorrect needle direction. This would result in a block of the sacral root in question and would not be accompanied by subcutaneous swelling. A second caudal may be attempted after the anatomical landmarks are clearly identified.

2.1.5.6 Partial or complete failure of the block

Complete or partial failure of epidural anaesthesia most often occur as a result of misplacement of the needle or due to "low resistance" wrongly identified as "loss of resistance". This is especially true when attempting epidural blockade in patients with abnormalities of the vertebral column (Koch & Nielsen, 1986). Fortuna (1967) reported nine complete and five partial failures in a series of 170 infants. He did not, however, elaborate on the possible cause for this failure.

2.1.5.7 Lateralisation of the block

A peculiarity of caudal epidural blocks is lateralisation of the block. When caudal epidural blocks are performed on patients in the lateral decubitis position, 50% have a level of anaesthesia two dermatomes higher on the side on which they are lying. This might be more (up to four dermatomes higher) if the local anaesthetic solution is injected at a very slow rate. The incidence of a unilateral block is always a probability, even when the procedure is correctly performed, although this incidence can be as little as one in every 1000 cases. Dalens (1995) however stated that the incidence may be as high as 1.2% of all caudal epidural blocks performed on paediatric patients.

The reason why a unilateral block occurs is not fully understood, but the occurrence can be very distressing if the side that is about to be operated is the one which is left “unanaesthetised” (Nunn & McKinnon, 1986; Shanks, 1986; Singh 1967). Such lateralisation may occur in the presence of adhesions that developed following previous surgery, or it may be due to inflammation or infection. Most often however, complete lateralisation is due to the presence of a complete plica mediana dorsalis, which divides the posterior epidural space into halves. Although the presence of such a median dorsal fold has been disputed, it has been described in the literature (Singh, 1967; Luyendijk, 1976; Bailey, 1986; Nunn & McKinnon, 1986; Shanks, 1986).

2.1.5.8 Infection due to the placement of a continuous catheter

Compared to lumbar epidural catheters, there is some concern regarding catheter infection with the prolonged use of caudally placed catheters due to the proximity of the sacral hiatus to the anus and rectum. It was found that caudal catheters have a greater risk of gram negative colonisation, whereas gram-positive colonisation was similar for both lumbar and caudal catheters. Adherence to strict aseptic techniques during placement is therefore of vital importance (Kost-Byerly *et al.,* 1998). Barrier flaps, to protect caudal catheters from soiling and contamination, is therefore recommended for young infants who lack sphincter control (McClain & Redd, 1993)

2.1.5.9 Other complications associated with caudal epidural blocks

Other rare complications have been described. Most are due to incorrect placement of the needle. They include:

- *Intraosseous injection,* which may lead to symptoms similar to that of intravascular injections (DiGiovanni, 1971; McGown, 1972; Weber, 1985).

- *Perforation of the pelvic viscera (rectum)* or vessels by a needle that has penetrated through the anterior surface of the sacrum into the pelvic cavity (DiGiovanni, 1971; Luyendijk, 1976). While simple needle puncture is not of grave concern, contamination of the needle is extremely dangerous if it is then withdrawn into the epidural space (Dalens, 1995).
- *Bone marrow injection or sampling during aspiration*. Injection of local anaesthetic solution into the bone marrow may result to systemic toxicity and should therefore be avoided (McGown, 1972).

2.1.6 Imaging modalities used for paediatric caudal and lumbar epidural blocks

2.1.6.1 Radiographic methods

Fluoroscopy allows anaesthesiologists to precisely identify the tip of the catheter at a specific spinal level (Stojanovic, 2007). However, without contrast, a radiograph will not be able to distinguish inadvertent intrathecal or subdural catheter placement from proper epidural placement. In addition, standard X-ray does not allow the anaesthesiologist to adjust the position of the catheter during insertion unless fluoroscopy is utilised. While fluoroscopy permits the real-time monitoring and adjustment of advancing catheters, it requires additional set-up, incurs significant increased expense, and increases a patient's exposure to ionizing radiation. As a result, fluoroscopy is not routinely used and is usually limited to difficult and/or special circumstances such as long-term epidural catheter placement for cancer pain (Kim, 2009).

Although the application of CT-guided fluoroscopy techniques for interventional radiology has become more popular, the majority of anaesthesiologists remain unfamiliar with the possibilities. CT fluoroscopy guidance allows more precise needle placement, lowers the volume of injectate, improves the results, and minimizes complications associated with catheter placements. Precise CT fluoroscopic monitoring prevents inadvertent injection of medications into the subarachnoid space and vascular structures, minimising the invasive nature of the epidural procedure (Illiasch *et al.*, 2007).

2.1.6.2 Ultra-sound guidance

Ultrasound-guidance allows for real-time visualisation of anatomical structures and offers the potential to guide epidural needles and catheter placement to the desired level with minimal risk of complications. It can therefore be beneficial for guided caudal epidural (Yoo *et al.,* 2005) (see Figure 2.4) and lumbar epidural blocks (Tsui, 2006), in both adult patients and in children. Unfortunately, calcification of the posterior vertebral bodies in children older than six months, prevents reliable imaging of the spinal cord, and makes visualisation of the spinal cord in adults and older children difficult. This is not the case in neonates and young infants, as the sacrum and vertebrae are not fully ossified (Scheuer & Black, 2000).

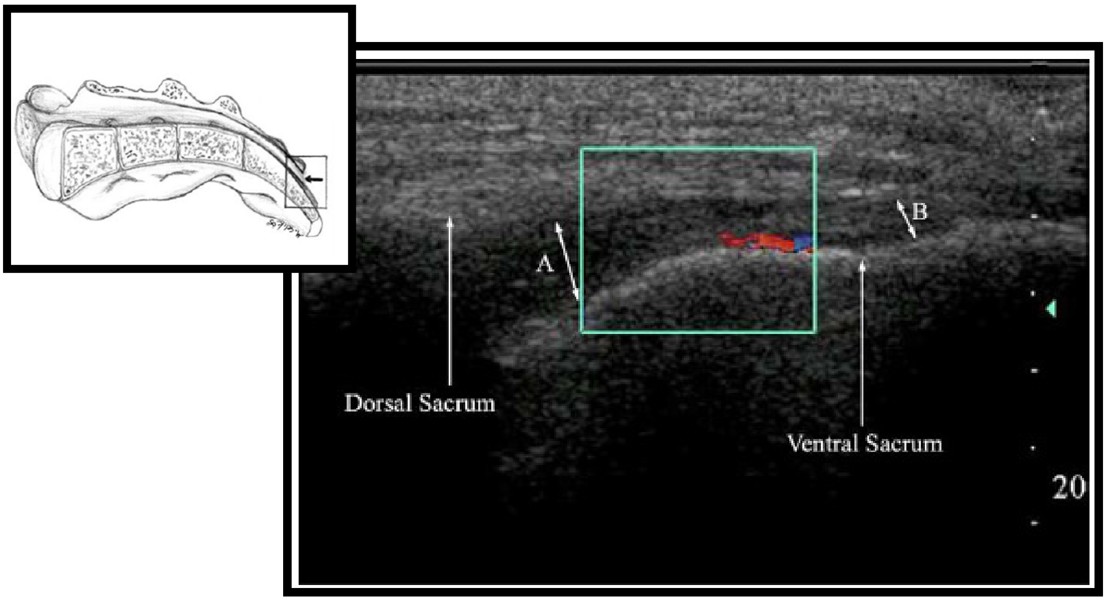

Figure 2.4: Colour Doppler ultrasonography, midsagittal view of the sacrum.

A predominantly one colour spectrum is revealed in the caudal epidural space after injection of a steroid. Red indicates flow toward, and blue away from, the ultrasound probe. (A) epidural space; (B) sacral hiatus (Yoon et al., 2005). Orientation drawing of the sacrum to show the caudal canal in the top left corner (Senoglu et al., 2005).

Cork *et al.* (1980) attempted to visualise the ligamentum flavum using ultrasonography. Because the epidural and subarachnoid spaces are surrounded by bony structures, anatomic assessment in this region is difficult since the majority of the ultrasound beam is reflected upon contacting these structures. With a linear or curved 4MHz to 7MHz probe, limited passage of the ultrasound beam is possible except through the interspinous space. The ligamentum flavum and the dura mater are both dense tissues that appear hyperechoic on ultrasound, while the low-density epidural space and the CSF in the intrathecal space appear hypoechoic.

More recent studies indicate that ultrasound determination of the spinal level is more accurate than clinical examination and the conus medullaris can be determined in over 70% of patients (Furness *et al.,* 2002). The markers were always placed within one interspace of the intended level.

Another advantage of ultrasonography is the ability to determine the depth of needle penetration to reach the epidural space and thus reduce the number of needle puncture attempts (Grau *et al.,* 2001).

2.2) Paediatric lumber epidural block

2.2.1 Introduction

Although not as popular as caudal epidural blocks, lumbar epidural blocks have been shown to be a very important technique for anaesthesiologists working with children. As a single-shot (for shorter surgical periods), or with the placement of an epidural catheter (for longer surgical procedures or analgesia well into the post-operative period), the lumbar approach can be used for any surgical procedures on the lower part of the abdomen and lower limbs. A catheter can even be threaded to the thoracic levels for any procedure that requires blocking the spinal nerves at higher levels.

In South Africa, the only 20% of the participants of a survey on paediatric regional anaesthesia (Appendix B) performed lumbar epidural blocks in their anaesthesiology practice.

2.2.1.1 History of lumbar epidural blocks

Although spinal anaesthesia was first described by Bier (1898), Cathelin (1901) performed the first caudal epidural blocks on adult patients at the beginning of the 20th century. Lumbar and higher epidural blocks were first reported by Pages (1921) and by Dogliotti (1931). It was Dogliotti however that is considered to be the one who promoted this procedure world-wide, as a result of his publications and good results (Fortuna & de Oliveira Fortuna, 2000).

Throughout the early 20th century, spinal anaesthesia dominated the central blocks performed on paediatric patients. Tyrrel-Gray (1909) reported on 200 cases of spinal anaesthesia in children (five of which were less than six months old). Marian (1932) published a study describing 653 cases spinal anaesthesia in children, with only fifteen failures and some minor complications. Balacesco (1935) reported a series of 1241 spinal anaesthesias in children. Vara Lopez (1942) described 438 cases of spinal anaesthesia in paediatric patients and in the same year, Etherington-Wilson (1942) reported performing spinal anaesthesia on 30 infants (from a total of 1600 spinal anaesthesias) without any major complications or death.

It was only in the 1950's when Ruston (1954) presented his work on lumbar epidural anaesthesia in children without any complications in either the pre- or post-operative period. He also presented a single case where the caudal route was used. The thoracolumbar approach was favoured, and a series of 77 infants was reported. He used the loss of resistance technique in order to identify the epidural space. Ruston (1964) published a study dealing with 172 surgical procedures managed under central blocks (either lumbar or thoracic epidural). In the same year, following Ruston's work on epidural blocks, Rodrigues (1964), published 36 lumbar epidurals performed on infants. Almost all of them involved high-risk infants and none of them experienced any complications related to the technique.

More recently, Zhan (1992) carried out more than 10 000 paediatric regional anaesthetic procedures, which included 5034 infants operated on under lumbar or thoracic epidural analgesia. He reported no neurological complications or deaths.

2.2.1.2 Advantages of lumbar epidural blocks over spinal anaesthesia

An advantage of lumbar epidural blocks over spinal anaesthesia is the ability to maintain continuous anaesthesia after placement of an epidural catheter, thus making it more suitable for procedures of long duration. The use of continuous epidural analgesia has been proven to be safe in both neonates and infants (Murrell *et al.,* 1993). This also allows this technique to be used for analgesia in the postoperative period, using lower concentrations of local anaesthetics (Meignier *et al.,* 1983; Ecoffey *et al.,* 1986; Wood *et al.* 1994; Williams *et al.,* 1997; Reich & Strumper, 2000; Kost-Byerly, 2003).

2.2.2 Indications and contraindications

2.2.2.1 Indications

Anaesthetic indications

Lumbar epidural anaesthesia can be used for urological, orthopaedic and/or general surgical procedures in the region of dermatomes T5-S5, which includes all procedures on the lower limbs, pelvis, perineum and lower abdomen (Melman *et al.,* 1975; Schulte-Steinberg, 1984; Armitage, 1985; Ecoffey *et al.,* 1986; Desparment *et al.,* 1987; Berde, 1989; Sethna & Berde, 1989; Yaster & Maxwell, 1989; Delleur, 1990; Ecoffey & McIlvaine, 1991; Wood *et al.,* 1994; Dalens, 1995; Williams *et al.,* 1997; Reich & Strumper, 2000; Markakis, 2000; Jankovic & Wells, 2001; Kost-Byerly, 2003).

It can also be used for surgical procedures on high-risk infants who are more prone to postoperative complications than other patients; and especially those susceptible to malignant hyperthermia (Eather, 1975; Jankovic & Wells, 2001), respiratory disabilities (Meignier *et al.,* 1983; Williams *et al.,* 1997), and myopathy (Delleur, 1990).

Analgesic indications

The versatility of a lumbar epidural block means that it can be used as an anaesthetic, as an analgesic adjuvant to general anaesthesia, and for postoperative analgesia in procedures involving the lower limbs, perineum, pelvis, abdomen and thorax (Dalens, 1995; Meignier *et al.,* 1983; Ecoffey *et al.,* 1986; Wood *et al.,* 1994).

Wee and Stokes (1999) described how they combined a lumbar epidural block and general anaesthesia on a two day old infant who underwent emergency closure of bladder extrophy. The advantage of this combination allowed them to avoid unnecessary neuromuscular blocking drugs and prolonged intensive care.

Williams and co-workers (1997) reported successful management of postoperative pain, using a continuous lumbar epidural catheter, in 17 infants who underwent upper and lower abdominal surgery.

2.2.2.2 Contraindications

General contraindications for performing regional anaesthesia have been covered in Chapter 1 (see *1.3.2: General contraindications or limitations of regional anaesthesia*). Contraindications, specific to lumbar epidural blocks are listed below.

Patients with increased ICP

Transient increases in the ICP have been reported in the literature and lumbar epidural anaesthesia should therefore not be performed on patients with a reduced intracranial compliance and increased ICP (Usubiaga *et al.,* 1967; Bromage, 1967; Duffy, 1969; Hilt *et al.,* 1986). See also *2.1.2.2 Contraindications: Patients with increased intracranial pressure.*

Abnormalities of the vertebral column

Anatomical abnormalities of the vertebral column (see *2.2.3.4: Abnormalities of the vertebral column*) may make the placement of an epidural technically impossible, and the risk *versus* benefit should be weighed before a lumbar epidural block is attempted (Ellis & Feldman, 1993; Dalens, 1995; Boon *et al.,* 2004).

Active disease of the central nervous system

See *2.1.2.2: Contraindications*: *Active disease of the central nervous system.*

Cardiovascular diseases

See *2.1.2.2: Contraindications: Cardiovascular diseases.*

Minor surgical procedures

See *2.1.2.2: Contraindications: Minor surgical procedures.*

2.2.3 Anatomy

2.2.3.1 Course of the epidural needle – from skin to epidural space

When inserting the epidural needle using the midline approach, it will pierce several structures before reaching the epidural space. These include the skin, subcutaneous fat and fascia, supraspinous ligament, interspinous ligament, and the ligamentum flavum, which is often absent in the midline (Boon *et al.,* 2004).

In contrast, using a paramedian approach, the needle will instead pierce the skin, subcutaneous fat and fascia, the erector spinae muscles and finally the ligamentum flavum.

Hasan and co-workers (1994) studied the depth of the epidural space from the skin in 586 paediatric patients amongst which 29 were neonates and 139 were infants. He found that the skin-to-epidural distance in neonates (mean weight: 3.8kg ± 1.1kg (mean ± SD)) was 9.0mm ± 2.0mm and in infants (mean weight: 6.4kg ± 1.8kg) it was 11.0mm ± 3.0mm.

In 1995, Bosenberg and Gouws measured the skin-to-epidural distance in 274 children (range 2kg – 43kg), who underwent lumbar epidural anaesthesia. When "loss of resistance" to air was detected, the needle was marked as it emerges from the skin. Distance from this point to the needle aperture, and not the tip, was then measured. Between the ages of 6 months and 10 years old (n=233) there was a good correlation between skin-to-epidural distance and both weight and age. This relationship between skin-to-epidural distance and body weight is described by the regression equation:

Skin-to-epidural distance (mm) = 0.8 x Weight (kg) + 3.93.

In the 22 children under 6 months of age the distance varied between 5mm and 12mm and showed poor correlation to the weight of the patient (Bosenberg & Gouws, 1995).

Bosenberg (1998) performed a series of 211 successful lumbar epidural blocks on infants and neonates, weighing between 0.9kg – 5.8kg, undergoing major abdominal surgery for intestinal atresia, omphalocoele, gastroschisis, and malrotation. He found that skin-to-epidural distance ranged between 3mm and 12mm (mean: 6.0mm ± 1.7mm).

Arthurs and co-workers (2008) used ultrasound to measure the skin-to-epidural space distance at the L3/L4 intervertebral space in 116 neonates. They found a strong correlation coefficient (R^2 = 0.76) between the depth of the epidural space and the weight of the patient. They subsequently developed the following formula for determining the skin-to-epidural space distance:

Skin-to-epidural space distance (mm) = 2.2 x Weight (kg) + 6.89mm.

Choi and co-workers (2009) evaluated the skin-to-epidural space distance in MR images of 662 children undergoing urological surgeries with epidural catheterisation for post-operative analgesia. They found that the patient's age and weight correlated significantly to the skin-to-epidural space distance. They derived the following multiple linear regression for determining the depth of the epidural space:

Skin-to-epidural space distance (mm) = 9 + 0.5 x Weight (kg) − 0.2 x Age (months).

2.2.3.2 Surface anatomy of the vertebral column

The effective use of epidural anaesthesia depends on precise knowledge of the segmental arrangement of the motor and sensory nerves, an appreciation of the increasing obliquity of the nerve roots and knowledge of the surface anatomy that relates to the vertebral canal. Only when all are understood, can the precise level of the epidural block be appropriately selected. In the thoracic region, the spinous processes of the vertebrae are palpable; the spine of T7, which overlies the level of the body of T8 (and is at the level of the spinal cord segment of T9/T10) lies at the level of the inferior angle of the scapula when in the anatomical position (Craven, 2004). By counting the vertebral spines from this point, one can identify the spines of the other thoracic vertebrae. The spine of L4 usually lies on a line drawn between the highest points of the iliac crests (Tuffier's or intercrestal line) in adults (Kim *et al.,* 2003) and approximately L5 in children (Tame & Burstal, 2003) (see Figure 2.5). From this point other vertebral levels can be identified.

