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PAEDIATRIC REGIONAL ANAESTHESIA:

A CLINICAL ANATOMICAL STUDY

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Submitted in fulfilment of the requirements for the degree

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Declaration of Original Work

I, Albert-Neels van Schoor, hereby declare that this thesis entitled,

"Paediatric Regional Anaesthesia – A Clinical Anatomical Study"

Which I herewith submit to the University of Pretoria for the Degree of Doctor of Philosophy in Anatomy, is my own original work and has never been submitted for any academic award to any other tertiary institution for any degree.

______________________________ ______________________________

A van Schoor **Date**

Foreword and acknowledgments

This study could not have been possible if not for the help and support of so many people in my life. I thank God for giving me the ability to undertake such a project, but also for the family, friends and dear colleagues that played such a vital role in my life.

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Summary

Paediatric Regional Anaesthesia: A Clinical Anatomical Study

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In 1973, Winnie and co-workers stated that no technique could truly be called simple, safe and consistent until the anatomy has been closely examined. This is evident when looking at the literature where many anatomically based studies regarding regional techniques in adults have resulted in the improvement of known techniques, as well as the creation of safer and more efficient methods. Anaesthesiologists performing these procedures should have a clear understanding of the anatomy, the influence of age and size, and the potential complications and hazards of each procedure to achieve good results and avoid morbidity. A thorough knowledge of the anatomy of paediatric patients is also essential for successful nerve blocks, which cannot be substituted by probing the patient with a needle attached to a nerve stimulator. The anatomy described in adults is also not always applicable to children, as anatomical landmarks in children vary with growth. Bony landmarks are poorly developed in infants prior to weight bearing, and muscular and tendinous landmarks, commonly used in adults, tend to lack definition in young children. The aim of this research was therefore to study a sample of neonatal cadavers, as well as magnetic resonance images in order to describe the relevant anatomy associated with essential regional nerve blocks, commonly performed by anaesthesiologists in South African hospitals. This research has brought to light the differences between neonatal and adult anatomy, which is relevant since the majority of paediatric regional anaesthetic techniques were developed from studies originally conducted on adult patients. Current techniques were also analysed and where necessary new improvements, using easily identifiable and constant bony landmarks, are described for the safe and successful performance of these regional nerve blocks in paediatric patients. In conclusion a sound knowledge and understanding of anatomy is important for the success of any nerve blocks. This study showed that extrapolation of anatomical findings from adult studies and simply downscaling these findings in order to apply them to infants and children is inappropriate and could lead to failed blocks or severe complications. It would therefore be more beneficial to use the data obtained from dissection of neonatal cadavers.

Opsomming

Pediatriese Regionale Narkose: 'n Kliniese Anatomiese Studie

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In 1973 het Winnie en medewerkers bevind dat geen mediese tegniek maklik, veilig of konstant genoem kan word alvorens die anatomie noukeurig bestudeer is nie. Dit is duidelik wanneer daar na die literatuur gekyk word dat a.g.v verskeie anatomiese gebaseerde studies wat met regionale narkose in die volwassene verband hou gelei het tot die verbetering van bestaande tegnieke. Derglike studies het ook aanleiding gegee vir die ontwikkeling van nuwer, veiliger, en meer doeltreffende prosedures. Narkotiseurs wat hierdie prosedures uitvoer moet 'n voldoende kennis van die anatomie, die invloed van ouderdom en grootte voortdurend in ag neem. Hulle behoort ook deeglik bewus te wees van potensiële komplikasies en slaggate van elke prosedure. Aangesien dit nodig is om goeie resultate te verkry en sodoende morbiditeit te vermy, is 'n deeglike kennis van die anatomie van pediatriese pasiënte'n noodsaaklikheid. Vir die suksesvolle uitvoering van senuweeblokke, behoort daar 'n prosedure ontwikkel te word wat die blindelingse rondsteek van 'n naald, wat aan 'n senuweestimuleerder gekoppel is, binne in 'n pasiënt te vervang. Die anatomie wat in volwassenes beskryf word is ook nie altyd toepasbaar in kinders nie, want anatomiese landmerke variëer in groeïende kinders. Benige landmerke is swak ontwikkel in jong kinders voor die ouderdom wat hulle hul eie gewig kan dra. Spier en tendineuse landmerke, wat oor die algemeen in volwassenes gebruik word, neig ook om ongedefinieer te wees in kinders. Die doelwitte van die navorsing was dus om 'n aantal neonatale kadawers, sowel as 'n aantal magnetise resonansie skanderings te bestudeer, met die doel om die relevante anatomie wat met noodsaaklike senuweeblokke geassosieerd word en wat deur narkotiseurs in Suid-Afrikaanse hospitale uitgevoer word, te beskryf. Die navorsing het die verskille tussen die anatomie in 'n neonaat en volwassene uitgelig. Dit is relevant aangesien die meerderheid van vorige paediatriese regionale narkotiese tegnieke, uit studies wat oorspronklik op volwasse pasiënte uitgevoer was, ontwikkel is. Om die suksesvolle uitvoering van hierdie regionale senuweeblokke in paediatriese pasiënte te verbeter, moes heidige tegnieke ge-analiseer word. Waar nodig was moes nuwe verbeteringe beskryf word deur van maklike identifiseerbare en konstante benige landmerke gebruik te maak met die doel om 'n volwaardige kennis en begrip van anatomie te bekom sodat enige senuweeblok suksesvol uit gevoer kan word. Hierdie studie wys dat om bloot ekstrapolasie van anatomiese bevindinge vanaf volwasse studies slegs af te skaal om dit op jong kinders te gebruik is onvanpas en kan lei tot onsuksesvolle blokke en ernstige komplikasies. Dit sal dus meer voordelig wees om data wat vanaf die disseksie van neonatale kadawers verkry is te gebruik.

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ISC:	Distance between the two sacral cornuae
SC Height:	Height of the sacrococcygeal membrane
SC Area:	Surface area of the sacrococcygeal membrane
CP-XS:	Distance (mm) between the coracoid process and the xiphisternal joint
CP-LBP:	Distance (mm) from the coracoid process to the LBP
CP-LBP %:	Distance from the coracoid process to the LBP as a percentage of the CP-XS line distance
CP-MBP:	Distance (mm) from the coracoid process to the MBP
CP-MBP %:	Distance from the coracoid process to the MBP as a percentage of the CP-XS line distance
LBP-MBP:	Distance (mm) between the LBP and MBP
LBP-MBP %:	Distance between the LBP and MBP as a percentage of the CP-XS line distance
MBP-Rib:	Distance between the MBP and the closest rib
ASIS-PT:	Distance (mm) between the ASIS and the PT
ASIS-N:	Distance (mm) from the ASIS to the femoral nerve
ASIS-N %:	Distance from the ASIS to the femoral nerve in a percentage of the ASIS-PT distance
ASIS-A:	Distance (mm) from the ASIS to the femoral artery
ASIS-A%:	Distance from the ASIS to the femoral artery in a percentage of the ASIS-PT distance
A-N:	Distance (mm) between the femoral nerve and the femoral artery
II–IH:	Distance between the ilio-inguinal and iliohypogastric nerves
CI 95%:	Confidence interval with a 95% confidence level
Lower:	Lower range of the Confidence interval with a level of confidence of 95%
Upper:	Upper range of the Confidence interval with a level of confidence of 95%

Chapter 1: Introduction

Regional anaesthesia has increased in popularity in recent years (Clergue *et al.,* 1999). This was prompted by two significant events. Firstly, the realisation that children do feel pain and require pain relief like adults; and secondly, that avoiding general anaesthesia in premature babies may have major advantages.

With the increased survival of premature infants in recent years, the number of premature neonates presenting for surgery has increased. These premature neonates present with either chronic or acute defects that urgently need to be corrected. The risk of general anaesthesia is significant in these patients as they are at a greater risk of developing respiratory failure and postoperative apnoea compared to term infants of the same age (Welborn *et al.*, 1986). Recent concerns regarding the deleterious effects of general anaesthesia on the developing brain further justifies the use of regional anaesthesia in this vulnerable age group (Sun *et al.* 2008).

The use of regional anaesthesia therefore may have considerable advantages not only in premature neonates but also in infants, children and adults. The stages of development can be classified as follows: Stage 1: Neonate or newborn (0-30 days), Stage 2: Infant or baby (1 month-1 year), Stage 3: Toddler (1-4 years), Stage 4: Childhood (prepubescence) (4-12 years), Stage 5: Adolescence and puberty (12-20 years), and Stage 6: Adulthood (21 years - death), which can be subdivided into early adulthood (21-39 years), middle adulthood (40-59 years) and advanced adults/senior citizen (older than 60 years) (Jones, 1946).

1.1) A brief history of paediatric regional anaesthesia

The 19th century was a time when fundamental changes were made in the concepts regarding medicine. This is especially true for the speciality of regional anaesthesia. It is also the period regarded as the birth of modern regional anaesthesia (Bonica, 1984; Dalens, 1995). The thought that the heart is the centre for pain reception was discounted and Bell in 1811 and

Magendie in 1822 showed that both motor and sensory impulses were relayed by the nerve tracts. By 1840, Muller established that the brain is the centre for perception and received all sensory information, including pain stimuli (Dalens, 1995).

August Bier is commonly regarded as the “father of regional anaesthesia” and discovered the “cocainization of the spinal cord”, using a spinal anaesthetic technique (Fortuna & de Oliveira Fortuna, 2000). Since then, the regional anaesthetic techniques of the time included spinal, caudal epidural and supraclavicular brachial plexus blocks. These procedures gained enthusiastic acceptance by the anaesthesiologists of the time (Bainbridge, 1901; Farr, 1920; Campbell, 1933). However, these procedures gradually fell into disuse and almost came to a complete halt after the Second World War. This was mainly due to the development of new anaesthetic agents and improved techniques for general anaesthesia, which were safer and more reliable to use.

The nineteen seventies saw a re-emergence of paediatric regional anaesthesia. Studies conducted by Lourey and McDonald (1973), Kay (1974) and Melman *et al.* (1975) caused a resurgence in the popularity of paediatric regional anaesthesia. The concept that regional and general anaesthesia can be used in a complimentary fashion, rather than being in contention with each other, also gained increasing acceptance (Dalens, 1995).