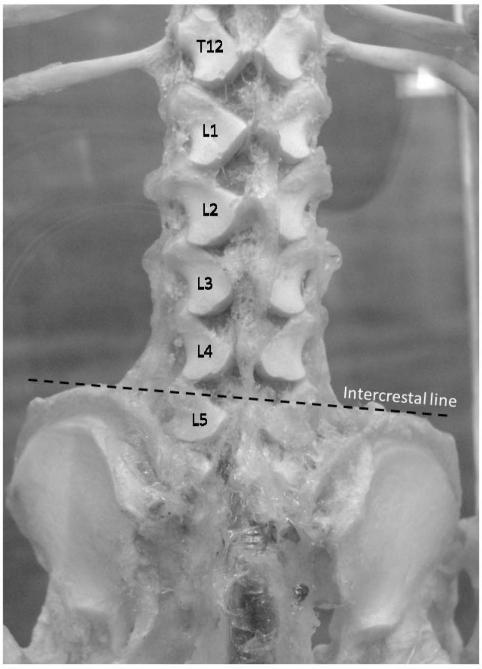

Figure 2.5: Posterior view of the neonatal vertebral column and iliac crests.

The 12th thoracic and 5 lumbar vertebrae are indicated, as well as the intercrestal or Tuffier's line (black dashed line).

2.2.3.3 Development of the vertebral column

At first, the paraxial trunk mesoderm is unsegmented. As development proceeds, epithelial spheres, called somites, are formed in a cephalocaudal direction. The somites mature during development according to this same cephalocaudal direction. This maturation leads to dissociation of the epithelial somite, forming the dermatome (dorsal), the myotome (intermediate), and the sclerotome (ventral). The dermatome is located underneath the surface ectoderm. It will give rise to dermal cells for the dorsal moiety of the body. The myotome gives rise to all striated muscle fibres of the body. The sclerotome differentiates into cartilaginous cells of the vertebrae, cells of the intervertebral discs and ligaments, and cells of the spinal meninges. Furthermore, the somite gives rise to endothelial cells. The sclerotome is first located ventrally, and it then spreads to cover the entire neural tube forming at its dorsal face, the so-called dorsal mesoderm that will lie between the neural tube and the surface ectoderm after disjunction. On a next step of differentiation, the sclerotomes divide in two horizontally. The bottom half of one fuses with the top half of another to form the vertebrae. Remnants of the notochord, found between the vertebrae, become the nucleus pulposus within the intervertebral disc (Rossi *et al*., 2006; Sadler, 2006).

Age related changes of the vertebral column

The vertebral anatomy is well defined in young patients. It allows for easy localization of the epidural and subarachnoid space (Kopacz, 1996).

In a study conducted by Boon and colleagues (2003), they evaluated the placement of epidural needles in 36 adult cadavers using the alternative paramedian approach. Radiographic measurements on anteroposterior lumbar spine X-rays in different age groups were also used to determine the dimensions of the interlaminar area. Their results showed that the interlaminar area decreases in height and width with advancing age. A similar study was conducted on a sample of neonatal cadavers and the results are discussed later in the thesis (see *5.2.2: The dimensions of the lumbar interlaminar spaces in neonates in both a prone and flexed position*).

2.2.3.4 Abnormalities of the vertebral column

Molecular and cellular tissue interaction and increasing organ complexity characterise the fundamental features of the embryonic developmental process during axial embryogenesis. Alteration in the molecular and macromolecular process may lead to structural defects involving the vertebral column and spinal cord. Such defects may occur prenatally, postnatally, or both, and are divided into three categories: Malformation, disruption, and deformation (Sadler, 2006).

Malformation of the vertebral column

Malformation is a failure of embryological differentiation, development, or both of a specific anatomical structure, causing it to be absent or improperly formed before the foetal period commences, e.g. hemi-vertebrae.

Once it is anatomically established, the defect may continue to adversely affect vertebral column development throughout the subsequent foetal and postnatal periods. The eventual type of malformation and its severity depend on the stage of the developmental or maturation cycle that is specifically affected.

Disruption of the vertebral column

Disruption is a structural defect resulting from destruction of a part that formed normally during the embryonic period. This mechanism involves the limbs more frequently than the vertebral column during the foetal stage.

Deformation of the vertebral column

Deformation is an alteration in the shape or structure of individual vertebrae or of the entire vertebral column during the foetal and/or postnatal periods, with the involved region having initially differentiated normally. Deformation may be classified as either intrinsically derived or extrinsically derived.

Intrinsic deformation results from the reduced ability of the foetus or child to move away from normal imposed forces and depends on the integrity of the neuromuscular system to respond effectively.

Extrinsic prenatal deformations are the result of reduction in the amount of space in which a developing foetus may move. Such a reduction may be either physiological or pathological.

Classification of abnormalities of the vertebral column

Minor malformations of the spine are seldom apparent, while more severe congenital malformations resulting in progressive scoliosis could have major clinical implications in children undergoing lumbar epidural blocks. These abnormalities may be simple and benign, causing no spinal deformity, or they may be complex, causing severe spinal deformity or even paraplegia. The three major patterns of congenital vertebral column deformities are: Scoliosis, kyphosis, and lordosis *(Letts, 2003)*.

Congenital vertebral deformities can be classified according to different types:

1. Failure of formation: This includes either partial failure of formation (e.g. wedge vertebra) or complete failure of formation (e.g. hemi-vertebra).
2. Failure of segmentation: This can be either unilateral (unilateral unsegmented bar) or bilateral failure of segmentation (e.g. block vertebra).
3. Mixed: Which contains elements of both failure of formation and failure of segmentation.

Defects of formation may be classified as follow:

- Anterior formation failure results in kyphosis, which is sharply angulated.
- Posterior formation failures are rare but can produce a lordotic curve.
- Lateral formation failure occurs frequently and produces the classic hemi-vertebrae of congenital scoliosis.

The scoliosis that develops may occur with kyphosis or lordosis, depending on the precise location of the defects. Specific defects of segmentation may be classified as:

1. Anterior segmentation failure (anterior unsegmented bar) leads to progressive kyphosis owing to the absence of anterior vertebral growth.
2. Posterior segmentation failure, if symmetrical, results in lordotic deformities.
3. Lateral segmentation failure (unilateral unsegmented bar) often produces some of the worst and most unrelenting scoliotic curves.
4. Total segmentation failure produces block vertebrae, which results in shortening of the spine.

5. Posterolateral and anterolateral segmentation failures are rare but produce lordoscoliosis and kyphoscoliosis, respectively, when they do occur.

Scoliosis

Congenital scoliosis is a lateral curvature of the spine caused by congenital anomalies of vertebral development. The vertebral abnormalities are present at birth, but clinical deformity may not be evident until later in childhood, when progressive scoliosis is evident.

Kyphosis

Kyphosis is caused by defects of segmentation or defects of formation. Defects of segmentation occur most often in the mid-thoracic or thoracolumbar regions and may involve 2 – 8 vertebral levels. They tend to produce a round kyphosis rather than a sharp angular gibbous; therefore, paraplegia rarely is a problem. The main clinical symptom is low back pain caused by the necessary compensatory lumbar hyperlordosis. The kyphosis caused by the defect of segmentation commonly starts in the late juvenile years with the progressive ossification of the disk space anteriorly.

Defects of formation are more common and may involve only one vertebral level, but multiple defects are possible. The failure of the formation can be purely anterior and cause kyphosis, or it can be anterolateral with a posterior corner hemivertebra, resulting in kyphoscoliosis.

Lordosis

Lordosis is a disorder defined by an excessive inward curve of the vertebral column. Hyperlordosis is the excessive inward curvature of the lumbar vertebrae and is caused by a failure of posterior segmentation in the presence of active growth anteriorly. Asymmetrical defects of segmentation, like a posterolateral unsegmented bar leading to lordoscoliosis, are more common.

Sacral or lumbosacral agenesis

This condition drastically distorts the anatomy of the lumbar area making finding of the correct needle insertion site and actual placement of the needle almost impossible. Lumbar epidural blocks should therefore be avoided in patients with the more advanced types of lumbosacral agenesis.

Rossi and co-workers (2006) classified congenital spinal abnormalities into two groups. The first is open spinal dysraphism which includes meningomyelocoele, myelocoele, hemimeningomyelocoele, and hemimyelocoele. The second is closed spinal dysraphisms, which include those with a subcutaneous mass.

2.2.3.5 The epidural space

The epidural space is a triangular space, which lies within the vertebral canal (see Figure 2.6), between the periosteum of the spinal canal and the outer surface of the dural sac and extends from the foramen magnum to the sacral hiatus. It is empty in extensive areas, where the dura is in contact with the pedicles and lamina of the vertebrae or with the ligamentum flavum. This results in epidural compartments that are discontinuous circumferentially and segmentally (Hogan, 2007). Due to the triangular shape of the epidural space, and the ellipsoid shape of the spinal cord, the widest part of the epidural space is found posteriorly in the midline. This makes the midline insertion route the safest approach to the epidural space (Ellis & Feldman, 1993; Standring et al., 2005).

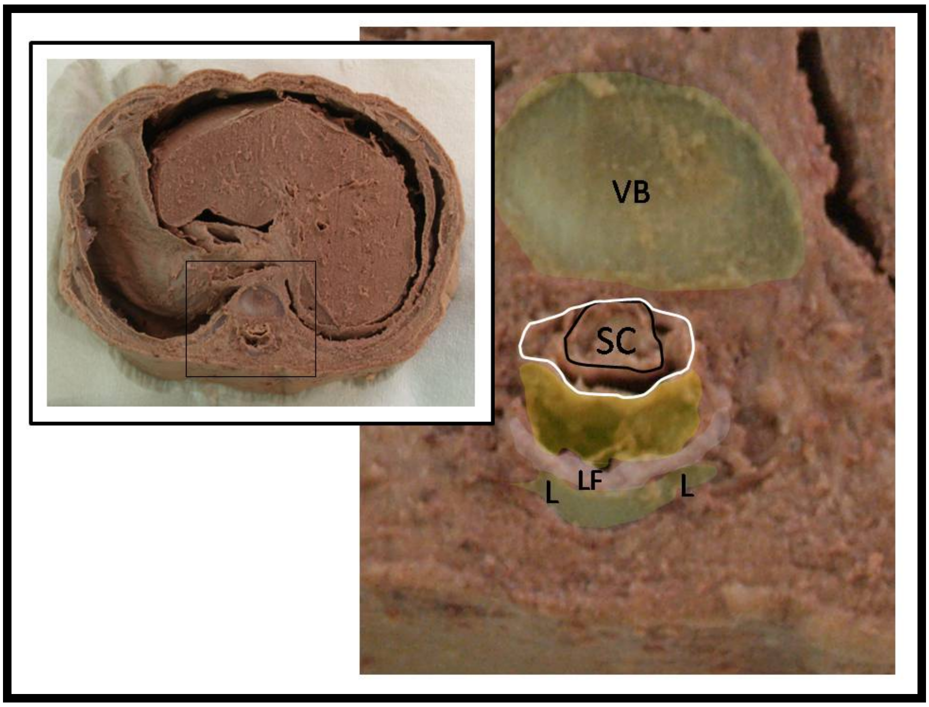

Figure 2.6: Transverse section through the L1 vertebra (highlighted in green) of a neonatal cadaver.

The L1 vertebral body (VB) can be seen ventrally with the two laminae (L), dorsally. The ligamentum flavum (LF) found between the laminae of two adjacent vertebrae are highlighted in white. The epidural space (highlighted in yellow) can be found between the laminae and the dura mater (indicated by the white line). The dura mater covers the spinal cord.

The widest midline point is occasionally divided by a fold of dura mater into two or three compartments that do not always communicate with one another. The consequence of this infrequent abnormality may be patchy analgesia after an epidural block. Although the dura mater is attached superiorly to the margins of the foramen magnum this cannot be relied on to prevent inadvertent passage of analgesic into the cranial cavity. Prolongations of the dura mater surround the nerve roots (dural cuffs) and fuse with them as they traverse the intervertebral foramina. The anterior and posterior nerve roots cross the epidural space before they join in the intervertebral foramina and can thus be anaesthetised by the epidural route (Craven, 2004).

Several studies have been conducted to describe the anatomy of the epidural space. The presence of a median epidural band, which divides the epidural space into an anterior and two dorsolateral spaces, has been described in the literature and could very well play a major role in the lateralisation of a lumbar epidural block (Luyendijk, 1976; Parkin & Harrison, 1985; Blomberg, 1986; Bailey 1986).

Hogan (1991) made cryomicrotome sections of the lumbar spines of 38 adult cadavers. He found that the epidural space is less uniform and more complex than previously thought. He maintains that further studies of the structural detail of the spinal soft tissue anatomy could lead to improved epidural techniques and a better understanding regarding the spread and distribution of local anaesthetic solution administered into the lumbar epidural space.

When the epidural needle is inserted at an angle, the skin-to-epidural distance would be increased. This distance may be increased by up to 1.5mm for 10mm perpendicular distance if the angle of insertion is 30° (Bosenberg 1995).

2.2.3.6 Content of the epidural space

The epidural space contains the dural sac, the spinal nerve roots, the extradural venous plexus, spinal arteries, lymphatics and areolar tissue (Craven, 2004) (see Figure 2.7 & 2.8).

Figure 2.7: Dissection of a neonatal vertebral column

The dural sac and epidural space was exposed by reflecting the laminae of the lumbar vertebrae superiorly. Within the epidural space one can find the vertebral venous (Batson's) plexus (indicated by the white arrows).

Figure 2.8: Areolar tissue found within the epidural space is being removed.

Between the dura mater and the vertebral canal is a layer of areolar tissue, which also contains the *internal vertebral venous (or Batson's) plexus* (See Figure 2.7) (Parkin & Harrison, 1985).

The fat is very fluid in infants and becomes more packed and less permeable to local anaesthetic solutions in children over 7 years-of-age (Schulte-Steinberg & Rahlfs, 1970). The fluidity of the areolar tissue within the epidural space of young infants allows for easier movement of epidural catheters within the epidural space. This permits safer relocation of the catheter from lower vertebral levels to higher ones.

2.2.3.7 The ligamentum flavum

The ligamentum flavum is an essential landmark for identifying the epidural space. It consists of strong yellow elastic fibres that are densely packed and can be up to 10mm thick in the lumbar region in adults and spans the interlaminar space between adjacent vertebrae (Parkin & Harrison, 1985; Hogan, 1991).

Fibres are stretched in the flexed position and can be more easily penetrated during lumbar puncture. If the needle is exactly in the midline, it may pass through the gap between the right and left ligamentum flavum (Hogan, 1991).

Through means of dissection of ten adult cadavers, Zarzur (1984) described the anatomy of the ligamentum flavum. He found the ligament to be between 3mm and 5mm thick at L2 – L3 levels and 12mm to 22mm wide. The internal surface forms an acute angle with its vertex that is in contact with the interspinous ligament.

2.2.3.8 The meninges

The dura mater lines the spinal canal to the level of S3/S4 in neonates and reaches the adult level of S1/S2 in infants older than 1 year old.

The arachnoid mater lines the dural sac to the level of the middle one-third of S3/S4 in neonates and S1/S2 (adult level) in infants older than 1 year. Binokay and colleagues (2006) found that the dural sac terminates at the lower one third of S2 in males, while it ends at the upper one third of S2 in females, although there was no significant difference between the sexes. The mean overall level of termination for the entire sample was at the upper one third of S2.

The pia mater leaves the spinal cord at the conus medullaris to form the filum terminale which traverses the subarachnoid space and terminates on the periosteum of the coccyx, after penetrating the dura and arachnoid mater at the level of S3/S4 in neonates and S1/S2 in infants older than 1 year (Ellis & Feldman, 1993; Standring et al., 2005).

2.2.3.9 Iliac crests as bony landmarks

Due to the lower termination of the spinal cord in children (L3) it is safer to choose L4/L5 or L5/S1 interlaminar space in patients younger than 1 year of age. The L3/L4 interlaminar space is used in patients over 1 year old, as the spinal cord terminates at the adult level of L1/L2.

In the adult, identification of the correct level of needle insertion is in a line drawn between the iliac crests (Tuffier's or intercrestal line); it crosses the spinous line at a level ranging from the 4th lumbar spinous process to the lower part of the interlaminar space between the 4th and the 5th lumbar vertebrae, depending on the degree of flexion of the vertebral column (Ievins, 1991).

Reynolds (2001) described seven cases in which neurological damage followed spinal or combined spinal-epidural anaesthesia in adult women. He therefore believes that Tuffier's line is unreliable in determining the lumbar interlaminar spaces. Anaesthesiologists, for example, often select a space of insertion one or two segments more cranial than they estimated using Tuffier's line.

Because of the variability of Tuffier's line in adults, Reynolds, as well as, Boon and colleagues (2004) recommends to rather go for one space lower, as the identified space is likely to be at least one interlaminar space too high.

In infants, a line drawn between the two iliac crests crosses the midline in the area of about L5 and at about L5/S1 in neonates (Jankovic & Wells 2001). Identifying the correct interlaminar space is essential before even contemplating a lumber epidural block in children.

Tame and Burstal (2003) evaluated the vertebral level of Tuffier's line in MR images of 35 children less than ten years old. They found that in their sample Tuffier's line intersected the L5 vertebra (with an interquartile range of 0.5 vertebral levels). These MR images were evaluated with the children in a neutral position (no flexion of the trunk). From evaluating 103 X-rays of adult patients in both a neutral and flexed position, Kim and co-workers (2003) found that Tuffier's line was slightly more caudal when flexed (from a L4 position to a L4/L5) position ($P < 0.001$).

2.2.3.10 Similarities between relevant anatomy for caudal and lumbar epidural blocks

The anatomy of the dural sac and the vascular anatomy of the epidural canal are as important to know when performing lumbar epidural blocks as when performing caudal epidural blocks. These topics have been discussed in *2.1.3.5: The dural sac* and *2.1.3.7: Vasculature of the spinal cord*).

2.2.4 Techniques

2.2.4.1 Classic technique: Single-shot lumbar epidural block

The objective of the lumbar epidural block is to approach the lumbar epidural space posteriorly and inserting the tip of the needle into its posterior part, using the midline or paramedian insertion route. The patient can either be placed in a *sitting position*, which is primarily used in adults or children older than seven, or the *lateral decubitis position*. The lateral decubitis position is the favoured position for performing a lumbar epidural block in children (Jankovic & Wells, 2001). In either of these positions, the spinal column should be well flexed to open the angle between the consecutive spinous processes and the vertebral laminae. This also allows the ligamentum flavum to be more easily penetrated with a midline insertion route (Boon *et al.,* 2004). This position also reduces the CSF pressure and increases the width of the posterior epidural space (Dalens, 1995). In rare circumstances, especially with orthopaedic procedures on patients with large plaster casts, the lateral or sitting position may be impossible; a third position, the *ventral decubitis (or prone) position* is the only other available option.