This increase in regional anaesthesia could be attributed to the constant refinement, and/or development of new techniques. Research into newer, safer and better local anaesthetic solutions, as well as the use of continuous infusions through pumps, has offered new ways of providing pre- and post-operative analgesia to patients scheduled for paediatric surgery (Cook *et al.*, 1995). With the above-mentioned advances in the field of anaesthesiology, the need for a strict protocol for administration, with reliable equipment, well-trained and alert personnel, become even more important (Fortuna & de Oliveira Fortuna, 2000).

1.2) The importance of clinical anatomy in regional anaesthesia

Despite all the opportunities in medical research today, as well as the advances made in medical technology, the effective performance of clinical procedures still rests on a solid anatomical basis. This is even more important for medical practitioners in developing countries where technology is often lacking and they are dependent on their anatomical knowledge for the successful performance of clinical procedures (AACA, EAC, 1999).

The practice of regional nerve blocks relies heavily on a sound knowledge of clinical anatomy (Winnie *et al.*, 1975). This is especially true for anaesthesiologists who perform these blocks on paediatric patients (Bosenberg *et al.*, 2002). Clinical procedures, such as regional nerve blocks, which either fail to achieve their objective or that result in complications, can often be linked to a lack of understanding, or even misunderstanding, of the anatomy relevant to the specific procedure (Ger, 1996; AACA, EAC, 1999).

Winnie and co-workers (Winnie *et al.*, 1973) states that no technique could truly be called simple, safe and consistent until the anatomy has been closely examined. This is quite apparent when looking at the literature where many anatomically based studies regarding regional techniques have resulted in the improvement of the technique, as well as the development of safer and more efficient methods. Anaesthesiologists performing these procedures should have a clear understanding of (a) the anatomy, (b) the influence of age and size, and (c) the potential complications and hazards of each procedure to ensure good results (Brown, 1985). Ellis and Feldman (1993) stated that anaesthesiologists required a particularly specialised knowledge of anatomy, which in some cases should even rival that of a surgeon. There is however a distinct lack of studies focusing on the anatomy of a paediatric population and relating it to a clinical setting (van Schoor *et al.*, 2005). The anatomy described for paediatric patients are in most instances, obtained from adults and could be flawed (see Table 3.1 for an example).

Performing regional anaesthetic procedures on paediatric patients have some additional complications and problems associated with it. Many anaesthesiologists may not be comfortable with working on a dose/weight basis. Most importantly, many anaesthesiologists not used to working with paediatric patients may lack the knowledge of the relative depths or position of certain key anatomical structures, as it is known that the anatomy of children of different ages may differ to a greater or lesser degree from that of adults (Bosenberg *et al.*, 2002, Brown, 1985, Brown & Schulte-Steinberg, 1988, Katz, 1993). A thorough knowledge of the anatomy in children is therefore essential for successful nerve blocks and it cannot be substituted by probing the patient with a needle attached to a nerve stimulator, while the effective use of ultrasound requires a sound knowledge of the anatomy of the specific region. The anatomy described in adults is not always, and in most instances not applicable, to children of different ages as anatomical landmarks in children vary with growth. Bony landmarks (e.g. the greater trochanter of the femur) are poorly developed in infants prior to weight bearing. Muscular and tendinous landmarks commonly used in adults, tend to lack definition in young children partly because of poorer muscle development (Bosenberg *et al.*, 2002), but also because they require patient cooperation to locate them. Most children are under sedation or general anaesthesia when the nerve block is being performed (Bosenberg *et al.*, 2002, Armitage, 1985). Finally, classical anatomical landmarks may be absent or difficult to define in children with congenital deformities (Bosenberg *et al.*, 2002).

1.3) Indications and limitations of paediatric regional anaesthesia

Regional anaesthesia has advantages over general anaesthesia since it covers not only the intra-operative but also the postoperative period. Regional anaesthesia can be used to treat both acute and chronic pain and, in addition, it also provides both sympathetic and motor blockades (Saint-Maurice, 1995). Like all clinical procedures, the indications of regional anaesthetic techniques is based on well-established criteria, such as patient safety, quality of analgesia, duration of surgery, and whether it is a minor or major surgical procedure (Melman *et al.*, 1975; Armitage, 1985; Saint-Maurice, 1995, Markakis, 2000, Wilder, 2000).

Indications should not be decided by the subjective preferences of the anaesthesiologist or on the basis of mastery of the specific technique (although this is vital when the procedure is actually performed), but solely on whether the technique is required by careful examination of the indications (Saint-Maurice 1995). In order to select the best anaesthetic technique available, the benefits and risks of the regional nerve block should first be weighed against the advantages and disadvantages of all other available techniques of analgesia (Dalens & Mansoor, 1994).

1.3.1 General indications of regional anaesthesia

Patients often have certain medical conditions, where the use of regional nerve blocks would be an advantage, these include:

1.3.1.1 Disorders of the respiratory tract

The presence of respiratory diseases is in most cases (except the interscalene block, which has a high incidence of blocking the phrenic nerve) an indication for the use of regional anaesthesia. A regional nerve block can safely be performed on paediatric patients with respiratory distress, provided that the needle insertion, as well as the surgical site, is easily accessible. In certain cases, regional anaesthesia can be performed under mild general anaesthesia, after the patient has been intubated. In these situations, peripheral nerve blocks may be more preferable than central blocks. The advantages of combining both regional and general anaesthesia include reducing the requirements for intravenous and inhalational agents, thereby decreasing the risk of complications and also decreasing the recovery time. The patient should be extubated only when fully conscious and with the effect of anaesthetic inhalant worn off. This will allow the anaesthesiologist to effectively avoid aspiration (Saint-Maurice, 1995).