Once the patient is in the correct position, the spinous process of the vertebral column and the iliac crests should be palpated and the marked as landmarks (Jankovic & Wells, 2001).

Midline approach

A line joining the most superior part of both iliac crests (Tuffier's or the intercrestal line) must be drawn. In adults, this line will intersect the midline at the L4 spinous process or L4/L5 interlaminar spaces (Ievins, 1991; Ellis & Feldman, 1993). While this line crossed the level of the L5 vertebral body in children (Tame & Burstal, 2003). Once the appropriate intervertebral space has been identified, the epidural needle can be carefully inserted (see *2.2.3.1: Course of the epidural needle*).

Paramedian approach

The oblique paramedian insertion route is suitable for a lumbar epidural block when a midline insertion was unsuccessful (Armitage, 1985; Boon *et al.,* 2003). Preparation for the paramedian approach is the same as for the midline approach, although this approach is usually performed with patients in the lateral decubitis position. An advantage of the paramedian approach is that entry to the epidural space can be obtained at any spinal level; however caution must always be taken when inserting a needle at any level where the spinal cord may be injured i.e. above L1/L2 (Boon *et al.,* 2003).

The needle is initially inserted next to the spinal process and slowly advanced in a direction perpendicular to the skin until lamina is contacted. It is important to take note of lamina depth as it provides an estimated depth of the epidural space from the skin (Boon *et al.,* 2003). The needle is redirected medial before being inclined cephalad toward the interlaminar space.

Many believe that this approach requires more skill and experience as the needle must be angled in two planes (i.e. medially and cephalad), and only anaesthesiologists with extensive experience and confidence in epidural analgesia should perform it (Kim, 2009).

2.2.4.2 Classic technique: Continuous lumbar epidural block

The length of the epidural needle should be compared with the marking points on the catheter, for easier identification of the length of the catheter after it has been inserted. The ability of the catheter to pass through the epidural needle is verified at the same time (see *2.2.5.7: Complications related to epidural catheters*). Formulae for estimating the distance from skin-to-epidural space distance have been proposed and have been discussed earlier in this chapter (see *2.2.3.1: Course of the epidural needle*). However, formulae are only guidelines and will change depending on the angle of placement of the epidural needle (Bosenberg, 1995).

Firstly, the specific anatomical landmarks are palpated and marked on the skin. Afterwards the point of needle insertion should be identified in the same manner as with the single-shot technique. The median approach in the L5/S1 region has proved particularly favourable for placing a catheter in the lumbar region in children (Jankovic & Wells 2001). Although identification of the intervertebral space and ligamentum flavum in most paediatric patients is easy, the ligament is less tensile in children and hence the distinctive "give" may not be felt when penetrating this layer. In addition, the distance from the skin-to-epidural space may be shallow.

The catheter is advanced a short distance past the tip of the needle provided that no resistance is experienced at any time. In neonates, infants and small children the catheter meets hardly any resistance, so that it can easily advance to upper lumbar or thoracic levels (Bosenberg *et al.,* 1988).

2.2.5 Complications

Many authors feel that only experienced anaesthesiologists should perform lumbar epidural blocks on neonates and small infants as to avoid the occurrence of disastrous complications. The less experienced anaesthesiologists should alternatively consider a single shot caudal epidural block for minor surgery or inserting a caudal catheter for more prolonged surgery (Desparment *et al.,* 1987; Murrell *et al.,* 1993; Bosenberg, 1998).

Wood and colleagues (1994) conducted a study to determine the incidence of side effects and complications with the use of epidural analgesia for 190 infants and children between 1 month and 18 years-of-age. They reported minor complications (e.g., nausea and vomiting, urinary retention, jitteriness) occurred in 67% of the sample while major complications (e.g. seizure, respiratory depression, and severe insertion site infection) occurred in only three patients (1.6%).

2.2.5.1 Dural puncture

The frequency of dural puncture, in a study conducted by Massey Dawkins (1969), occurred in 2.5% of the patients.

Bosenberg (1998) performed a series of 211 lumbar epidural blocks on infants and reported dural puncture in only one patient (0.5%). He therefore concluded that lumbar epidural anaesthesia is a safe and effective procedure to perform on neonates for major abdominal surgery if the correct technique is followed and provided that the anaesthesiologist is careful not to puncture the dura mater.

If a dural puncture occurs, the needle must be withdrawn. Another attempt is allowed, giving special attention to the cardio-respiratory monitors and to the speed of the injection. If a dural puncture occurs for the second time, the needle must again be withdrawn and the use of an alternative technique should strongly be considered (Dalens, 1995).

According to Desparment (1990), if a dural puncture occurs it would be wiser to abandon a second attempt, as he believes the risk of total spinal anaesthesia is too high due to leakage of local anaesthetic through the puncture hole in the dura to the subarachnoid space.

2.2.5.2 Vascular puncture

Although formation of a haematoma following a lumbar epidural block is rare, it is still a possible complication (Gingrich, 1968; Helperin & Cohen, 1971). Every anaesthesiologist should be extremely aware of this medical emergency as the presence of a space-occupying lesion may compress the spinal cord or nerve roots and, if the diagnosis is delayed, cause permanent damage or paralysis.

Bosenberg (1998) reported a single incidence (0.5%) of vascular puncture in an infant after performing series of 211 lumbar epidural.

See *2.1.5.2: Vascular puncture*.

2.2.5.3 Systemic toxicity

See *2.1.5.3: Systemic toxicity*

2.2.5.4 Trauma of the spinal cord and roots

Direct trauma to the spinal cord or spinal roots may occur during a lumbar epidural block. This is a rare complication, as most punctures are carried out inferior to the conus medullaris (Jankovic & Wells, 2001).

Neurological disorders may result from the insertion of the tip of the needle into the perineural sheath or within nerve fibres of the spinal roots. Injecting local anaesthetic solution into the spinal roots could tear the nerve fibres and/or produce compression lesions of the roots (Dalens, 1995).

Prevention of trauma

- Advance the needle with the utmost care.
- The procedure should be interrupted if pain occurs during the puncture, while introducing the catheter and/or during the injection (intraneural positioning) (Jankovic & Wells, 2001).

2.2.5.5 Partial or complete failure of block

See *2.1.5.6: Partial or complete failure of block.*

2.2.5.6 Lateralisation of the block

A lateralised block is a rare occurrence during lumbar epidural anaesthesia. The reason why unilateral blocks occur is not clearly understood but the occurrence can be very distressing if the side about to be operated on remains unanaesthetised (Nunn & McKinnon, 1986; Shanks, 1968; Singh, 1967).

Such lateralisation may also occur due to the presence of adhesions that developed following previous surgery, or it may be due to inflammation or infection. Most often however, complete lateralisation is due to the presence of a complete plica mediana dorsalis (see Figure 2.9), which divides the posterior epidural space into two halves (Singh, 1967; Shanks, 1968; Luyendijk, 1976; Bailey, 1986; Nunn & McKinnon, 1986).

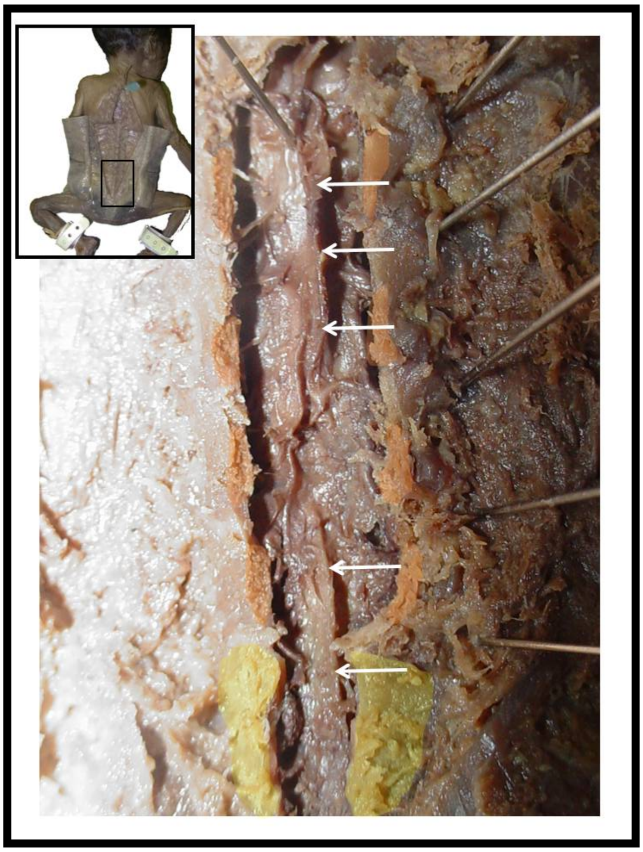

Figure 2.9: Dissection of a neonatal vertebral column.

The laminae and spinous processes of the lumbar vertebrae (highlighted in orange) and the sacrum (highlighted in yellow), have been removed. This exposed the dura mater within the vertebral canal. The white arrows indicate the presence of an incomplete median fold of dura mater (plica mediana dorsalis).

2.2.5.7 Complications related to epidural catheters

Complications with epidural catheters include misplacement, kinking, or partial removal (either while the epidural needle is withdrawn or due to the patient moving or inappropriate tension placed on the catheter).

Bosenberg (1994) described how when using certain needles the catheter can actually bend within the cuvette so that the force required to push the catheter is not transmitted down the catheter. According to him this might lead to a false impression that the catheter is entering the epidural space when it is in fact being curled up in the cuvette. If this remains undetected it could lead to failure of the block.

According to Wood and colleagues (Wood *et al.,* 1994), technical problems associated with catheters include: size, flexibility, tensile strength and hole placement. Leakage of anaesthetic solution at the catheter site was the most frequent occurrence and presented as bubbles of solution under the patient's dressing. The catheter should therefore be frequently inspected for premature discontinuations of the epidural infusion.

2.2.5.8 Complications due to "loss of resistance" with air

Although testing for "loss of resistance" using air is a reliable method, Swartz and Eisenkraft (1993), as well as, Flandin-Bléty and Barrier (1995) disagrees with the use of air to test for loss of resistance in order to locate the epidural space in children. They suggest that it should be avoided as reports indicate that children may develop a life-threatening venous air embolism from small quantities of air used during loss of resistance identification. These authors recommend the use of saline.

Injection of air into the epidural space during lumbar epidural anaesthesia may cause complications such as patchy blocks or nerve root pain due to air lock around the nerve roots (Dalens *et al.,* 1987; Beilin *et al.,* 2000; Overdiek *et al.,* 2001).

Too much air injected into the epidural space may cause subcutaneous emphysema as the air migrates (Laman & McLesky, 1978, Rozenberg *et al.,* 1988).

Saberski *et al.* (1997) searched the Medline scientific data bank from 1966 to 1995, for case reports of epidural complications following loss of resistance using air. They believe that the potential complications associated with the use of air for identifying the epidural space with the loss of resistance technique may outweigh the benefits and advocate the use of saline to identify the epidural space may help to reduce the incidence of complications.

2.2.5.9 Infection due to the placement of a continuous catheter

See *2.2.5.8: Infection due to the placement of a continuous catheter*

2.3) Paediatric infraclavicular brachial plexus block

2.3.1 Introduction

2.3.1.1 History of brachial plexus blocks

Although the infraclavicular brachial plexus block has a history that stretches as far back as 1917 (Bazy, 1917), it is still considered by many anaesthesiologists as the alternative to the axillary brachial plexus block. The latter is thought to have originated by Hirschel in 1911, six years prior to the advent of the infraclavicular block. Some inherent problems, mostly due to the equipment of the time, forced Kulenkampff to develop the supraclavicular brachial plexus block (Kulenkampff, 1911) in the same year as Hirschel's axillary block. There was no doubt that the supraclavicular block provided much better accuracy than the axillary block and the surgeons of the time readily adopted Kulenkampff's technique, because it used easily identifiable landmarks and had a high success rate. However, reports of complications, particularly pneumothorax, indicated that the supraclavicular block wasn't without risk (Raj, 1997). This led to a search for a safe alternative and ended when Bazy (1917) described his infraclavicular block. In the next decade, two modifications of Bazy's technique were proposed by Babitzki in 1918 and Balog in 1924. Although they found their failure rate to be no different to that of Kulenkampff's supraclavicular block, they stressed that it should only be considered as an alternative to the more popular supraclavicular block.

In 1973, Raj *et al.,* (1973) developed a technique whereby the local anaesthetic is deposited within the sheath found in the infraclavicular space. The rationale was that the local anaesthetic would block the three cords and branches proximal to the formation of the musculocutaneous and axillary nerves. Because the medial cord also becomes anaesthetised, the intercostobrachial nerve is included, which in turn means that a tourniquet may be used without any additional nerve blocks.

Since Raj and co-workers (1973) introduced the infraclavicular block, many modifications have been made to his technique, each one aiming to increase its efficacy and safety. Sims (1977) felt that Raj's technique was difficult to master and described more easily identifiable landmarks to determine the puncture site. Whiffler (1981) described a "coracoid block" that used the coracoid process as the bony landmark to determine the puncture site. He claimed that his technique did not require the need for a nerve stimulator, which was evident in the very high success rate of 92.5% described in his study.

Up until recently there has been a multitude of research conducted that either evaluated (Kapral *et al.*, 1999; Koscielniak-Nielsen *et al.*, 2000; Deleuze *et al.*, 2003; Fleischmann *et al.*, 2003; Haro *et al.*, 2003; Heid *et al.*, 2005), enhanced the safety and efficacy of the infraclavicular block (Mukherji *et al.*, 2000; Sandhu & Capan, 2002; Rodríguez *et al.*, 2004a; Rodríguez *et al.*, 2004b; Bloc *et al.*, 2006), compared it to the axillary block, or described new approaches to the brachial plexus (Kilka *et al.*, 1995; Wilson *et al.*, 1998; Kapral *et al.*, 1999; Salazar & Espinosa, 1999).

There are numerous reasons why the coracoid infraclavicular block is considered a safe and valued addition to any anaesthesiologist's repertoire (Desroches, 2003): (a) there is no need to abduct the arm 90^{o} in order to perform the block; (b) the coracoid process, an easily identifiable bony landmark, is used to determine the puncture site; (c) the single injection coracoid infraclavicular block takes only approximately 5min ± 2min to perform; (d) all five branches of the brachial plexus are blocked with a success rate ranging from 91% (Desroches, 2003) to 100% (Kapral *et al.*, 1999); (e) because the intercostobrachial nerve is anaesthetised in 84% of patients, the use of a tourniquet often doesn't require additional nerve blocks (Desroches, 2003).

Research on brachial plexus blocks in children was conducted in the 1950's and 1960's (Small, 1950; Clayton & Turner 1959). Small (1950) used either a supraclavicular or axillary block on 151 patients (ages ranging from 15 months to 12 years) and had a 91% success rate with only a few complications. Clayton and Turner (1959) advocated the use of an axillary block in children to avoid the possibility of causing a pneumothorax, which is a well-described complication when performing a supraclavicular block in adults. Since then, the axillary block has become the gold standard in paediatric regional anaesthesia of the upper extremity. Even though there are many studies that compared the infraclavicular and axillary blocks in adults (Kapral *et al.*, 1999; Koscielniak-Nielsen ZJ *et al.*, 2000; Gaertner *et al.*, 2002; Deleuze *et al.*, 2003; Haro *et al.*, 2003; Heid *et al.*, 2005), Fleischmann *et al.,* (2003) aimed to compare these two techniques in children. In their sample of 40 patients (age range: 1-10 years old) they found that the infraclavicular block had a higher success rate as well as a more effective sensory and motor blockade, when compared to the axillary block. This coincided with research conducted on adults that showed that there were no significant differences between the safety and success rates of the axillary and infraclavicular blocks.

One major reason for the preference of the axillary block over an infraclavicular block could be the technique. The axillary block technique hasn't changed much over the years, whereas a multitude of new and improved techniques have been devised for the infraclavicular block. There is also surprisingly little research on the anatomy of the paediatric population, especially young infants and neonates. The only literature currently available utilises techniques that were originally described for adults. The success rates are improved when a nerve stimulator was used to identify the brachial plexus (Fleischmann *et al.*, 2003; De Jose Maia & Tielens, 2004) and other regional blocks (Rodríguez *et al.*, 2004b; Bloc *et al.*, 2006; Kechner *et al.*, 2006).

Rural or district hospitals in third world countries often have to cope without the use of modern or even basic technical equipment and only the anatomical knowledge of the physician determines whether a procedure is successful or not. It is however not only in developing countries where thorough anatomy knowledge is required. Winnie *et al.,* (1975) maintained that, even with the aid of nerve stimulators, ultrasound or CT guidance, no technique could truly be called simple, safe and consistent until the anatomy has been closely examined.

Few research publications have looked specifically at the anatomy of the neonatal or infant brachial plexus. It was only in 2000, with the use of MR imaging that the brachial plexus was studied in infants and children in order to detect and correct brachial plexus neuropathies (Birchansky & Altman, 2000).

2.3.1.2 Comparison between infraclavicular and axillary blocks

Almost since its inception, the infraclavicular block has been considered to be no more than a useful alternative to other brachial plexus blocks and more specifically, the axillary block. The axillary block is still considered to be the gold standard (Tobias, 2001) despite several studies done to prove the effectiveness of the infraclavicular block and even to show the advantages it has over the axillary block. With the resurgence of research on the infraclavicular block, Raj *et al.* (1973) analysed the axillary block and found that it was limited by the fact that (a) the patient's arm had to be abducted 90^{o}, which may be difficult in patients with fractures, (b) blockade of the musculocutaneous and axillary nerve are often missed and (c) when a tourniquet is used, the intercostobrachial nerve needs to be blocked separately. More recently, Desroches (2003) attested to these findings. Another advantage of the infraclavicular block is that is a more effective technique for continuous catheter placement because the catheter can be secured to the immobile infraclavicular region (Fisher *et al.*, 2006) with a lower risk of infection (Grossi *et al.*, 1999).

Kapral *et al.* (1999) compared the lateral infraclavicular block with the axillary block for hand and forearm surgery in 40 adult patients. The lateral infraclavicular approach provided a high success rate and a greater extent of blockade compared to the axillary block. An extensive review by Tobias

(2001) looked at diverse brachial plexus blocks in children and listed some of the shortcomings of axillary blocks. These, like the ones listed by Raj *et al.* (1973), included (a) painful arm position during puncture, (b) ineffective analgesia of the upper arm (Fisher *et al.*, 1999), and (c) inconsistent block of the musculocutaneous nerve, which frequently branches from the lateral cord higher up in the axilla and is not encased in the fascia surrounding the three cords.

Fleischmann *et al.* (2003) compared the quality and spectrum of the lateral infraclavicular block to the axillary block for brachial plexus analgesia in 40 children (ages 1-10 years old) undergoing hand or forearm surgery. Based on all assessable children, the sensory blockade of the various nerves was significantly more effective in patients who had a lateral infraclavicular block (axillary nerve: $P < 0.0001$; musculocutaneous nerve: $P=0.002$; medial brachial cutaneous nerve; $P=0.008$). Motor blockade was also significantly more effective (axillary nerve: $P < 0.0001$; musculocutaneous nerve: $P=0.003$). No major complications were observed in either group. Fleischmann *et al.* (2003) suggested that the lateral infraclavicular block can be safely performed in children and that they add to the spectrum of sensory and motor blockade seen with the axillary approach.

Heid *et al.* (2005) compared the vertical infraclavicular plexus block to a modified axillary plexus block in two randomised groups of 30 patients in each group (age range 18–80 years old). They found that both techniques provided sufficient surgical anaesthesia. However, the infraclavicular plexus block more effectively blocked the musculocutaneous, axillary and radial nerves and in a shorter time.

2.3.1.3 Advantages of the infraclavicular brachial plexus block

One of the most obvious advantages of the infraclavicular block is that, unlike the axillary approach, abduction of the arm is not required. Although minimal manipulation of the extremity may be necessary to position the patient, it is not essential (Sims, 1977).

Unlike the supraclavicular and interscalene approaches, the infraclavicular block carries no risk of accidental intrathecal, epidural, or intravertebral injection; stellate ganglion block, or paralysis of the hemi-diaphragm (phrenic nerve block). It has a low incidence of pneumothorax (Whiffler, 1981; Ecoffey & McIlvaine, 1991; Wilson *et al.*, 1998; Borgeat *et al.*, 2001; Gentili *et al.*, 2002).

In order to avoid complications the needle should be pointing away from the lung and other vascular and neurological structures of the neck. Complications of the supraclavicular block (pneumothorax) and interscalene block (injection into carotid and vertebral arteries, the internal jugular vein, the subarachnoid or epidural spaces, or blocking the phrenic and vagus nerves) can be prevented (Sims, 1977).

Infraclavicular block is considered easy to teach as easily identifiable bony landmarks are used to identify the site of needle insertion (Borgeat *et al.*, 2001; Desroches, 2003). Studies have also showed that the infraclavicular block can successfully block the musculocutaneous nerve, as well as providing a complete plexus block, even with a single nerve stimulation and injection (Borgeat *et al.*, 2001; Jandard *et al.*, 2002; Dadure *et al.*, 2003; Desroches, 2003). The single injection makes it very time efficient and on average takes only five minutes to perform (Desroches, 2003) as opposed to a multiple injection axillary block that takes twice that time (Koscielniak-Nielsen *et al.*, 1998).

The infraclavicular region is also an ideal site for the insertion of continuous catheters for long term postoperative pain management. For anatomical reasons a catheter can be securely fastened to the immobile infraclavicular region (Fisher *et al.*, 2006). This allows for prolonged postoperative pain relief and can be used for physical therapy and wound dressing of the anaesthetised arm (Brown, 1993; Dalens, 2003; Dadure *et al.*, 2003). Although the use of continuous infraclavicular blocks has been well described in adults, this is not the case for paediatric patients. Fisher and co-workers (2006) reported successful placement of a catheter in the brachial plexus of a ten year old undergoing multiple operations of the fifth digit with planned range-of-motion exercises for 48 hours postoperatively.

Hadzic *et al.* (2004) compared the use of an infraclavicular block with short-acting local anaesthetic with general anaesthesia for hand and wrist day-case surgeries. A total of 62 adults were studied and it was found that the infraclavicular block was time-efficient, allowed faster recovery, had fewer adverse effects, better analgesia, and greater patient acceptance than general anaesthesia.

2.3.1.4 Disadvantages of the infraclavicular brachial plexus block

In obese patients, locating the specific landmarks for finding the correct needle insertion site could be difficult (Grossi *et al.*, 1999). This is usually not a problem when performing infraclavicular blocks on paediatric patients. Another possible disadvantage of using the coracoid process as a landmark in the very young is that it only fully ossifies during the fifteenth to the eighteenth month after birth. Ossification starts in the middle of the coracoid process, and will only fuses with the scapula at the age of fifteen (Scheuer & Black, 2000).

Although complications are rare, vascular puncture and haematoma are the most frequent. If this happens, external compression of the blood vessel and puncture site is more difficult because of the presence of the clavicle (Grossi *et al.*, 1999).

Some commonly voiced disadvantages of regional blocks include the time required to perform the block and the potential that, although the patient may have better pain relief postoperatively, he/she may experience more pain when the block wears off. In a study by Hadzic and co-workers (2004) they compared an infraclavicular block with general anaesthesia in 52 patients undergoing wrist or hand surgery and found no substance to the two above-mentioned claims.

2.3.2 Indications & contraindications

2.3.2.1 Indications

The indications for the infraclavicular block are essentially the same as for the axillary block, which can be used for intra- and postoperative pain relief of any procedure of the arm, forearm and hand (Brown, 1993; De Jose Maia & Tielens, 2004); prevention of inappropriate movements of the upper limb following plastic surgery (Dalens, 1995), tendon and tendon sheath operations (Kulenkampff & Persky, 1928), and phantom limb therapy using a continuous peripheral nerve block catheter (Haro *et al.*, 2003).

Infraclavicular block can be used during emergency procedures in conscious patients for the treatment of unstable fractures of the upper extremity (AACA, EAC, 1999); reduction of dislocations; reduction of fractures (Kulenkampff & Persky, 1928; AACA, EAC, 1999); amputations (Kulenkampff & Persky, 1928); and procedures of the upper extremities, especially when the lesions involve the forearm and/or the hand (Dalens, 1995; Wilson *et al.*, 1998).

The infraclavicular technique also simplifies blocking of the ulnar segment of the medial cord and intercostobrachial nerve, thus preventing tourniquet pain without the need for additional infiltration (Ecoffey & McIlvaine, 1991).

This block can also be considered in instances where abduction of the arm is uncomfortable or difficult, in patients with shoulder ankylosis or stiffness, upper limb fractures, previous lymphadenectomy of the axilla, and scars or local infection (Schulte-Steinberg, 1990; Ecoffey & McIlvaine, 1991; Kapral *et al.*, 1996; Wilson *et al.*, 1998; Grossi *et al.*, 1999).

2.3.2.2 Contraindications

Specific contraindications

Specific contraindications depend largely on the technique used to block the brachial plexus. Axillary blocks should be avoided in the presence of axillary lymph adenopathies, unstable fractures or lesions in which the movement of the upper extremity is prohibited (Dalens, 2003). In these cases, the use of infraclavicular blocks are ideally suited for blocking the brachial plexus, especially since the arm can remain adducted against the body using this techniques (see *2.3.4: Techniques*).

Although the lack of a nerve stimulator or imaging modalities such as ultrasound isn't an absolute contraindication, they have been shown to improve the reliability of the technique and the success rate of the block. The frequency of complications is also decreased when using nerve stimulators or ultrasound, and their use is therefore highly recommended (Tuominen *et al.*, 1987; Ecoffey & McIlvaine, 1991; Brown, 1993; Bosenberg *et al.*, 2002; Sandhu & Capan, 2002; Bigeleisen, 2007).

2.3.3 Anatomy

A thorough knowledge of the anatomical distribution of the brachial plexus is essential for performing infraclavicular blocks according to the surgical indications involved. Knowledge of potential complications associated with damage to the surrounding structures is important. The following section concentrates on the anatomy of the brachial plexus and surrounding structures as described in classical anatomy textbooks as well as from descriptive and imaging studies conducted on the area artery (Ellis & Feldman, 1993; Standring et al., 2005; Ajar et al., 2007). Although reference is made to the brachial plexus anatomy in children, there are very few studies pertaining to the anatomy of the paediatric brachial plexus. For the most part, all the anatomy described in the literature is based on adult human anatomy.

The three trunks of the brachial plexus are located posterior to the subclavian artery in the costoclavicular depression. The inferior trunk lies postero-inferiorly to the artery. At the superior border of the clavicle, after crossing over the first rib, the three trunks divide into the six divisions (each trunk will form an anterior and posterior division), which lie in relation to the first part of the axillary. These divisions pass close to the coracoid process where the medial, lateral and posterior cords form in relation to the second part of the axillary artery. At this point, the axillary nerve branch from the posterior cord and leaves the axillary sheath. The musculocutaneous nerve will branch from the lateral cord, also leaving the sheath, but slightly more distal (Standring et al., 2005). The rest of the cords will terminate at the inferior margin of the pectoralis minor muscle, at the level of the scapulohumeral joint, where the median, ulnar and radial nerves originate (Haro *et al.*, 2003) (see Figure 2.10).

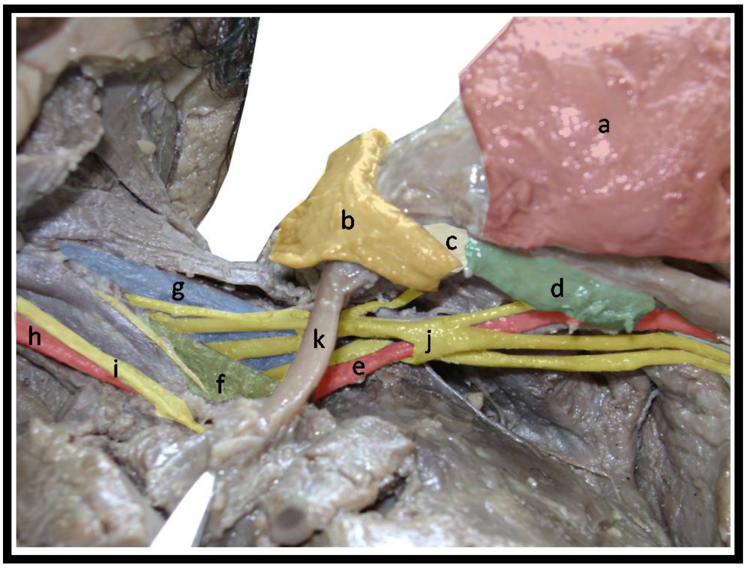

Figure 2.10: Brachial plexus and related structures within the axilla and at the root of the neck.

Structures include the: (a) pectoralis major and (b) pectoralis minor muscles, (c) coracoid process, (d) coracobrachialis muscle, (e) axillary artery, (f) anterior and (g) middle scalene muscles, (h) common carotid artery, (i) vagus nerve, (j) brachial plexus, and (k) clavicle.

2.3.3.1 Axilla and related bony landmarks

The axilla is a pyramid-shaped space located between the lateral thoracic wall and the medial aspect of the arm, which has an apex, a base and four walls. The *apex* is limited to the outer border of the first rib, the superior aspect of the scapula, and the posterior surface of the clavicle. The *base* consists of the skin and the soft tissue of the axilla. The *anterior wall* is formed by the pectoralis major and minor muscles, while the *posterior wall* is formed by the subscapularis, teres major and latissimus dorsi muscles. The *medial wall* is formed by the lateral thoracic wall and the *lateral wall* is formed by the medial aspect of the arm. Within the axilla are the axillary blood vessels, brachial plexus and a significant amount of soft tissue, consisting of lymph nodes, adipose and areolar tissue (Standring *et al.*, 2005).

The two pleural layers at the cupola of the lung are in close relation to the structures within the axilla and the space between them is only a potential one. These pleural layers could be punctured by a needle entering the axilla, which, in turn, could fill with air, resulting in a pneumothorax. During the infraclavicular block, if the needle is placed perpendicular to the table, keeping it in the sagittal plane, as was described by Wilson *et al.* (1998), there is a very small risk of entering the thoracic cavity and injuring the parietal pleura, thus causing a pneumothorax. This risk is increased if the needle is aimed medially.

2.3.3.2 Roots of the brachial plexus

The brachial plexus is formed by the ventral roots of spinal nerves C5 to T1 with some contributions from C4 and T2. It extends from the lower part of the side of the neck to the axilla. It presents as a broad plexiform arrangement at its commencement between the anterior and middle scalene muscles. It becomes narrower opposite the clavicle and again presents as a broad, dense interlacement of nerves in the axilla, dividing opposite the coracoid process into its terminal branches that supply the upper extremity (Standring *et al.*, 2005).

2.3.3.3 Trunks of the brachial plexus

The roots of C5 and C6 unite near their exit from the spine, between the anterior and middle scalene muscles, to form the superior trunk. C7 may also join this trunk near the outer border of the middle scalene muscle to form one large single cord, or remain separate to form the middle trunk of the brachial plexus. The ventral rami of the C8 and T1 spinal nerves unite deep to the anterior scalene muscle to form inferior trunk. These trunks lie posterior to the subclavian artery (superior and deep to the clavicle) and vein (which lies anterior and inferior to the artery) as the trunks accompany the vessels into the axilla (see Figure 2.10).

2.3.3.4 Divisions of the brachial plexus

Each of the trunks divides into three anterior and three posterior divisions at the lateral border of the first rib, posterior to the clavicle.

2.3.3.5 Cords of the brachial plexus

The six divisions continue into the axilla and unite to form a lateral, medial and posterior cord (named after their relationship to the axillary artery), upon emerging from the inferior border of the clavicle.

The cords are formed as follows:

- Lateral cord is formed by anterior divisions of the superior and middle trunks
- Medial cord is formed by the continuation of the anterior division of the inferior trunk
- Posterior cord is formed by all three of the posterior divisions.

2.3.3.6 *Terminal branches of the brachial plexus*

The terminal branches of the brachial plexus form the peripheral nerves that supply the upper extremity (Ellis & Feldman, 1993; Standring *et al.*, 2005). These terminal branches are:

- The musculocutaneous nerve (C5-C7), which originates from the lateral cord;
- The median nerve (C5-T1), originating from both the lateral and medial cords and has a relation with the axillary and brachial arteries;
- The ulnar nerve (C7-T1), which originates from the medial cord;
- The radial (C5-T1) and the axillary (C5, C6) nerves, which both originate from the posterior cord.

In order to be able to identify the correct muscle twitch during nerve stimulation, it is important to know the motor innervation of the terminal branches of the brachial plexus. Table 2.1 summarises the muscle innervated by each terminal branch as well as the muscle's action.

Table 2.1: Upper limb neural innervation pathways (De Andres *et al.*, 2005)

Nerve	Action	Muscle	Cord	Root
Musculo-cutaneous	Forearm flexion and supination	Biceps brachii	Lat	C5–C6
Axillary	Arm abduction	Deltoid	Post	C5–C6
Radial	Forearm extension	Triceps brachii	Post	C7–C8
		Anconeus	Post	C7–C8
	Forearm supination	Brachioradialis	Post	C5–C6
	Carpal extension	Extensor carpi radialis	Post	C6–C7
	Fingers extension	Extensor digitorum	Post	C7–C8
		Extensor indicis	Post	
Median	Forearm pronation	Pronator teres	Lat	C6–C7
	Carpal flexion	Flexor carpi radialis	Lat/Med	C6–C7
	Forearm pronation	Pronator quadratus	Med	C8–T1
	Thumb opposition	Opponens pollicis	Med	C8–T1
	Fingers flexion (I–II)	Flexor digitorum profundus (I–II)	Lat/Med	C7–T1
Ulnar	Cubital–carpal flexion–lateralization	Flexor carpi ulnaris	Lat/Med	C7–T1
	Fingers flexion (III–IV)	Flexor digitorum profundus (III–IV)	Lat/Med	C7–T1

C=cervical; Lat=lateral; Med=medial; Post=posterior; T=thoracic.

Some common responses to nerve stimulation and the course of action to obtain the proper response is summarised in Table 2.2.

Table 2.2: Responses to incorrect nerve stimulation and corrective action when performing the coracoid infraclavicular block (Claudio, 2009)

Stimulation	Motor Response	Explanation	Corrective Action
Pectoralis muscle–direct muscle stimulation	Arm adduction	Placement of the needle too shallow	Continue advancing the needle
Latissimus dorsi	Arm adduction	Placement of the needle too deep	Withdraw the needle to skin level and reinsert in another direction (superior/inferior)
Axillary nerve	Arm abduction	Needle placed too distal	Withdraw the needle to skin level and reinsert with a more proximal orientation
Musculocutaneous nerve	Biceps brachii twitch	Needle placed too proximal	Withdraw the needle to skin level and reinsert with a small distal orientation

2.3.3.7 Axillary artery and vein

The subclavian arteries arise from the brachiocephalic trunk on the right and the aortic arch on the left. They both enter the root of the neck at the medial aspect of the anterior scalene muscle and then pass posterior to this muscle. They then descend inferiorly, posterior to the midpoint of the clavicle and become the axillary artery at the lateral border of the first rib.

The pectoralis minor muscle is an important landmark in the infraclavicular region and it divides the axillary artery into three parts. The first part lies between the lateral border of the first rib and the medial border of the pectoralis minor muscle. The second part lies posterior to the muscle, while the third part lies between its lateral border and the inferior border of the teres major muscle, where the artery continues into the arm as the brachial artery.

The first part of the axillary artery is related to the three trunks of the brachial plexus. The second part is surrounded by the cords of the brachial plexus, which divide into terminal branches at the level of the third part of the axillary artery. The relationship of the terminal branches of the brachial plexus to the axillary artery is by no means constant. Theoretically the ulnar nerve is situated medially, the median nerve medially and the radial nerve posteriorly.

In a study done by Partridge *et al.* (1987) on 36 adult cadavers, they found that:

- The median nerve was situated posterior and superior to the axillary artery, the ulnar nerve slightly inferior and anterior to the artery while the radial nerve was positioned directly posterior and slightly inferior to the axillary artery in 28 cases.
- The radial nerve passed anterior to the artery and adjacent to the ulnar nerve in 4 cases.
- All the nerves passed anterior to the artery in 2 cases.
- The axillary vein was outside the neurovascular sheath in 2 cases.
- The subclavian vein passed slightly inferior and more anterior than the subclavian artery. The subclavian vein is the continuation of the axillary vein and, together with the internal jugular vein, forms the brachiocephalic vein.

2.3.3.8 Axillary sheath

This is a continuous sheath of fascia derived from the deep cervical fascia and those that surround the scalene muscles. It surrounds the brachial plexus and axillary artery as it enters axilla. A single injection of local anaesthetic within the axillary sheath can block all the components of the enclosed brachial plexus if a sufficient volume is injected into the space and provided that the distribution is free within the space (Dalens, 2003). Studies have shown the presence of a barrier between the interscalene and axillary space at the level of the coracoid process. Local anaesthetic solution injected into the axillary space, i.e., axillary block, doesn’tt necessarily spread superiorly within the sheath to block the nerves that branched proximal to this fascial barrier. These nerves include the suprascapular, axillary and, in approximately half of all patients, the musculocutaneous nerves (Thompson and Rorie, 1986; Dalens, 2003).