1.3.1.2 Disorders of the central nervous system

This is often considered to be a contraindication for performing regional nerve blocks. It is however more likely that an anaesthesiologist would refrain from performing regional nerve blocks on these patients more from the fact that there is a concern that the regional nerve block might worsen the disease state. The only true contraindications for performing regional nerve blocks on these patients are mechanical (neuropathy) and infectious conditions (infections in the vicinity of the block). Nevertheless, all children with disorders of the central nervous system should undergo careful evaluation before performing any regional nerve block on them. A neurologist should preferably do the evaluation and, as always, the risk *versus* benefit ratio should be carefully examined. (Saint-Maurice 1995)

1.3.1.3 Myopathy and myasthenia

Regional anaesthesia is especially indicated for patients with muscular dystrophy because it avoids the complications associated with general anaesthesia, particularly malignant hyperthermia. Unfortunately, due to the various anatomical deformities often found in these patients, certain regional nerve blocks might be more difficult to perform (Saint-Maurice 1995).

1.3.2 General contraindications or limitations of regional anaesthesia

Regional anaesthesia has a very important place in children. Like any technique, it has its distinct advantages and specific indications. However, it also has limitations, disadvantages and contraindications that should be taken into account when performing regional blocks. Although contraindications are block dependant and should be known before attempting any regional nerve block, general contraindications for regional anaesthesia include:

1.3.2.1 Patient refusal

Patient refusal is an absolute contraindication to regional anaesthesia. Appropriate information should be given to the patient regarding the technique, its advantages, disadvantages and potential complications. Informed consent must be obtained (Eledjam *et al.*, 200).

1.3.2.2 Local infections at the needle insertion site

Skin infections at the needle insertion site are an absolute contraindication to regional anaesthesia (Ecoffey & McIlvaine, 1991). This is also true for inflammation of the lymph nodes near the site of needle insertion.

1.3.2.3 Septicaemia (presence of pathogens in the blood)

1.3.2.4 Coagulation disorders

Coagulation disorders, as well as patients who are undergoing antithrombotic or anticoagulant treatment are contraindications to a regional block because of the potential risk of haematoma formation (Dalens, 1995; Ecoffey & McIlvaine, 1991). Most of the complications have been described with epidural anaesthesia due to multiple traumatic vascular punctures and needle placement difficulties (Dalens, 1995).

1.3.2.5 Neurological diseases involving the peripheral nerves (neuropathy)

Although neuropathy (due to neurological or metabolic diseases) is not an absolute contraindication to perform a regional block, a clear benefit over general anaesthesia should be made (Ecoffey & McIlvaine, 1991).

1.3.2.6 Allergy to the local anaesthetic solution

Less then 1% of all adverse reactions to local anaesthetics are due to patient allergy to the solution (Ramamurthi & Krane, 2007). Ester-linked local anaesthetics which are metabolized to para-amino benzoic acid (PABA) are far more likely to be associated with allergic reactions compared to amide local anaesthetics. Allergic reactions with amide local anaesthetics have yet to be reported in medical literature, although preservatives like methylparaben, present in many commercial preparations of amide local anaesthetics, are responsible for occasional allergic reactions (Naguib *et al.*, 1998). Ester local anaesthetic allergies are true anaphylactic IgE-mediated allergies and not anaphylactoid reactions more commonly associated with other drugs used in the practice of anaesthesia (Ramamurthi & Krane, 2007).

1.3.2.7 Lack of training

Adequate skills regarding a specific technique are essential for a successful procedure to avoid complications and malpractice claims. Skills and expertise are key points to success in regional anaesthesia (Eledjam *et al.*, 2000).

1.4) Equipment used for paediatric regional anaesthesia

The importance of selecting the appropriate devices and have them readily available when performing a regional block in children has long been underestimated and virtually all types of needles have been used for almost all types of block procedures (Dalens, 1999). Specifically designed needles and catheters are currently available for paediatric regional anaesthesia and it is now well established that a significant proportion of complications are directly related to the use of the wrong device (Giaufre *et al.*, 1996). The importance of the correct equipment for a successful block was further confirmed in a survey of South African paediatric anaesthesia (van Schoor, 2004).

Dalens (1999) stated that in addition to skin preparation solutions and sterile drapes to protect the site of puncture from bacterial contamination, the materials required to perform local or regional anaesthesia are rather simple but, nevertheless, specific. Sterile needles specifically designed to perform the relevant technique have to be used in children. He summarised the relevant equipment in a table (see Appendix A).

An intravenous cannula should always be inserted in either the upper or lower limb in case of local anaesthetic toxicity caused by an accidental intravenous injection, or profound sympathetic blockade from a high epidural block. Light general anaesthesia is normally given to the paediatric patient. The procedure must be carried out with a strict aseptic technique. The skin should be thoroughly prepared and sterile gloves must be worn as infection in the caudal space is extremely serious (Jankovic & Wells, 2001).