2.3.3.9 Paediatric anatomy

Very little information regarding the anatomy of the brachial plexus can be found in the literature or in anaesthesia and anatomy textbooks. In a textbook of regional anaesthesia, Katz (1993) stated that "except for the absence of subcutaneous fat in children, the anatomy of the neurovascular bundle in the infraclavicular and axillary regions are *presumed* to be essentially the same as in adults. The depth of the brachial plexus is shallower in children".

Birchansky & Altman (2000) evaluated the use of MR imaging for visualisation of the brachial plexus in children. Although the authors give a description of the brachial plexus in a paediatric population, it was all cited from studies conducted on adult samples. They continue to discuss the techniques of imaging of the brachial plexus and conclude that imaging of the plexii and peripheral nerves of infants and children is a challenging endeavour at the cutting edge of current MR imaging technology.

2.3.4 Techniques

2.3.4.1 Safety precautions

Care must be taken with the technique of injection. Firstly, all injections must be preceded by a negative aspiration test and an uneventful test dose. Secondly, the injection must be performed at a slow rate (over a period of one minute). If any unusual resistance is felt, the injection must be ceased immediately and the needle repositioned and repeated after careful re-evaluation of landmarks and needle insertion site.

2.3.4.2 Infraclavicular approach according to Raj et al. (1973)

The anatomical landmarks used for determining the point of needle insertion includes the entire length of the clavicle and the pulse of the subclavian artery palpated superior to the clavicle. If the pulse of the subclavian artery cannot be located; the midpoint of the clavicle can be used. The pulse of axillary artery, within the axilla, as well as the transverse process of the 6^{th} cervical vertebra (Chassaignac's tubercle) can also be palpated. Once all the above-mentioned landmarks are identified and marked, a line is drawn from Chassaignac's tubercle to the axillary artery (this line should pass over the midpoint of the clavicle). These landmarks can be simplified by drawing a straight line perpendicular to the midpoint of the clavicle. The site of puncture should lie on this line immediately lateral to the axillary artery, i.e., approximately 10mm–30mm below the clavicle, depending on the age of the child.

2.3.4.3 Technique developed by Sims (1977)

Sims (1977) reported improved landmarks for the technique described by Raj *et al.* (1973) These landmarks include the coracoid process of the scapula, the inferior border of the clavicle and, the palpable depression in the groove between the coracoid process, the clavicle, and the superior portion of the pectoralis major muscle.

After identifying these landmarks, the index finger is placed in the groove between the coracoid process and the inferior border of the clavicle. The fingertip is advanced inferiorly and medially with moderate pressure on the skin. It will fall into a depression bordered inferiorly and medially by the superior portion of the pectoralis major muscle, laterally by the coracoid process, and superiorly by the clavicle. The site of puncture is marked on the skin at the level where the depression is palpated.

2.3.4.4 Technique developed by Whiffler (1981)

Using the Raj technique, Whiffler (1981) described a needle insertion site that is medial and inferior to the coracoid process. This location was determined by palpation of vascular landmarks with the affected arm abducted and the relevant shoulder depressed. This position should move the neurovascular bundle closer to the coracoid process. The needle direction is directly posterior to avoid the occurrence of a pneumothorax.

2.3.4.5 Technique described by Kilka et al. (1995)

The following landmarks should be identified and marked: The ventral acromion process of the scapula (lateral landmark) and the jugular notch (medial landmark). After marking the above-mentioned landmarks, a point midway between these landmarks should then be marked on the patient.

2.3.4.6 Lateral infraclavicular technique as described by Kapral et al. (1996)

The patient lies supine with the arm adducted to the trunk and the elbow flexed at 90° with the forearm placed on the abdomen (Kapral *et al.*, 1996). The coracoid process should then be identified and marked.

The needle is inserted directly posterior (perpendicular to the table) until the needle comes into contact with the coracoid process. After bone contact the needle is withdrawn about 2mm-3mm and, with a parallel shift inferior, the needle is reinserted inferior to the coracoid process until the needle comes into contact with the brachial plexus.

Fleischmann *et al.* (2003) performed the lateral infraclavicular block on 20 children (ages 1-10 years old). He described a needle puncture site to be 5mm inferior of the coracoid process.

2.3.4.7 Technique described by Wilson et al. (1998)

The patient lies supine with the arm in either position, i.e., abducted or adducted against the body. The coracoid process is then palpated and marked on the patient. In the adult patient the needle insertion site is found 20mm medial and 20mm inferior from the tip of the coracoid process. These measurements are obviously different for neonates, and the measurements should be changed if used on a neonatal patient. It is not known how this will differ in neonates.

2.3.4.8 "Modified" Raj technique developed by Borgeat et al., (2001)

In 2001, Borgeat *et al.* modified the technique developed by Raj *et al.* in 1973. They evaluated the "modified" Raj technique on a sample of 150 adult patients undergoing elective surgery of the forearm wrist and hand. They obtained a very high success rate (97%) after a distal response, elicited in 118 patients.

The following landmarks are used to perform the "modified" Raj technique: The ventral acromion process of the scapula (lateral landmark), the jugular notch (medial landmark) and the pulse of the axillary artery. The pulse of the axillary artery is identified and marked together with the entire length of the clavicle. A point bisecting the line between the ventral acromion process of the scapula and the jugular notch is then marked. A skin weal is raised 10mm caudal to the inferior border of the clavicle at its central point.

2.3.4.9 Niedhart–Haro techniques (Haro et al., 2003)

This technique serves to block the trunks of the brachial plexus, or at least the anterior and posterior divisions. Using a nerve stimulator, a proximal axillary nerve or distal radial or median nerve response should be elicited. Firstly, the coracoid process of the scapula and clavicle is then palpated and marked on the patient. The needle insertion site is one fingerbreadth (the finger width of the patient should be used) medial to the coracoid process and one fingerbreadth inferior of the clavicle. The needle is then directed cranial, posterior and medial. It is important that the needle should be angulated over the skin of the chest at strictly 45^{o}.

2.3.4.10 Continuous infraclavicular block

Several studies have shown the continuous infraclavicular block to be safe and effective for postoperative pain management in adults (Salazar & Espinosa, 1999; Jandard *et al.*, 2002). In the literature there are few reports on the safety and efficiency of continuous infraclavicular blocks in children, they do however report the successful use of the continuous technique for postoperative analgesia in children without any complications (Dadure *et al.*, 2003; Fisher *et al.*, 2006).

Ponde (2008) inserted a continuous brachial plexus catheter in 25 patients (age range: 8 months to 3 years; weight range: 7kg–14 kg) scheduled for forearm and hand surgeries. The infraclavicular brachial plexus was located using a nerve stimulator. The catheter was inserted 10mm inferior and 10mm lateral to the midpoint of the clavicle and advanced toward the coracoid process maintaining an angle of 30^{o} with the skin. Continuous infusion was discontinued on the second postoperative day and intermittent boluses were administered every four to six hours. In all patients the catheter was removed after 48 hours. Twenty-four patients (96%) had a successful block. The catheter was passed with ease in all but four children. However, in these four patients, slight needle angulation and a bolus of local anaesthetic solution was required to overcome the resistance. None of the patients had catheter dislodgements or accidental removal, haemorrhagic tap, or pneumothorax. It was therefore concluded that this technique for continuous infraclavicular brachial plexus block helps secure the catheter and provides effective intra- and postoperative pain relief in paediatric patients.

2.3.5 Complications

As with other brachial plexus blocks, several complications are possible when performing the infraclavicular brachial plexus block. The most common complication reported in the literature is vascular puncture (see Table 2.3).

Table 2.3: Complications of infraclavicular blocks reported in the literature (excluding single case studies).

Author	Complications			
	Vascular puncture	Horner's syndrome	Pneumothorax	Phrenic nerve block
Raj *et al.,* 1973	Not reported			
Sims, 1977	Not reported			
Whiffler, 1981	50%	-	-	-
Kapral *et al.,* 1996	0-5%	0-4%	-	-
Salazar & Espinosa, 1999	0.001%	-	-	-
Koscielniak-Nielsen *et al.,* 2000	23%	-	-	-
"Modified" Raj (Borgeat *et al.,* 2001)	2%	-	-	-
Desroches, 2003	-	-	0.7%	-
Niedhart-Haro (Haro et al., 2003)	8-11.5%	-	0.01-0.5%	-
De Jose Maria & Tielens, 2004	1.8%	3.6%	-	-

2.3.5.1 *Vascular puncture*

As with any regional anaesthetic procedure there is the risk of puncturing blood vessels in the region of the needle insertion (McIntyre, 1999). Puncturing the axillary artery is undesirable, even though it has no major consequence in most patients, and occasionally it might lead to transient vascular insufficiency (Lennon & Linstromberg, 1983; Dalens, 1995). The literature lists the incidence of arterial puncture to be between 33%–50% as opposed to 18% for venous punctures (Haro *et al.*, 2003)

Puncturing the axillary vein could lead to the formation of a haematoma if pressure isn't applied to the punctured vessel (Lennon & Linstromberg, 1983; Jankovic & Wells, 2001). Compression of vascular structures, due to the local anaesthetic solution injected into the neurovascular axillary sheath, may also occur (Dalens, 1995).

De Jose Maria & Tielens (2004) performed the vertical infraclavicular block (as described by Kilka and co-workers (1995)) on a sample of 55 paediatric patients and reported no clinical signs of inadvertent puncture of major blood vessels. There was however a report of one mild superficial haematoma at the puncture site, which cleared up after 24 hours.

2.3.5.2 Systemic toxicity

See *2.1.5.3: Systemic toxicity.*

2.3.5.3 Pneumothorax

This can be caused when a needle pierces the parietal pleura. Although rare in modern infraclavicular blocks, a pneumothorax may occur when inappropriate insertion routes are chosen (Dalens, 1995), especially if the needle is aimed medially instead of staying in the sagittal plane. Whiffler (1981) purposely attempted in a cadaver study, without success, to penetrate the thoracic cavity using the infraclavicular block he described. The incidence of pneumothorax is dependent predominantly on the technique used, i.e., site and direction of needle insertion. This can range from anything between 0%–1.5% (Haro *et al.*, 2003).

Recent modifications to the infraclavicular block have lead to a decrease in the occurrence of a pneumothorax when performing the procedure. Raj *et al.* (1973); Sims (1977); Whiffler (1981); Kapral *et al.* (1996); Borgeat *et al.* (2001) and De Jose Maria & Tielens (2004) all attested to a 0% occurrence.

The risk of pneumothorax is always present when performing infraclavicular blocks. This was shown in the studies done by Desroches (2003) and Haro *et al.* (2003) who reported a 0.7% and 0.01%-0.5% incidence of pneumothorax, respectively. Although rare, the risk should still be taken very seriously when performing infraclavicular blocks. This is especially true in patients with distorted anatomical landmarks, obese patients where the identification of these landmarks are difficult, or in the very young where the bony landmarks have not ossified yet, making its identification difficult for the inexperienced. Crews *et al.* (2007) reported a case of pneumothorax in an adult after undergoing a coracoid infraclavicular block, described by Wilson *et al.* (1998). The authors reported using the correct measurements, but the incorrect landmark (medial instead of lateral border of the coracoid process).

2.3.5.4 Phrenic nerve block

Because of the close anatomical proximity of the cords of the brachial plexus to that of the phrenic nerve (C3–C5), injection of a large volume of anaesthetic solution could spread proximally and block the phrenic nerve on the side where the solution is injected. This complication is more common in block procedures with a more proximal needle insertion site such as interscalene (Urmey *et al.*, 1991) and supraclavicular blocks (Mak *et al.*, 2001), but there have also been reports of it occurring after vertical infraclavicular blocks (Gentili *et al.*, 2002).

2.3.5.5 Horner's syndrome

This complication is more common in supraclavicular and interscalene blocks where the incidence can be very high. For infraclavicular block, Horner's syndrome is a rare complication and Haro *et al.* (2003) reported an occurrence of between 0%–6.9% of cases.

De Jose Maria & Tielens (2004) performed the vertical infraclavicular block originally described by Kilka *et al.* (1995) on a sample of 55 paediatric patients and reported two patients developing Horner's syndrome. This disappeared spontaneously after reversal of the block. The anaesthetic solution needs to spread proximal in order to reach the cervical sympathetic chain and is less likely to occur when a more distal insertion site is used as the spread is limited proximally by discreet fascial layers (Thompson & Rorie, 1983).

2.3.5.6 Nerve injury

As with any regional anaesthetic procedure, there is always the risk of nerve injury when inserting a needle into the brachial plexus (Dalens, 1995). Clinical indications of nerve damage include paraesthesia, shooting or sharp stinging sensations, and excessive pain during needle insertion.

2.3.6 Use of nerve stimulation and other imaging modalities

2.3.6.1 Nerve stimulators and infraclavicular blocks

There are many studies that show that infraclavicular block techniques, using the coracoid process as a landmark, are safe and effective for blocking the brachial plexus (Minville *et al.*, 2005).

The number of stimulations and volume of local anaesthetic to be injected remains controversial. Although distal radial, ulnar, and median nerve motor responses are usually considered adequate for high-volume infraclavicular blocks, Bloc and co-workers (2006) performed 500 infraclavicular blocks on adult patients in order to assess the ideal *single* motor response when using low volume infraclavicular blocks. A radial response was defined as any evoked extension of the wrist (and/or fingers). Lightly holding the patient's wrist allowed the authors to distinguish between an ulnar (medial deviation of the wrist) and *median* (flexion of the wrist) response.

2.3.6.2 Ultrasound guidance for improving infraclavicular blocks

Ultrasound-guided nerve blocks are rapidly becoming popular in the field of regional anaesthesia (Ting & Antonakakis, 2007). The smaller body size of children, allows the use of high-frequency, high-resolution probes, making ultrasound particularly suitable to facilitate the practice of peripheral nerve blocks in a paediatric patient (Kim, 2009). The effectiveness of ultrasound for the use in paediatric anaesthesia has been well documented in recent years (Rapp & Grau, 2004; McCormack & Malherbe, 2008; Aziz *et al.,* 2009).

Although infraclavicular blocks with the aid of a nerve stimulator is reported to be safe and effective (Fleischmann *et al*., 2003; De Jose Maria & Tielens, 2004), in children, the vertical approach to the infraclavicular block is not recommended because any puncture halfway between the jugular incisure and the acromion carries a risk of injuring the cervical pleura (Greher *et al.,* 2002). Fleischmann and co-workers (2003) used a lateral approach below the level of the coracoid process and using nerve stimulation achieved a more effective sensory blockade of the musculocutaneous, axillary, and medial cutaneous nerve of the arm, as well as better motor blockade of the musculocutaneous and axillary nerves, when compared with the axillary block.

Ultrasound-guided infraclavicular blocks may result in shorter sensory/motor onset times than the nerve stimulator-guided technique as well as significantly longer block durations. Additionally, the block placement in conscious, sedated children with forearm fractures resulted in less discomfort using ultrasound-guided nerve blocks compared to nerve stimulation (Marhofer *et al*., 2004).

2.4) Paediatric Femoral nerve block

2.4.1 Introduction

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There has been resurgence in the use of peripheral nerve blocks for the management of postoperative pain in children. The short duration of analgesia with single-shot techniques have been overcome by placing a catheter along the nerve path for continuous analgesia well into the post-operative period (Dalens, 2003). It is also believed that the femoral nerve block is the most commonly performed lower limb block in paediatric patients and is of particular value for pain management in children with a fractured femur shaft. In this situation a femoral nerve block should be performed as early as possible to ensure the comfort of the patient during transport, physical and radiological examinations, wound dressing, and orthopaedic procedures (Dalens, 2003; Jankovic & Wells, 2001; Ronchi *et al.*, 1989).

Femoral nerve blocks have been used for analgesia in adults for a wide range of clinical procedures on the lower extremity (Nielsen *et al.*, 2003). According to a survey conducted by Buist (1990), the femoral nerve block is the most commonly performed peripheral nerve block of the lower extremity in adults. According to his findings, more than half of the anaesthesiologists that participated of the survey perform femoral nerve blocks on a regular basis.

It is also the most frequently performed lower extremity block amongst South African anaesthesiologists. A survey on the paediatric regional nerve blocks showed that 22.5% of anaesthesiologists perform femoral nerve blocks on paediatric patients (van Schoor, 2004).

2.4.1.2 Advantages of femoral nerve blocks

The femoral nerve block is a quick, safe and easy block to perform with the minimum amount of equipment necessary (Berry, 1977; Tondare & Nadkarni, 1982; McNicol, 1986; Kester Brown, 1990; Serpell *et al.,* 1991; Dalens, 1995). It is also the most common peripheral nerve block of the lower limb in children according to Dalens (1995), as it is believed that the most painful operations in paediatric practice are performed on the lower extremities. Femoral nerve blocks also provide more rapid recovery and a lower incidence of complications when compared with spinal anaesthesia for outpatient procedures (Vloka *et al.*, 1997).

When there are other injuries that contraindicate general anaesthesia, a femoral nerve block is regarded as the quickest and most effective method of pain relief for femoral shaft fractures, since systemic reactions to the block procedure in negligible (Berry, 1977).

When epidural blocks cannot be used due to infection at the site of injection, anatomical deformities of the vertebral column (i.e., spina bifida), or due to the inability to position the patient for the approach to the epidural space, the femoral nerve block - in combination with other peripheral nerve blocks, i.e., lateral femoral cutaneous nerve block, obturator nerve block and sciatic nerve block - may pose as a reliable alternative to effect analgesia of the lower limb (Dalens, 1995).

2.4.1.3 Disadvantages of femoral nerve blocks

Femoral nerve blocks are rarely performed alone and are often used in combination with other peripheral nerve blocks of the lower extremities, i.e. sciatic nerve block, lateral femoral cutaneous nerve block and obturator nerve block. Because of the complexity of the sensory supply of the lower extremities (Dalens *et al.*, 1989), surgical anaesthesia of the entire lower extremity can only be obtained when the “3-in-1” block (Winnie *et al.*, 1973) or the fascia iliaca compartment block (Dalens *et al.*, 1989) is combined with the sciatic nerve block (Katz, 1993), or when all four nerves are blocked individually.

2.4.2 Indications & contraindications

2.4.2.1 Indications

Surgical indications

The femoral nerve block is ideal for pre- or postoperative analgesia for femoral shaft fractures as studies have shown that the femoral nerve block may be superior to systemic opioid administration in providing analgesia in femoral shaft fractures (Triner *et al.*, 2004).

With femoral shaft fractures, a femoral nerve block should be performed as soon as possible after the incident to improve the clinical status of the patient during transport, physical and radiological examinations, application of wound dressings, orthopaedic procedures, as well as relieving muscle spasm around a fractured femur (Berry, 1977; Kester Brown & Schulte-Steinberg, 1980; Tondare & Nadkarni, 1982; McNicol, 1986; Denton & Manning, 1988; Berde, 1989; Ronchi *et al.,* 1989; Sethna & Berde, 1989; Kester Brown, 1990; Katz, 1993; Dalens, 1995; Markakis, 2000).

A femoral nerve block can also be used for total hip arthroplasty (Striebel & Wilker, 1993). And, in combination with a lateral femoral cutaneous nerve block, could provide excellent analgesia for operations for varicose veins of the lower limbs and of the patella (Löfström & Englesson, 1979; Fiutek & Fiutek, 2008).

Femoral nerve blocks also provides superficial surgical anaesthesia for saphenous vein stripping, often in conjunction with a block of the genital branch of the genitofemoral nerve for analgesia of the groin near the area of the incision (Vloka *et al.*, 1997), wound care, skin transplantation and muscle biopsies on the lower extremities (Jankovic & Wells, 2001). A femoral nerve block alone will suffice for vastus medialis muscle biopsies, however the lateral femoral cutaneous nerve should also be anaesthetised if a vastus lateralis muscle biopsy is intended (Maccani *et al.*, 1995; Jankovic & Wells, 2001).

The femoral nerve block, in combination with a sciatic nerve block is also a preferred technique for anaesthesia for outpatient knee arthroscopy (Goranson *et al.*, 1997; Montes *et al.*, 2008). The combined peripheral nerve block showed no significant difference in recovery or discharge times when compared with spinal anaesthesia (Montes *et al.*, 2008).

Therapeutic indications

Femoral nerve blocks prove to be excellent for postoperative pain management, for procedures performed on the hip, knee and femoral shaft, when combined with other peripheral nerve blocks of the lower limb, i.e., sciatic, obturator, and lateral femoral cutaneous nerve blocks (McNicol, 1986; Serpell *et al.*, 1991; Edwards & Wright, 1992; Striebel & Wilker, 1993; Jankovic & Wells, 2001).

It also allows for post traumatic pain management in children (Jankovic & Wells, 2001), early mobilisation after hip or knee joint operations (Serpell *et al.,* 1991; Edwards & Wright, 1992; Jankovic & Wells, 2001), treatment of arterial occlusion disease and poor perfusion in the lower extremities, and finally, post-amputation pain relief and treatment of phantom limb pain (Jankovic & Wells, 2001).

Continuous femoral nerve block indications

Continuous femoral nerve blocks are well established and commonly performed in adults. On the other hand, the performance of continuous femoral nerve blocks in infants and children, although producing effective analgesia (Tobias, 1994; Dadure & Capdevila, 2005) and having a low incidence of side effects (Dadure & Capdevila, 2005), are much less widely used.

Postoperative analgesia can be continued for days with a local anaesthetic infusion when a catheter is placed within the connective tissue "sheath" of the femoral nerve. This technique has been shown to significantly reduce systemic opioid requirements with a minimum of complications following hip or knee procedures (Dahl *et al.*, 1988; Finlayson & Underhill, 1988; Lynch *et al.,* 1991; Singelyn, 2002; Dadure & Capdevila, 2005).

2.4.2.2 Contraindications

Lower extremity compartment syndrome

Femoral nerve blocks is contraindicated in situations where a dense sensory block (i.e., in combination with a sciatic nerve block) could mask the onset of lower extremity compartment syndrome, a complication of fractures of the tibia and fibula, or especially traumatic and extensive elective orthopaedic procedures of the tibia and fibula (Beerle & Rose, 1993). This contraindication is not specific for the femoral nerve blocks but rather applies to regional anaesthesia of the lower extremity in general. The surgeons should be consulted as to the likelihood of the development of compartment syndrome and their own preferences of postoperative analgesic techniques when considering the risks and benefits of performing regional anaesthesia (Heckman *et al.*, 1994).

Haematoma in the femoral triangle

The presence of a haematoma in the femoral triangle could distort the normal anatomy of the area, thereby making the performance of the femoral nerve block inadvisable *(Jankovic & Wells, 2001)*.

Distorted anatomy

This can be due to prior surgical interventions, trauma to the inguinal and thigh regions. An informed decision regarding the risks and benefits should be taken in patients with the following clinical presentations: coagulation disorders, stable central nervous system disorders, local neural injury, contralateral neural paresis, and in patients with a femoral bypass (Jankovic & Wells, 2001).

2.4.3 Anatomy

2.4.3.1 The lumbar plexus

The lumbar plexus is formed by fusion of the ventral rami of the first four lumbar spinal nerves (L1-L4). It usually receives a branch from the 12th thoracic nerve. The 4th lumbar spinal nerve subsequently gives a branch to the sacral plexus, i.e., the lumbosacral trunk (Standring et al., 2005) (see Figure 2.11).

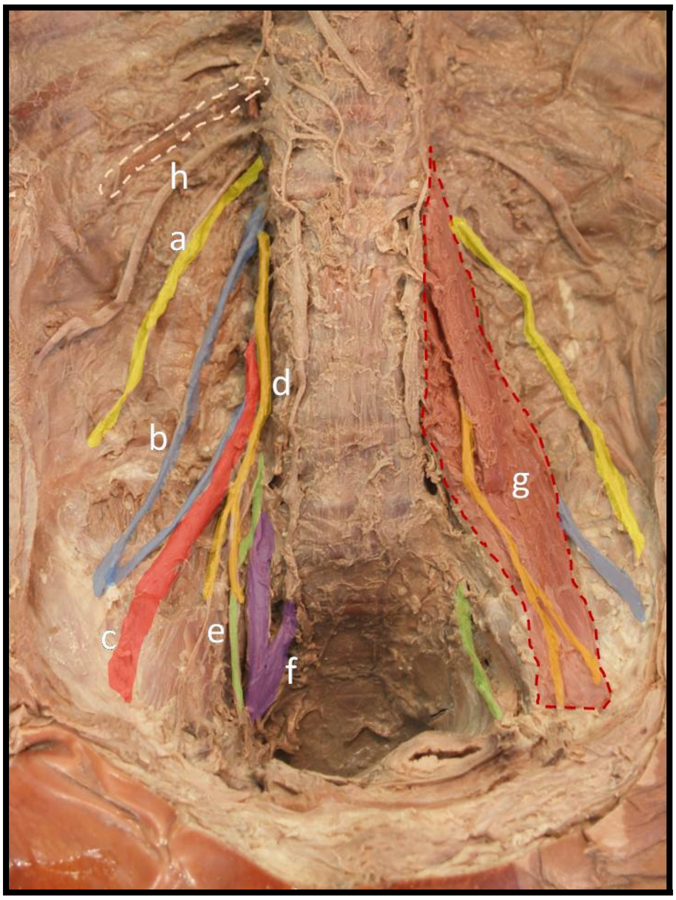


Figure 2.11: The lumbar plexus of a neonate.

Structures include the (a) ilio-inguinal and iliohypogastric nerves (yellow), (b) the lateral femoral cutaneous nerve (blue), (c) the femoral nerve (red), (d) the genitofemoral nerve (orange), (e) obturator nerve (green) and (f) the lumbosacral trunk that will form part of the sacral plexus (purple). The psoas major muscle (g) is indicated by the red dashed line. The 12th rib is indicated by the cream dashed line and subcostal nerve is also marked (h).

The lumbar plexus lies posterior to the psoas major muscle, in a fascial plane called the “psoas compartment”. This term was first used by Chayan *et al.* (1976) and is delineated by the dorsal muscles attached to the transverse processes of the lumbar vertebrae (transversospinalis and erector spinae muscles), the ventral muscles attached to the vertebral bodies and intervertebral discs (the psoas major and quadratus lumborum muscles), and lastly the bodies and transverse processes of the lumbar vertebrae.

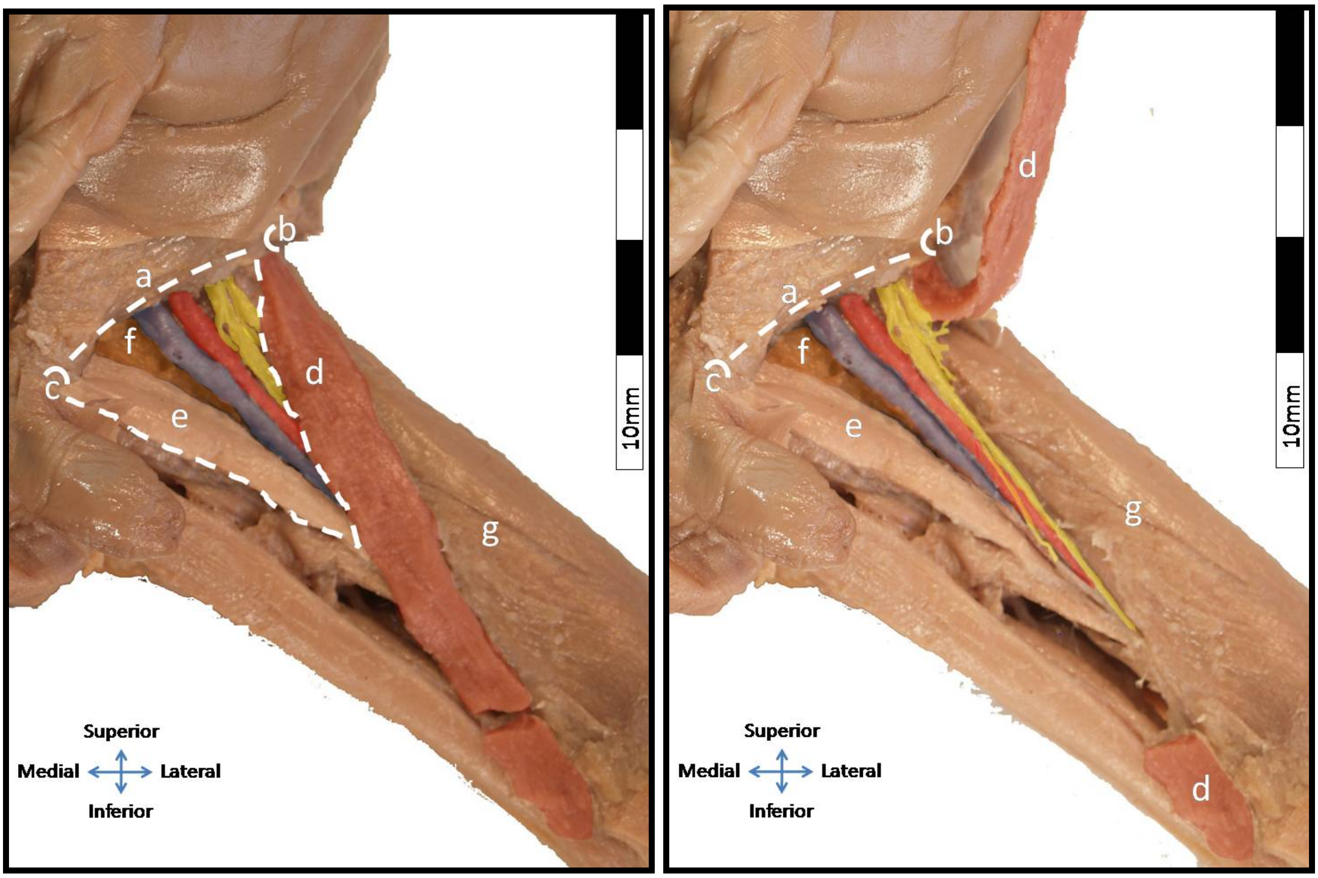
The upper parts of the plexus (T12-L1 spinal nerves) gives rise to nerves supplying the pelvis, the iliohypogastric and ilio-inguinal nerves (fibres from the L1 spinal nerve), the genitofemoral nerve (L1-L2), the branches supplying motor innervation to the quadratus lumborum (T12-L4), psoas minor (L1), and psoas major (L2-L4) muscles.

The remaining lumbar plexus nerves divide into ventral and dorsal branches. The ventral branches originate from L1-L3 spinal nerves and the femoral nerve. The dorsal branches unite to form the obturator nerve (L2-L4) and the inconstant accessory obturator nerve (L3-L4).

2.4.3.2 The femoral triangle

The femoral triangle is an inverted triangle found in the proximal aspect of the anterior thigh. Its medial border is formed by the medial border of the adductor longus muscle, while its lateral border is formed by the medial border of the sartorius muscle. The apex of the triangle is where these two muscles intersect and the base is formed by the inguinal ligament (see Figure 2.12a & b).

The floor of the triangle is formed (from medial to lateral) by the adductor longus, pectineus, and iliopsoas muscles, while the roof is formed by the fascia lata, subcutaneous fat and skin (from deep to superficial) that cover the triangle.



(a) **(b)**

Figure 2.12a: The femoral triangle (indicated by the white dashed line) dissected in order to expose its content in a neonate.

From lateral to medial, the femoral nerve (highlighted in yellow), artery (red) and vein (blue) is visible. Also visible is (a) the inguinal ligament, (b) the anterior superior iliac spine (ASIS), (c) the pubic tubercle (PT), and the (d) sartorius, (e) adductor longus, (f) pectineus, and (g) quadriceps femoris muscles.

Figure 2.12b: The sartorius muscle is reflected to show the structures travelling within the adductor canal.

These include the femoral artery and vein, nerve branches to the quadriceps femoris muscle and the saphenous nerve.

The fascia lata separates the subcutaneous tissues of the thigh from the underlying muscle and vessels. The fascia iliaca invests the iliopsoas muscle and also covers the femoral nerve. The fascia iliaca is continuous with the pectineal fascia medially (Dalens *et al.*, 1989) and is composed of two layers (Dias Filho *et al.*, 2003). Because of the round shape of the psoas muscle in cross section, the border between the psoas major and iliacus muscles often is "C"- shaped and faces medially. Of neighbouring structures, the psoas major tendon has a similar ultrasonographic appearance to the femoral nerve, but is more likely to lie deep to the femoral artery, thereby separating the femoral artery from the hip joint.

These structures are the femoral nerve, femoral artery, femoral vein, the femoral canal that contains lymph nodes (see Figure 2.13), and the lacunar ligament.

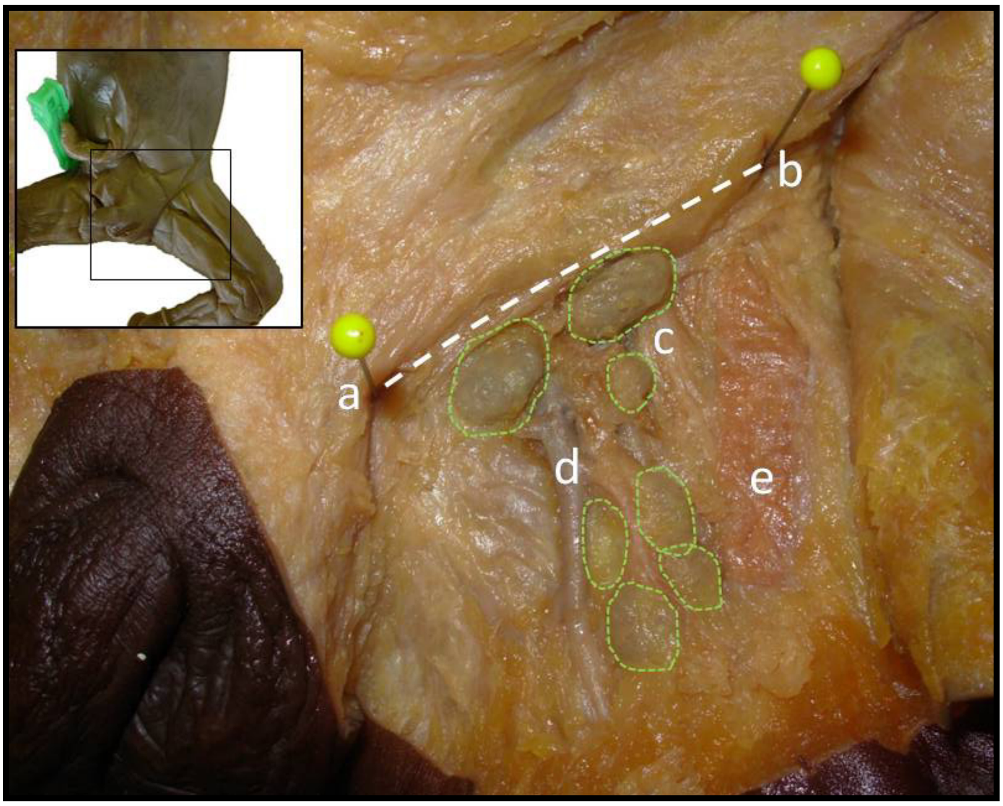


Figure 2.13: Superficial dissection of a neonatal femoral triangle with enlarged superficial inguinal lymph nodes.

Yellow pins are inserted into (a) the PT and (b) the ASIS with the inguinal ligament (indicated by a white dashed line) found between these two bony landmarks. Also visible is (c) the femoral nerve, (d) the great saphenous vein, and (e) the sartorius muscle. The superficial lymph nodes are indicated by the green dashed circles.

The femoral nerve and artery enters the femoral triangle deep to the inguinal ligament, while the femoral vein drains the lower limb and enters the abdominal cavity posterior to the inguinal ligament. The femoral canal is a potential space medial to the femoral vein. It is open to the abdominal cavity via the femoral hiatus, found posterior to the inguinal ligament.

2.4.3.3 Femoral nerve (L2-L4)

The femoral nerve is the largest branch of the lumbar plexus, and lies lateral to the femoral artery and vein. It runs within the substance of the psoas major muscle and emerges in the groove formed by this muscle and the iliacus muscle. The femoral nerve passes posterior to the inguinal ligament and enters the femoral triangle, lateral to the femoral artery. It supplies the sartorius and the quadriceps femoris muscles.

The femoral nerve runs outside the femoral sheath, which contains both the femoral artery and the vein. As it passes the inguinal ligament, it is situated deep to the femoral sheath and is therefore covered by both the fascia transversalis (anterior layer of femoral sheath) and fascia iliaca (posterior layer of femoral sheath) (Ellis, 1997).

The ultrasonographic appearance of the femoral nerve has been described in detail (Gruber *et al.*, 2003). The femoral nerve can be visualized from 100mm above to 50mm below the inguinal ligament, with best visibility near the inguinal crease. In the inguinal region the femoral nerve lies on the groove between the iliacus and psoas major muscles, approximately 5mm lateral to the femoral artery. It is wider in its medial to lateral dimension (9.8mm ± 2.1mm) than in its anteroposterior dimension (3.1mm ± 0.8mm). The femoral nerve is more likely to be oval shaped than triangle shaped (67% versus 33% in the supra-inguinal region; 95% versus 5% in the inguinal region, respectively, n=40 nerves).

As the femoral nerve passes posterior to the inguinal ligament and enters the femoral triangle, the following branches are formed by the anterior division:

- The intermediate cutaneous nerve of the thigh. This supplies the skin of the thigh down to the knee.
- The medial cutaneous nerve of the thigh, which further divides into two branches:
    - An anterior branch, which supplies the skin down to the knee.
    - A posterior branch, which runs along the posterior border of the sartorius muscle, reaches the knee - where it gives off a branch to the saphenous nerve - and provides sensory innervation to the medial aspect of the thigh.