1.5) Imaging techniques used to aid in regional anaesthesia

1.5.1 Nerve stimulators and regional anaesthesia

The idea of stimulating a motor nerve in order to determine the ideal injection site for regional anaesthesia was first suggested by Von Perthes in 1912. Although, only within the past twenty years, have peripheral nerve stimulators (see Figure 1.1) become popular as clinical and teaching tools in regional anaesthesia practice (Visan *et al.*, 2002). Nerve stimulators enable confirmation of the correct needle placement without inducing paraesthesia (Vloka *et al.*, 1999) and, in turn, allow anaesthesiologists to perform the block in sedated or anaesthetised patients (Brown, 1993).

Figure 1.1: Some commercially available peripheral nerve stimulators (Vloka *et al.*, 1999).

Since Pither *et al.* (1985) made recommendations on the use of nerve stimulators in regional anaesthesia; there has been an explosion of new and varied nerve stimulators available on the market. Although the advances in the technology surrounding nerve stimulators have made their use to localise the desired nerve(s) much easier, the wide variety of functions and features can be confusing for first-time users. This could in turn leave anaesthesiologists with an insufficient understanding of the basic principles behind nerve stimulation.

1.5.1.1 Basic principles of nerve stimulation

Nerve stimulation techniques rely on the elicitation of appropriate motor responses to electrical current to confirm the proximity of the needle or catheter to the target nerve structure. Typically, nerve stimulation involves application of electrical current once the needle/catheter has penetrated the subcutaneous tissue, although surface mapping by transcutaneous electrical stimulation of peripheral nerves in children has been described (Bosenberg *et al.*, 2002).

The relationship between the strength and duration of the current and the polarity of the stimulus is of particular importance to nerve stimulation (Pither *et al.*, 1985). To propagate a nerve impulse, a certain threshold level of stimulus must be applied to the nerve. Below this threshold, no impulse is propagated. Any increase of the stimulus above this threshold results in a corresponding increase in the intensity of the impulse (Tsui, 2007).

It is also possible to estimate needle-to-nerve distance by using a stimulus of known intensity and pulse duration. A clear motor response achieved at 0.2 to 0.5 mA indicates an appropriate needle-to-nerve relationship. The tip of the needle is therefore close enough to the desired nerve to cause an effective block if the anaesthetic solution is administered. Nerve stimulation at <0.1 mA may indicate intraneural placement of the needle. This should be avoided as it may lead to nerve injury if the local anaesthetic is injected (Visan *et al.*, 2002).

Another important aspect to remember is that the cathode can be up to four times more effective at nerve depolarization than the anode, and thus it is the preferred stimulating electrode. Some problems may arise when nerve stimulators are not made to connect properly for other manufacturers' stimulating needles and an adapter would therefore be required. It is best to use similarly manufactured stimulators and needles if possible (Tsui, 2007).

A surface electrode is required to complete the electrical circuit and the optimal position to place the electrode on the patient's body during peripheral nerve blocks is controversial (Tsui, 2007). According to Hadzic and co-workers (2004), this is less critical than was previously thought due to the introduction of constant-current nerve stimulators.

1.5.1.2 Essential features of nerve stimulators

According to Visan *et al.* (2002), the essential features of the nerve stimulator include:

- *Constant current output:* This assures automatic compensation for changes in tissue or connection impedance during nerve stimulation, in turn, assuring accurate delivery of the specified.

- *Current display:* The ability to read the current being delivered is of utmost importance because the current intensity at which the nerve is stimulated gives the operator an approximation of the needle-to-nerve distance.
- *Current intensity control:* Current can be controlled using either digital means or an analogue dial. Alternatively, current intensity can be controlled using a remote controller, such as a foot pedal, which allows a single operator to perform the procedure and control the current output (Hadzig & Vloka, 1996)
- *Short pulse width:* Many peripheral nerve stimulators lack the ability for the user to control pulse width.
- *Stimulating frequency:* Nerve stimulators with a 1 Hertz (Hz) stimulation frequency (1 pulse per second) are the norm. A model with a 2 Hz stimulation frequency may prove to be more clinically advantageous because it allows faster manipulation of the needle.
- *Malfunction indicator:* This is a necessary feature because the operator should know when the stimulus is not being delivered because of malfunctions such as poor electrical connection and/or battery failure.

A study conducted by Bosenberg (1995) revealed that a relatively cheap, unsheathed needle could be successfully used to locate peripheral nerves with the aid of a nerve stimulator in anaesthetised children. Although a slightly larger current is required to produce a motor response when compared to sheathed needles, a success rate of greater than 98% underlines its value as a cost-effective teaching tool, and the ease with which a technique can be mastered when using a nerve stimulator.

Surface nerve mapping or transdermal nerve stimulation is a modification of the standard nerve stimulator technique and can be used to trace the path of a nerve prior to skin penetration. Surface nerve mapping could prove to be most useful in paediatric patients since anatomical landmarks are less precisely defined (Bosenberg *et al.*, 2002), and paediatric patients are at the greatest risk for complications of regional anaesthesia.

(Giaufre *et al.*, 1996) Nerve mapping offers a further dimension for localisation of superficial peripheral nerves prior to skin penetration in both infants and children (Bosenberg *et al.*, 2002).

For locating superficial nerves, in patients of normal weight or paediatric patients, a special device can be used together with the nerve stimulator to trigger a transdermal response from the target muscle. The pulse duration of the device is set to 1 millisecond (ms) and the current range to 5 mA. In this way, it is possible to get a better fix on the puncture site or even correct the puncture direction. This also serves as an invaluable training tool for anaesthesiologists. Not only can the correct stimulus response be demonstrated but needle localisation and direction can be practiced before the needle is inserted (www.nerveblocks.net, 2009)

Bosenberg and co-workers (2002) stated that peripheral nerve stimulation should not be a substitute for sound anatomical knowledge and careful technique. In a study, they did however show that using a nerve stimulator does provide a greater degree of reliability and accuracy in finding the correct needle insertion site, compared to using only anatomical landmarks or paraesthesias to perform nerve blocks. It is also a safer technique for attaining close proximity to the actual nerve.

A combination of using a nerve stimulator/surface nerve mapping device and anatomical landmarks seem to be the best method for accurate, safe and successful blockade (Bosenberg, 1995).

1.5.2 Ultrasound guidance and regional anaesthesia

1.5.2.1 Advantages of ultrasound guidance during regional anaesthesia

The use of ultrasound guided techniques for performing regional anaesthesia has greatly increased within the past decade. Recent studies show that ultrasound guided nerve blocks may have many advantages over traditional techniques. These studies reported less vascular puncture, higher success rates, and a reduced dose of local anaesthetic required in order to obtain a successful block (Marhofer *et al.*, 2004; Sandhu *et al.,* 2004; Bigeleisen, 2007).

1.5.2.2 Basic principles of ultrasound

Ultrasound machines can typically deliver sound waves of 2–15 MHz. Characteristically, the higher the frequency, the less the penetration depth but the better the resolution and *vice versa*. In the paediatric population, a high frequency linear probe is usually sufficient as the anatomy is much smaller and most structures being blocked are reasonably superficial. Sound waves propagate through the body and the amplitude of the reflected signals is based on different acoustic impedance of human tissue and fluids. Signals of least intensity appear dark (hypoechoic) or black as with body fluids, while signals of greatest intensity appear white (hyperechoic) as with bones and with intermediate intensities appearing as shades of gray. A common artefact is anisotropy, which is caused by an incidence angle of less than 90^o between the probe and the structure being imaged. This results in poor or no reflection of the ultrasound beam from the tissue and, consequently, an inability to visualise it. The ultrasound beam must be oriented perpendicularly on the nerve axis to be able to visualise it (Marhofer *et al.* 2005; Brain *et al.*, 2007).

1.5.2.3 Ultrasound guided regional anaesthesia:

The success of ultrasound guided nerve blocks relies on several aspects (Perlas & Chan, 2008):

- *Quality of image:* This depends on the quality of the ultrasound machine and transducers, proper transducer selection (e.g., frequency) for each nerve location, sonographic anatomy knowledge pertinent to the block, and good hand-eye coordination to track needle movement during advancement.

- *Patient position and technique:* Optimal patient positioning and sterile technique is essential. This is particularly important for the continuous catheter technique when it is necessary to use sterile conducting gel and a sterile plastic sheath to fully cover the entire transducer.
- *Nerve stimulation:* Nerve localisation by ultrasound can be combined with nerve stimulation. Both tools are valuable and complementary and not mutually exclusive. Ultrasonography provides anatomical information, while a motor response to nerve stimulation provides functional information about the nerve in question.
- *Spread of anaesthetic solution:* Ultrasound allows the anaesthesiologist to observe the spread of the local anaesthetic solution as well as real-time visual guidance to navigate the needle toward the target nerve.

Two approaches are generally available to block peripheral nerves. The first approach aims to align and move the block needle inline with the long axis of the ultrasound transducer, so that the needle stays within the path of the ultrasound beam (see Figure 1.2a). In this manner, the needle shaft and tip can be clearly visualized. This approach is preferred when it is important to track the needle tip at all times (e.g., during a supraclavicular block to minimize inadvertent pleural puncture). The second approach places the needle perpendicular to the probe (see Figure 1.2b). In this case, the ultrasound image captures a transverse view of the needle, which is visible as a hyperechoic "dot" on the screen. Accurate moment-to-moment tracking of the needle tip location can be difficult, and needle tip position is often inferred indirectly by tissue movement. This approach is particularly useful for continuous catheter placement along the long axis of the nerve.

(a) **(b)**

Figure 1.2: (a) Probe and needle alignment during performance of an interscalene block.

Note the relative position of the needle in line with the probe, which allows visualisation of the entire needle trajectory (Perlas & Chan, 2008).

Figure 1.2: (b) Probe and needle alignment during performance of a subgluteal sciatic nerve block.

Note the relative position of the needle perpendicular, or "out of plane" with the probe (Perlas & Chan, 2008).