The posterior division of the femoral nerve has the following branches:

- Motor branches to the quadriceps femoris muscle.
- Articular branches, supplying the hip joint and the knee joint.
- The saphenous nerve (with some contribution from the posterior branch of the anterior division). This is the largest terminal branch of the femoral nerve and runs within the adductor canal and descends along the tibia where it ends at the medial aspect of the ankle. The branches of the saphenous nerve give rise to the subsartorial plexus as well as infrapatellar branches forming the patellar plexus. The femoral nerve also supplies sensory innervation to the periosteum of the femur (Standring *et al.*, 2005).

2.4.3.4 Femoral blood vessels

The femoral artery and vein are enclosed by the femoral sheath and lie immediately below the fascia lata. The femoral nerve is lateral to the femoral artery, but deep to the fascia iliaca and outside the femoral sheath (Dalens *et al.,* 1989). The nerve has a close relationship to the femoral artery and femoral artery puncture could possibly occur if the correct technique is not followed or the landmarks are not properly determined.

2.4.3.5 Paediatric anatomy

According to Katz (1993), the anatomy of the femoral nerve and related structures, of and within the femoral triangle, is similar to that of adults. In children the femoral nerve and artery is separated by the termination of the psoas major muscle, this distance is approximately 10mm. The depth that the needle has to advance when performing a femoral nerve block is also much shallower.

2.4.4 Techniques

2.4.4.1 Classic femoral nerve block technique

The first step is drawing a line extending from the ASIS to the pubic tubercle (PT). This represents the position of the inguinal ligament, which is situated between these two bony landmarks. The pulse of the femoral artery is then palpated either slightly inferior to the inguinal ligament or at the inguinal crease. According to Dalens (1995), needle insertion is between 5mm-10mm lateral of the pulse of the femoral artery and between 5mm-10mm inferior of the inguinal ligament (see Figure 2.14).

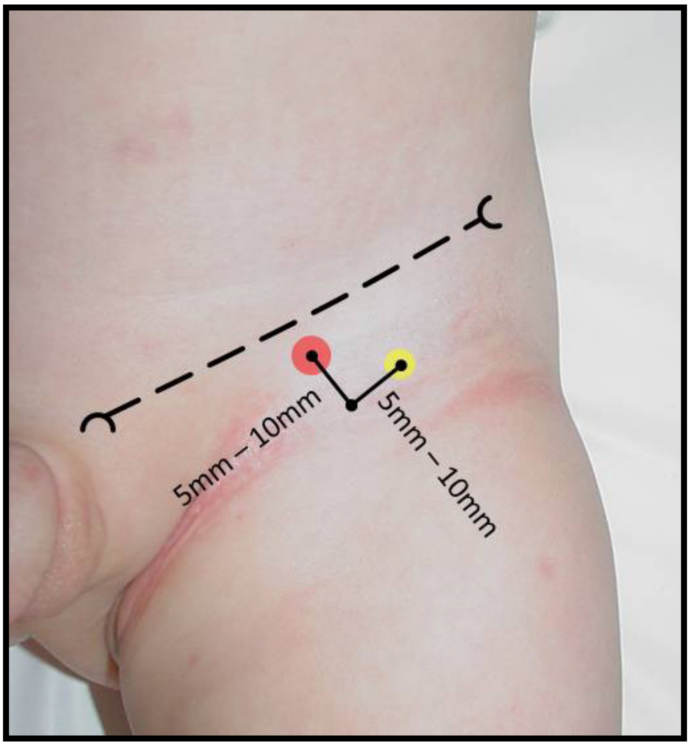


Figure 2.14: Classical femoral nerve block technique on an infant.

ASIS and PT are palpated marked on the skin. Inguinal ligament can be found between the above-mentioned landmarks. The pulse of the femoral artery (red circle) is palpated and the point of needle insertion (yellow circle) can be found 5mm–10mm lateral to the femoral artery and inferior to the inguinal ligament.

In a study conducted by Vloka *et al.* (1999), on nine adult cadavers and with subsequent follow-up clinical study on 100 adult patients undergoing a femoral nerve block, they found that the femoral nerve is most accurately and easily located at the level of the inguinal crease. This study was however conducted on both adult cadavers and patients and its relevance in paediatric femoral nerve block procedures is a question that needs to be addressed. Denton and Manning (1988) suggests a needle insertion site in children just lateral to the pulse of the femoral artery at the level of the inguinal ligament. They make no mention of the distance lateral to the femoral artery.

2.4.4.2 "3-in-1" block technique as described by Winnie et al. (1973)

The femoral nerve block should be distinguished from the "3-in-1" block, as this technique blocks the lateral femoral cutaneous nerve and obturator nerve, as well as the femoral nerve. The technique consists of injecting the local anaesthetic solution close to the femoral nerve, at the level of the inguinal ligament, and then to force the solution cephalad towards the lumbar plexus, within the perineural envelope, which is formed by the fasciae of the psoas major, iliacus, and transverse abdominis muscles.

The "3-in-1" block can be performed in almost any position provided that the femoral artery can be palpated and the inguinal ligament located. Anatomical landmarks for the "3-in-1" block are essentially the same as with the femoral nerve block technique. In contrast to the femoral nerve block, the needle is inserted in a cephalad direction at an angle of 30°-40° to the skin, almost parallel to the course of the femoral artery. The needle is advanced until muscle twitches of the quadriceps femoris muscle are elicited and movement of the patella ("dancing patella") becomes visible (Jankovic & Wells, 2001).

If the patient's condition allows it, the placement of a tourniquet at the upper part of the thigh will significantly improve the procedure by favouring the upward diffusion of the local anaesthetic solution (Dalens, 1995).

2.4.4.3 Fascia iliaca compartment block as described by Dalens et al. (1989)

Dalens *et al.* (1989) developed a new technique (fascia iliaca compartment block) after they re-evaluated the gross anatomy of the lumbar plexus nerves and fasciae of the groin and thigh in children. The authors then compared their new technique with the "3-in-1" block described by Winnie *et al.* (1973).

It was found that the hypothesis Winnie and his co-workers stated in their article was not even supported by their own data. Dalens did not observe any spread of local anaesthetic solution from within the psoas compartment, where the solution was directly introduced, towards either the femoral or obturator nerves or the lateral femoral cutaneous nerve. Furthermore, adequate analgesia of all three the target nerves was only obtained in 20% of the patients given the “3-in-1” block, whereas the fascia iliaca compartment block yielded a 90% success rate. The fascia iliaca compartment block could therefore be considered as an easy, reliable and safe alternative to the femoral nerve block.

Dalens and Mansoor (1994) also believe that the fascia iliaca compartment block is the preferred procedure for lower limb surgery in neonates as all the lumbar plexus nerves supplying the lower limb can be blocked with a single injection with the least amount of risk involved.

The fascia iliaca compartment block is based on the fact that the obturator and femoral nerves, as well as the lateral femoral cutaneous nerve pass over the iliacus muscle. Thus injecting sufficient amounts of local anaesthetic solution beneath the fascia iliaca should block these nerves by simple spread of the solution over the surface of the iliacus muscle. Ideally the patient should lie in a supine position, as for a “classical” femoral nerve block. However, any position that allows for the palpation of the femoral artery may be suitable. A line is drawn between the ipsilateral ASIS and the PT, which is subsequently divided into three equal parts.

The preparation and determination of the insertion site for a continuous catheter is the same as the classic femoral nerve block technique (see *2.4.4.1: Classic femoral nerve block technique*). After determining the insertion site, the needle is inserted at right angles to the skin while gentle pressure is exerted on the barrel of a syringe filled with local anaesthetic (Dalens, 1995). After an aspiration test and administration of a test dose, incremental injection of local anaesthetic solution is then administered.

If the needle is inserted too medially, the tip of the needle may enter the perineural sheath, resulting in a pure femoral nerve block. Therefore, the occurrence of paraesthesias (in alert patients) or muscle twitches (when a nerve stimulator is being used) requires the needle to be removed and inserted more laterally (Dalens, 1995). However, if this occurs it might be beneficial to inject a small measure of local anaesthetic solution to produce a consistent femoral nerve block before the needle is withdrawn and reinserted more laterally (Dalens, 1995).

2.4.4.4 Continuous femoral nerve block technique (Johnson, 1994)

The preparation and determination of the insertion site for a continuous catheter is the same as the classic femoral nerve block technique (See *2.4.4.1: Classic femoral nerve block technique*).

The needle is inserted in a cephalad direction at an angle of 30°-40° to the skin, almost parallel to the course of the femoral artery, and pierces the skin, fascia lata, and both the fascia transversalis (anterior layer) and the fascia iliaca (posterior layer) (Ellis, 1997). The needle tip location can be further adjusted using a peripheral nerve stimulator to achieve good quadriceps muscle contractions. Through this needle cannula, the catheter can then be threaded into the fascia iliaca sheath.

After an aspiration test and administration of a test dose, the catheter is secured and a bacterial filter is put into place. After another aspiration test, a local anaesthetic solution can then be administered on an incremental basis.

2.4.5 Complications

Very few complications have been reported during the performance of the femoral nerve block, “3-in-1” block or fascia iliaca compartment block (Winnie *et al.,* 1973; Winnie, 1975; Kester Brown & Schulte-Steinberg, 1980; McNicol, 1986; Dalens *et al.,* 1989; Dalens & Mansoor, 1994).

Lynch and co-workers (1991) placed a continuous catheter for femoral nerve analgesia in 208 adult patients (ages 18–65 years) who underwent explorative knee surgery and anterior cruciate ligament repair. The complications they encountered were few and ranged from arterial puncture (5.3%) to intravascular catheter placement (1%) and arterial bleeding after catheter placement (1%).

2.4.5.1 Vascular puncture

Vascular puncture is the most commonly occurring complication (Kester Brown & Schulte-Steinberg, 1980; McNicol, 1986; Johr, 1987; Denton & Manning, 1988; Dalens *et al.,* 1989; Dalens & Mansoor, 1994). In cases of a vascular puncture, the procedure should be halted while pressure is applied to the injured vessel for about 5–10 minutes in order to prevent haematoma formation. Another, more careful, attempt may be made (Dalens, 1995).

There is a higher risk of thrombosis in the femoral artery after an accidental puncture in children. Smith and Greene (1981) conducted a review on cases of paediatric vascular injuries and found that deliberate penetration of the femoral artery (for diagnostic purposes, i.e., blood-gas sampling) was a common cause for thrombosis in the femoral artery, which is especially hazardous in infants and children (Cahill *et al.,* 1967)

McNicol (1986) performed femoral and lateral femoral cutaneous nerve blocks on 50 paediatric patients. Blood was aspirated from the femoral artery on three occasions (6%) without the development of a haematoma and he surmised that this could have been due to the narrow gauge needle that was used for the block.

Dalens *et al.* (1989) compared the “3-in-1” block with the fascia iliaca compartment block in 60 children between 8 months and 17 years of age. In the group who underwent the “3-in-1” block, nine had to undergo a second attempt due to reflux of blood into the syringe and due to misplacement of the needle. No complications occurred in the group who underwent the fascia iliaca compartment block.

2.4.5.2 Systemic toxicity

See *2.1.5.3: Systemic toxicity.*

2.4.5.3 Nerve trauma

Another possible complication that might occur is direct neural injury that presents as weakness of the quadriceps femoris muscle, postoperatively.

The mechanism of nerve injury include direct nerve trauma from the needle, injury from intraneural injection, and compressive-ischaemic injury caused by local haematoma formation (Johr, 1987).

2.4.6 Use of nerve stimulation and other imaging modalities

2.4.6.1 Nerve stimulation

Bosenberg (1995) performed a series of 419 femoral nerve blocks on children presenting for elective of emergency lower limb surgery. Location of the femoral nerve was confirmed by the so-called "patellar kick" or "dancing patella" that is caused by the contraction of the quadriceps femoris muscle. In this study he used unsheathed needles to successfully locate the nerve. Although a slightly larger current was required to produce a motor response than has been described for sheathed needles, he still obtained a 98% success rate.

2.4.6.2 Ultrasound guidance

The femoral nerve is considered by many authors to be a beginner's block, as it is relatively easy to perform, due to the familiar and uncomplicated anatomy of the area, and the large size and superficial position of the nerve on ultrasound that makes visualisation of the nerve easy. The inguinal ligament is identified and the femoral artery pulsation palpated just below it. A high frequency linear probe is positioned transversally and the artery is identified which can be confirmed by colour Doppler. The femoral nerve can be visualised just lateral to the femoral artery as a large hyperechoic (light) rectangular or triangular structure (Aziz *et al.*, 2009).

Ultrasound guidance of the femoral nerve can reduce the volume of local anaesthetic used (Oberndorfer *et al.*, 2007) and also increase the success rate (Marhofer *et al.*, 1997). The significant failure rate when performed without ultrasound may be due to the close proximity of the fascia iliaca and fascia lata to the nerve, which may prevent appropriate spread of local anaesthesia. Dynamic visualisation of the spread of local anaesthesia is important to avoid injection above the fascia that could result in an unsatisfactory block (Aziz *et al.*, 2009).

2.5) Paediatric ilio-inguinal/iliohypogastric nerve block

2.5.1 Introduction

Repairing inguinal hernias and hydrocoeles, successfully and without complications, is an integral part of modern paediatric surgical practice. Most paediatric surgeons perform hundreds of hernia repairs each year. Given the low complication rate of hernia repair, any new approach to diagnosis or treatment must meet or exceed a high standard.

The vast majority of infants and children undergoing hernia repair require general anaesthesia. An exception to this rule would be the repair of hernias in the premature infant who may have the procedure performed under spinal anaesthesia, caudal epidural anaesthesia or an ilio-inguinal/iliohypogastric nerve block under a light general anaesthesia. The use of regional and local anaesthesia during the repair of inguinal hernia in children is designed to provide postoperative analgesia.

Caudal anaesthesia is more commonly performed by an anaesthesiologist, whereas an ilio-inguinal/iliohypogastric block can be performed by either the surgeon after exposing the nerves during surgery, or by an anaesthesiologist pre-operatively. If the ilio-inguinal/iliohypogastric nerve block is performed before the skin incision, external landmarks are used to guide the introduction of the local anaesthetic solution (Lau *et al.*, 2007).

Inserting the needle blindly does have its risks and carries a failure rate (either complete or partial) of approximately 20%–30% (Eichenberger *et al.*, 2006). One attempt to improve the success rate and the safety of the procedure was the incorporation of ultrasound guidance. Willschke and co-workers (2005) used a 10-MHz ultrasound probe to identify the ilio-inguinal and iliohypogastric nerves before infiltration of local anaesthetic solution before inguinal hernia repair in children. The anaesthetic was infiltrated under ultrasound guidance to confirm that the nerves were identified and surrounded. This strategy resulted in the use of less anaesthetic and improved pain relief. This offers a potential advantage when performing the block before the incision.

The main alternative to the ilio-inguinal/iliohypogastric nerve block is a caudal epidural block, which is very effective (Markham *et al.*, 1986; Hannallah *et al.*, 1987; Cross & Barrett, 1987; Stow *et al.*, 1988). Early research, comparing caudal epidural blocks with the ilio-inguinal/iliohypogastric nerve block, demonstrated that there was no significant proof indicating that the one technique is better than the other (Markham *et al.*, 1986; Hannallah *et al.*, 1987; Cross & Barrett, 1987; Carré *et al.*, 2001). However, Martin (1982) believes that caudal epidural blocks are not worth the time, risk and expense involved to perform on children undergoing minor surgical procedures.

2.5.2 Indications & contraindications

2.5.2.1 Indications

Anaesthetic indications

The ilio-inguinal/iliohypogastric nerve block is a technique that is safe, effective and easy to perform on neonates and infants, for a range of surgical procedures. These include elective procedures of the inguinal region such as: Inguinal hernia repair (inguinal herniorraphy), varicocoele, orchidopexy, hydrocoele surgery, and strangulated hernia with intestinal obstruction (Von Bahr, 1979; Shandling & Steward, 1980; Smith & Jones, 1982; Markham, *et al.*, 1986; Hannallah *et al.*, 1987; Cross & Barrett, 1987; Reid *et al.*, 1987; Hinkle, 1987; Brown & Schulte-Steinberg, 1988; Sethna & Berde, 1989; Schulte-Steinberg, 1990; Dalens, 1995; Dalens, 2000; Carré *et al.*, 2001;

Yazigi *et al.*, 2002; Suraseranivongse *et al.*, 2003). The ilio-inguinal/iliohypogastric nerve block is not considered as a primary anaesthetic technique, as it doesn't abolish visceral pain (see *2.5.5.7: Failure to abolish visceral pain*). It can therefore safely be combined with a light general anaesthesia for the performance of the above-mentioned procedures (Shandling & Steward, 1980; Hannallah *et al.*, 1987).

Therapeutic indications

Ilio-inguinal/iliohypogastric nerve blocks can also be used for intra- and postoperative pain management for surgical procedures on the inguinal region (Shandling & Steward, 1980; Markham *et al.,* 1986; Cross & Barrett, 1987; Hinkle, 1987; Hannallah *et al.,* 1987; Reid *et al.,* 1987; Dalens, 1995; Dalens, 2000; Jankovic & Wells, 2001).

2.5.2.2 Contraindications

There are no specific contraindications to the ilio-inguinal/iliohypogastric nerve block, apart from local infection, bleeding disorders or parental refusal. There may be uneven spread of the anaesthetic solution due to difficulty in determining the various anatomical landmarks in obese patients (Dalens, 1995).

2.5.3 Anatomy

2.5.3.1 L1 spinal nerve

The ilio-inguinal and iliohypogastric nerves are branches of the primary ventral ramus of the L1 spinal nerve, which in turn stems from the lumbar plexus and receives a branch from the T12 spinal nerve. They travel in series with the intercostal (T1-T11) and subcostal (T12) nerves, which are located in the intercostal spaces and below the 12th rib respectively.

The L1 primary ventral ramus enters the upper part of the psoas major muscle where it branches into the ilio-inguinal and iliohypogastric nerves that emerge at the lateral border of the psoas major muscle, anterior to the quadratus lumborum muscle and posterior to the kidneys.

At the lateral border of the quadratus lumborum muscle, the two nerves pierce the lumbar fascia to reach a plane between the internal oblique and transversus abdominis muscles (Ellis & Feldman, 1993; Standring et al., 2005) (see Figure 2.11).

2.5.3.2 The ilio-inguinal nerve

The ilio-inguinal nerve runs ventrally, inferior to and at a deeper plane than the iliohypogastric nerve. It perforates the transversus abdominis muscle at the level of the iliac crest and continues ventrally deep to the internal oblique muscle. It pierces both the internal and external oblique muscles to reach the lower border of either the spermatic cord (in males) or the round ligament of the uterus (in females) where it finally reaches the inguinal canal.

It contributes fibres to the internal oblique muscle, the skin of the upper medial part of the thigh, and either the skin of the upper part of the scrotum and the root of the penis in males, or the skin covering the labia major and the mons pubis in females (Ellis & Feldman, 1993; Standring et al., 2005).

2.5.3.3 The iliohypogastric nerve

The iliohypogastric nerve may be found superior to the ilio-inguinal nerve and continues ventrally between the internal and external oblique muscles. At the level of the iliac crest the iliohypogastric nerve divides into two terminal branches: a *lateral cutaneous branch*, which perforates the internal and external oblique and supplies the skin over the ventral part of the buttocks, and a *medial cutaneous branch* that continues ventrally until it gradually pierces the internal oblique muscle and later the aponeurosis of the external oblique muscle and supplies the skin covering the abdominal wall above the pubis (L1 dermatome) (Ellis & Feldman, 1993; Standring et al., 2005).

2.5.3.4 Paediatric anatomy

The anatomy of these nerves in children is described in the literature as being essentially the same as in adults with the exception that the distance from the ASIS is about 5mm to 15mm in children. The depth that the needle has to advance when performing a nerve block is also much shallower (Katz, 1993).

It is believed that this distance is much closer to the ASIS than previously thought.

2.5.4 Technique

2.5.4.1 Technique described by Von Bahr (1979)

This technique consists of multiple injections of local anaesthetic solution both subcutaneously and below the aponeurosis of the external oblique in order for the solution to reach the ilio-inguinal and iliohypogastric nerves. The patient is supine position during the injection.

The specific anatomical landmarks, the umbilicus and the ipsilateral ASIS, are palpated and then marked on the skin. The insertion site is on a line drawn from the ASIS to the umbilicus that is subsequently divided equally into four parts. The point of insertion is at the junction of the lateral one-fourth or medial three-fourths of this line (see Figure 2.15)

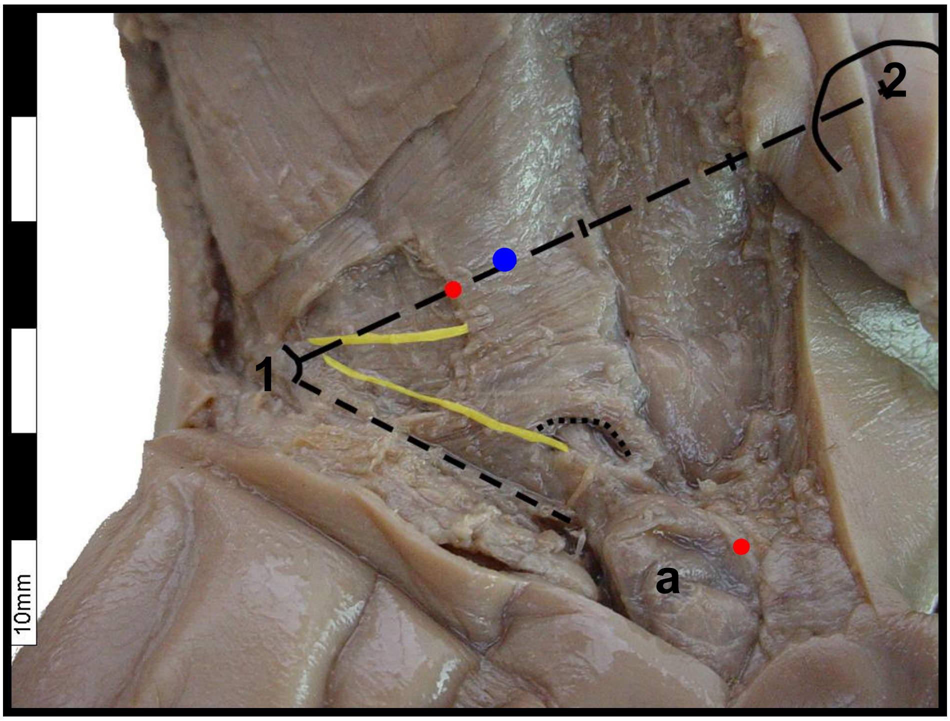


Figure 2.15: Technique described by Von Bahr (1979).

A line is drawn between (1) the ASIS and (2) the umbilicus and subsequently divided into quarters. The first point of needle insertion (red circle) is on this line at the junction of the medial quarter and lateral three quarters, while the second insertion site is slightly proximal to the PT. The ilio-inguinal and iliohypogastric nerves are highlighted in yellow. The blue circle indicates the technique described by Jagannathan and Suresh (2007). The dashed line represents the inguinal ligament, while the curved, dotted line is the conjoint tendon; (a) is the testis.

The needle is introduced into the subcutaneous tissue; a quarter of the total dose is injected at this site in a fan-like manner from lateral to medial. Aspiration should always precede every injection of local anaesthetic solution. The needle is then advanced through the external oblique where another quarter of local anaesthetic solution is injected in a fan-shaped manner.

A second point of insertion is on a line drawn between the ASIS and the PT, immediately proximal to the tubercle. The needle is advanced through the skin and the third quarter of the anaesthetic solution is injected, in a fan-like manner from lateral to medial, subcutaneously. As before, the needle is further advanced through the aponeurosis of the external oblique and the remaining anaesthetic solution is injected with the same technique as described above.

Alternative technique described by Nolte (1990)

This technique is essentially the same as described by Von Bahr (1979) except that there is no second needle insertion site (just superior to the PT). A single dose of anaesthetic solution is injected between the external and internal oblique in a fan-like manner.

Classic technique (Jagannathan & Suresh, 2007)

In their description of the paediatric ilio-inguinal/iliohypogastric nerve block, Jagannathan & Suresh (2007) describes the “classic” technique where the method of determining the needle insertion site is by drawing a line between the ipsilateral ASIS and the umbilicus and dividing it into thirds. The needle insertion site is then found between the medial two thirds and lateral third of this line (McBurney point on the right) (see Figure 2.15–the blue circle indicates the needle insertion site).

As can be seen in *5.5.1: Anatomical considerations of the neonatal ilio-inguinal/ iliohypogastric nerve block,* the needle insertion site described by Von Bahr (1979) is already far too medial to the nerves to allow for an adequate nerve block. Dividing the line between the ASIS and the umbilicus into thirds places the needle insertion site even further away from the ilio-inguinal and iliohypogastric nerves. This is evident when observing the success rate of the “classic” technique. The failure rate is reported to be between 20%–30%, due to the variability of the position of these nerves in a paediatric population and because of the distance of the needle insertion site to the nerves (Eichenberger *et al.*, 2006).

2.5.4.2 Technique described by Sethna and Berde (1989)

This technique consists of a single insertion site, where the local anaesthetic solution is injected in a fan-shaped manner at a level between the transversus abdominis and the internal oblique to block the nerves before they perforate the muscles of the anterior abdominal wall.

The ipsilateral ASIS is firstly palpated and marked on the skin. The needle insertion site is at a point 10mm medial and 10mm inferior to the ASIS (see Figure 2.16).

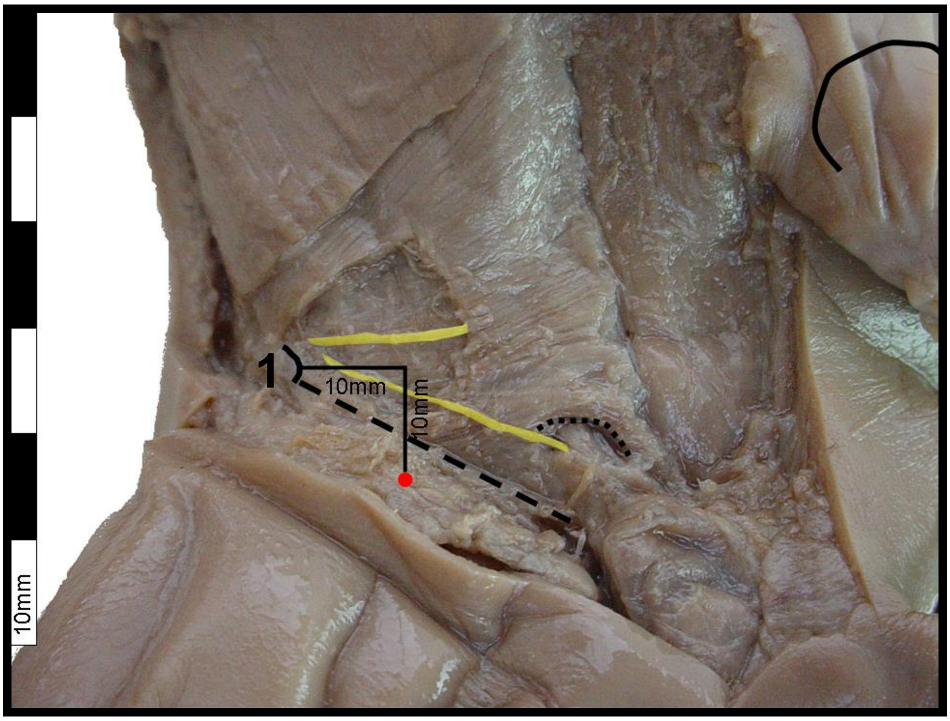


Figure 2.16: Technique described by Sethna and Berde (1989).

Needle insertion (red circle) is 10mm medial and 10mm inferior to (1) the ASIS. The ilio-inguinal and iliohypogastric nerves are highlighted in yellow.

2.5.4.3 Technique described by Schulte-Steinberg (1990)

This technique consists of a single injection at a level between the internal and external oblique muscle in a supine patient. The ipsilateral ASIS is palpated and marked on the skin. The needle is then inserted at a point just medial and inferior of the ASIS. The distance medial depends on the age of the patient - between 5mm and 10mm in infants and 20mm adolescents (see Figure 2.17).

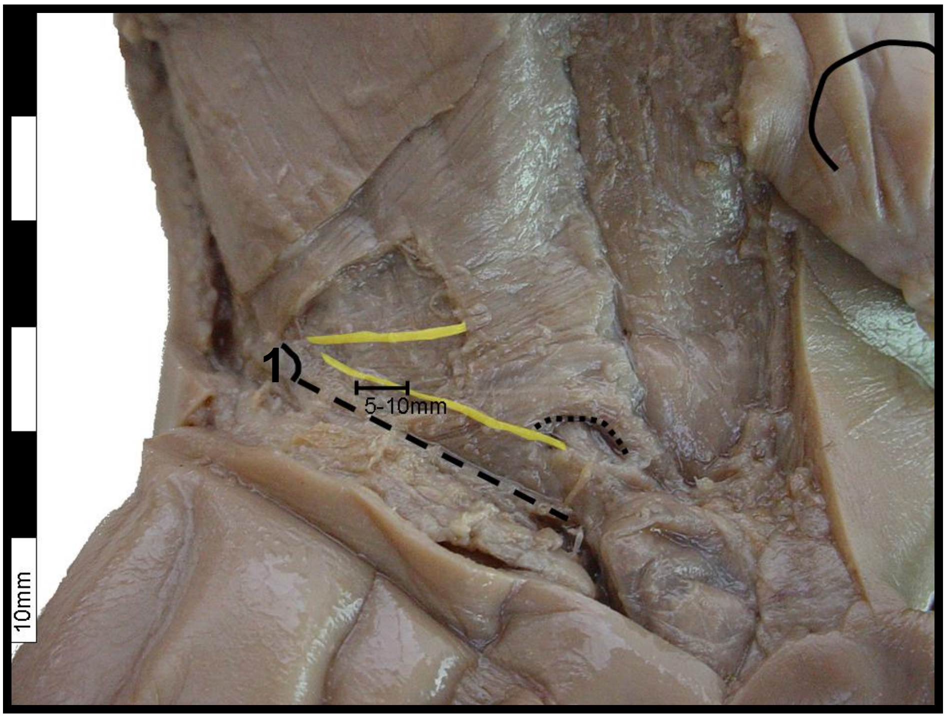


Figure 2.17: Technique described by Schulte-Steinberg (1990).

Needle insertion is between 5mm to 10mm medial and slightly inferior to (1) the ASIS. The ilio-inguinal and iliohypogastric nerves are highlighted in yellow.

Using the neonatal population, a needle was then inserted according to the methods described by Von Bahr (1979), Sethna and Berde (1989) and Schulte-Steinberg (1990), after complete dissection and identification of the nerves. The respective position of the needle and its relationship to the nerves were documented for each of the specimens dissected.

2.5.4.4 Proposed technique by the author

See *6.5.1: Anatomical considerations of the neonatal ilio-inguinal/ iliohypogastric nerve block* for the proposed technique, developed from the data obtained in this study.

2.5.4.5 Ultrasound-guided technique described by Willschke et al. (2005)

The target nerves and associated structures are identified in a cross-sectional view and the needle is inserted between the internal and external oblique muscles. Once the needle is visualised by ultrasound and is placed in an optimal position relative to the nerves, a single injection may be administered under real-time ultrasound control until both nerves are surrounded by the local anaesthetic solution.

2.5.5 Complications

Complications for the ilio-inguinal/iliohypogastric nerve block are rare (Smith & Jones, 1982; Markham *et al.*, 1986; Cross & Barrett, 1987; Reid *et al.*, 1987; Hinkle, 1987; Nolte, 1990; Dalens, 1995). Minor complications have been reported in the literature, they include:

2.5.5.1 Partial or complete failure of block

The main disadvantage of this nerve block is either a complete or partial failure (Sethna & Berde, 1989; Dalens, 1995). It is estimated that, even in experienced hands, complete failure of this block could occur in about 10% of cases. Partial failure to block these nerves occurs even more frequently - between 10 and 15%. This could even be as high as 25% (Dalens, 1995; Markakis, 2000; Lim *et al.*, 2002).

The failure rate is higher in children under 2 years of age, even when the nerve is exposed at surgery (Trotter *et al.* 1995). The failure rate was higher when the local anaesthetic was injected in two sites with the so-called "double shot technique" (Lim *et al.* 2002).

More recently, Eichenberger and co-workers (2007) reported a failure rate as high as 20%–30% in children when using the classic technique for blocking the ilio-inguinal and iliohypogastric nerves (see *2.5.4: Techniques*).

A lack of spatial knowledge regarding these nerves could be the reason for this high failure rate. It was found in a cadaveric study of 52 neonates that the ilio-inguinal and iliohypogastric nerves were located much closer to the ASIS than was previously thought *(see 5.5.1: Anatomical considerations of the neonatal ilio-inguinal/iliohypogastric nerve block)*.

2.5.5.2 Intravascular injection

There is always the risk in regional anaesthetic procedures of inserting the needle into a blood vessel. In this highly vascular area, haematoma formation is common, but of little lasting consequence (Carron *et al.*, 1984). Aspiration before injecting local anaesthetic solution is therefore recommended, although a negative aspiration test doesn't necessarily assure extravascular placement of the needle.

Vaisman (2001) reported the formation of a pelvic haematoma after an ilio-inguinal/iliohypogastric nerve block on a 40 year old patient. According to the author, because the patient had undergone previous abdominal surgery, risks beyond those normally associated with this nerve block, such as viscous and blood vessel perforation, should have been considered. Abnormal scar tissue also distorted the normal anatomy, predisposing to unusual complications, despite appropriate needle depth. There is no mention of this complication in the paediatric literature.

2.5.5.3 Systemic toxicity

See *2.1.5.3: Systemic toxicity.*

2.5.5.4 Intraperitoneal injection

If the needle is inserted too deeply, an intraperitoneal injection may be given unintentionally. Jöhr and Sossai (1999) reported a case of accidental colonic puncture after an ilio-inguinal/iliohypogastric nerve block was performed on a child.

2.5.5.5 Nerve damage

Nerve damage is always a possibility when the correct equipment for the technique is not available or if there is a lack of spatial anatomy knowledge of the ilio-inguinal and iliohypogastric nerves (Dalens, 1995). Clinical indications of nerve damage include paraesthesias and excessive pain during needle insertion in conscious patients.

2.5.5.6 Transient femoral nerve block

Associated femoral nerve block is also a recognised complication of ilio-inguinal/iliohypogastric nerve blocks (Shandling & Steward, 1980; Roy-Shapira *et al.*, 1985; Reid *et al.*, 1987; Rosario *et al.*, 1994; Szell, 1994; Rosario *et al.*, 1997; Lipp *et al.*, 2000; Lim *et al.*, 2002) with an incidence of 11% in a prospective study in children between 2 and 12 years (Lipp *et al.*, 2000).

An adult cadaver study found, by injecting methylene blue in a sample of adult cadavers, that when the solution was injected deep to the internal oblique muscle, the bony and fascial attachments of the fascia iliaca caused the injected media to track medially and collect around the femoral nerve, which lies in a natural gutter between the psoas major and iliacus muscles, within the fascia iliaca. It is therefore considered that the space between the internal oblique and transversus abdominis muscles is continuous with the fascia iliaca within which the femoral nerve is situated. This, in turn, could result in a transient femoral nerve block during the performance of an ilio-inguinal/iliohypogastric nerve block if the needle is advanced to deeply (Rosario *et al.*, 1997).

2.5.5.7 Failure to abolish visceral pain

Supplemental anaesthesia is sometimes needed for hernia orifice and spermatic cord infiltration. This nerve block is not adequate to abolish the visceral pain produced from peritoneal traction, as well as exploration and manipulation of the spermatic cord and testicles (Dalens, 1995).

Within the spermatic cord there are sympathetic fibres accompanying the arteries as well as sympathetic (from T7 spinal segment) and parasympathetic (from the vagus nerve) fibres accompanying the ductus deferens forming the testicular nerve plexus. These autonomic sensory nerves carry the impulses that produce deep visceral pain when the testis is squeezed or injured, producing excruciating visceral pain and a sickening sensation (Standring *et al.,* 2005).

Hannallah and co-workers (1987) believe that testicular innervation can be traced up to the 10th thoracic segment and therefore a T10-level block, i.e., a caudal epidural block, may be required to prevent visceral pain if the procedure requires testicular traction and/or manipulation.

2.5.6 Ultrasound guidance during the ilio-inguinal/iliohypogastric nerve block

Ultrasound guided nerve blocks offer the advantage of direct visualisation of the nerves and the adjacent anatomical structures, which is of utmost importance when performing nerve blocks on neonates and small infants. The real-time imaging of the local anaesthetic spread around the nerves maintains the quality of the block, whilst significantly reducing the amounts of local anaesthetic required, compared with the recommended dose for conventional methods (Willschke *et al.*, 2005).

In a recent study, Willschke and co-workers (2005) compared the ultrasound-guided ilio-inguinal/iliohypogastric nerve block to the conventional “fascial click” method in one hundred paediatric patients. The study showed that the by using ultrasound, the nerves were successfully visualised in all cases and a significantly smaller volume of local anaesthetic solution successfully blocked the nerves.