1.5.2.4 Ultrasound in children

Most nerve blocks can be performed on children using 5 to 10MHz linear ultrasound transducers. In addition, small probes are required due to the narrow anatomical relationships in children. "Hockey-stick" probes, with a surface length of 25mm, are particularly well suited for this purpose. Also, higher-frequency transducers are available for portable ultrasound units. Theoretically, superficial nerve structures can be better visualised using these higher frequencies. Lower frequencies (2 to 4MHz) are preferable for deeper blocks, such as psoas compartment blocks in larger children (Kim, 2009).

1.5.3 Magnetic Resonance (MR) Imaging

Imaging of peripheral nerves have, for many years, been limited by the small size of the nerves as well as the difficulty in distinguishing neural structures from the surrounding soft tissue, especially in paediatric patients. MR imaging has, due to recent advances in the technology, become the method of choice for visualisation of peripheral nerves (Birchansky & Altman, 2000). Although this can not be done while the block is being performed (as with ultrasound), it appears to be ideal to study the position of the peripheral nerves and associated landmarks for any potential anatomical abnormalities. However, the availability and high cost of MR imaging remains a limiting factor for most hospitals, especially in developing countries. In addition, specialised non ferro-magnetic needles would be required to place the block.

1.6) A survey into paediatric regional anaesthesia in South Africa: Clinical anatomy competence, pitfalls & complications

Precise information on epidemiology and morbidity of paediatric regional anaesthesia, especially from a clinical anatomy perspective, is scarce. A survey was therefore conducted amongst anaesthesiologists working in both private and government hospitals (n=80). This survey aimed to (a) determine, through means of a questionnaire, the scope of regional anaesthetic techniques performed on paediatric patients in South Africa, (b) determine the competence of anaesthesiologists to perform these procedures based on their clinical anatomy knowledge regarding each nerve block; and (c) select five problem procedures based on the anatomical competence that anaesthesiologists display when performing each nerve block (van Schoor, 2004).

A list of 18 regional anaesthetic procedures common in paediatric practice was compiled and a detailed questionnaire (see Appendix B) was completed by a randomly selected sample of anaesthesiologists. The problem procedures chosen were based on those that were performed most often, ranked important, encountered most difficulties and complications, where anaesthesiologists felt uncomfortable performing the procedures and where the influence of clinical anatomy knowledge on the safe and successful performance of the procedure was ranked highest.

This survey addressed the need for better understanding of the anatomy behind regional nerve blocks in paediatric patients as well as realising the importance of a sound anatomical knowledge base that acts as the foundation on which successful clinical procedures, such as regional nerve blocks, rest. The survey also aimed to gain a better understanding of paediatric regional anaesthesia in South Africa and serve as a basis on which regional nerve blocks could be taught in residency programs.

Anatomy knowledge contributes greatly to the success of any clinical procedure. It also increases the comfort levels of the anaesthesiologist performing the procedure, which in turn will decrease the occurrence of complications. There is a substantial “hiatus” in the precise clinical anatomy knowledge of the paediatric population. Standard paediatric practice is to take the normal anatomy of adults and then extrapolate the data to paediatric patients.

Using the data obtained from the survey, five problem regional anaesthetic procedures performed regularly on paediatric patients were identified (see Appendix C). These procedures were (1) the caudal epidural block; (2) lumbar epidural block; (3) the axillary approach to the brachial plexus; (4) the femoral nerve block; and (5) the ilio-inguinal/iliohypogastric nerve block. After conducting an intensive literature review regarding the above, a series of anatomical pitfalls for each procedure that could have contributed to the occurrence of complications during the performance of each, was identified.

The axillary approach to the brachial plexus was abandoned because the clinical situation could not be replicated. The pulse of the axillary artery is obviously absent in cadavers. Therefore, in order to validate the subsequent anatomical studies it was decided to use the infraclavicular approach instead.

Recent studies have shown this technique, although not popular, to be as safe and effective as the axillary approach with the same, if not more, indications for surgery of the upper extremities in paediatric patients (Dalens, 1995; Kapral *et al.*, 1996; Wilson *et al.*, 1998; Borgeat *et al.*, 2001). Recent modifications made to the original technique described by Raj and co-workers (1973) have also eliminated many of the complications, such as pneumothorax, which made anaesthesiologists wary of performing the procedure on paediatric patients (Kapral *et al.*, 1996; Wilson *et al.*, 1998; Borgeat *et al.*, 2001).

This thesis focuses on these five procedures and attempts to highlight the anatomical pitfalls identified in the survey. In addition this dissertation compares data obtained from anatomical dissections performed on neonates in our laboratory with those published and with those obtained from adult dissections.

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 17^{th} 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.

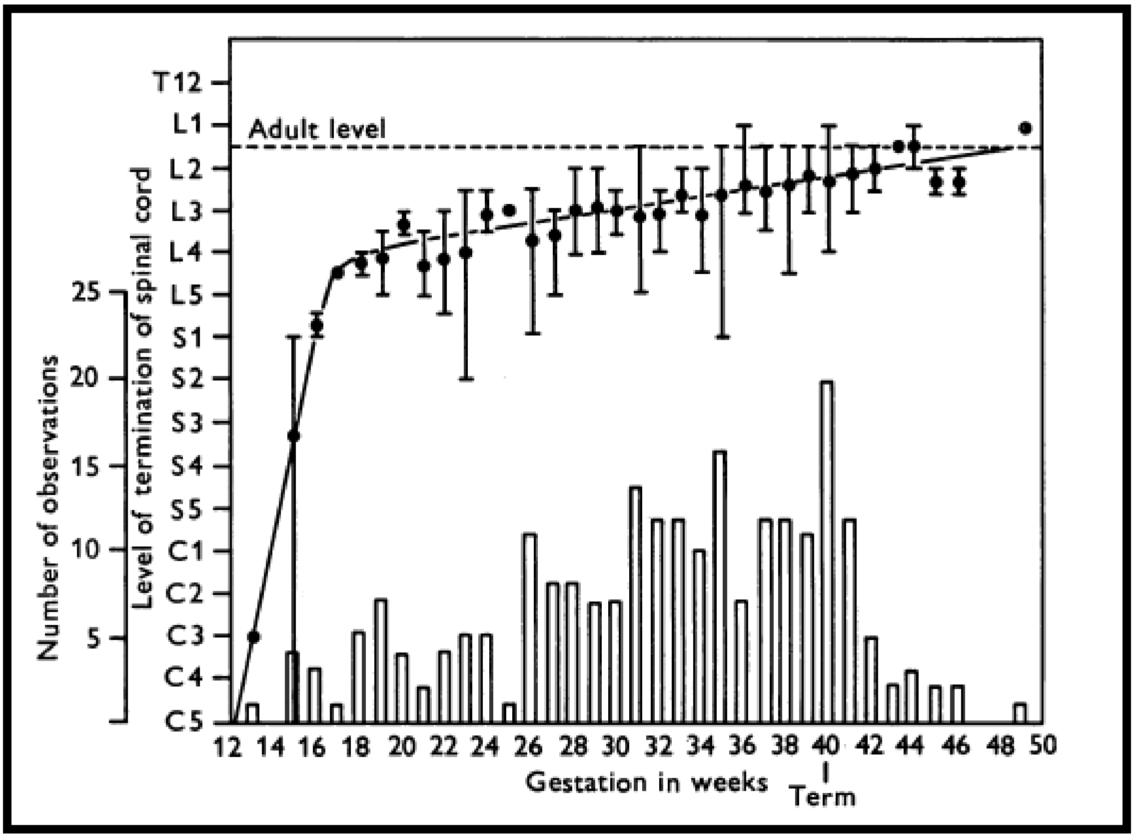

Figure 2.2: Level of termination of the spinal cord plotted against gestational age.

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)

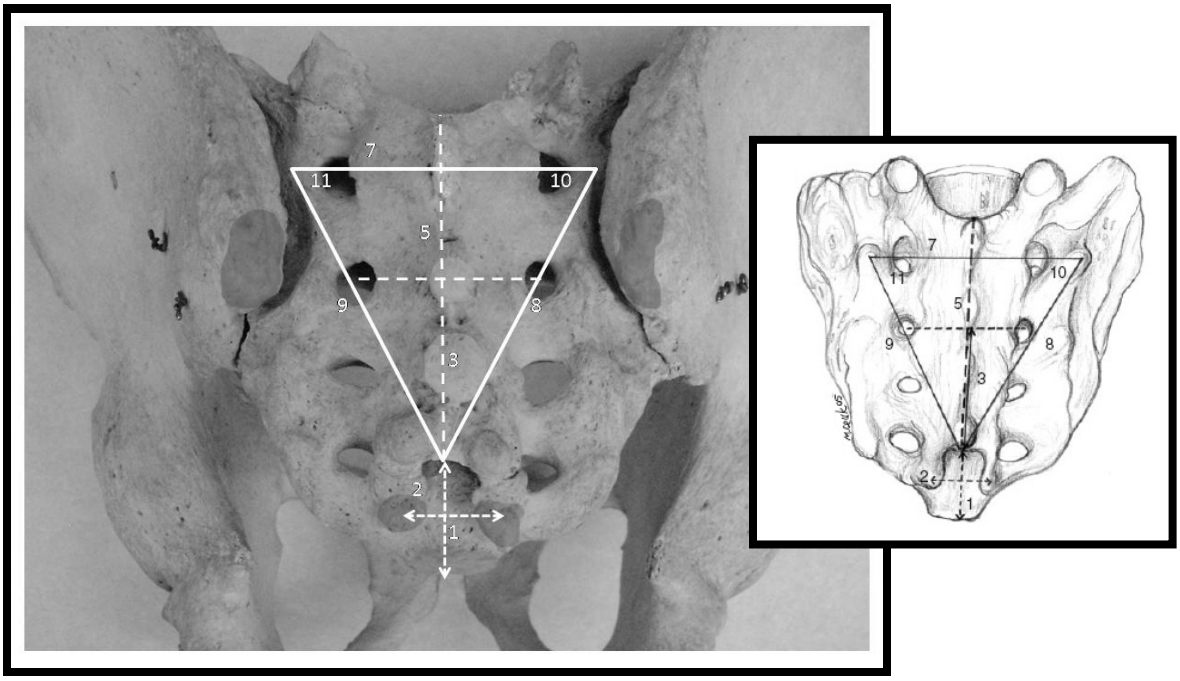

Figure 2.3: The equilateral triangle and bony landmarks described by Senoglu *et al.,* 2005.

(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).

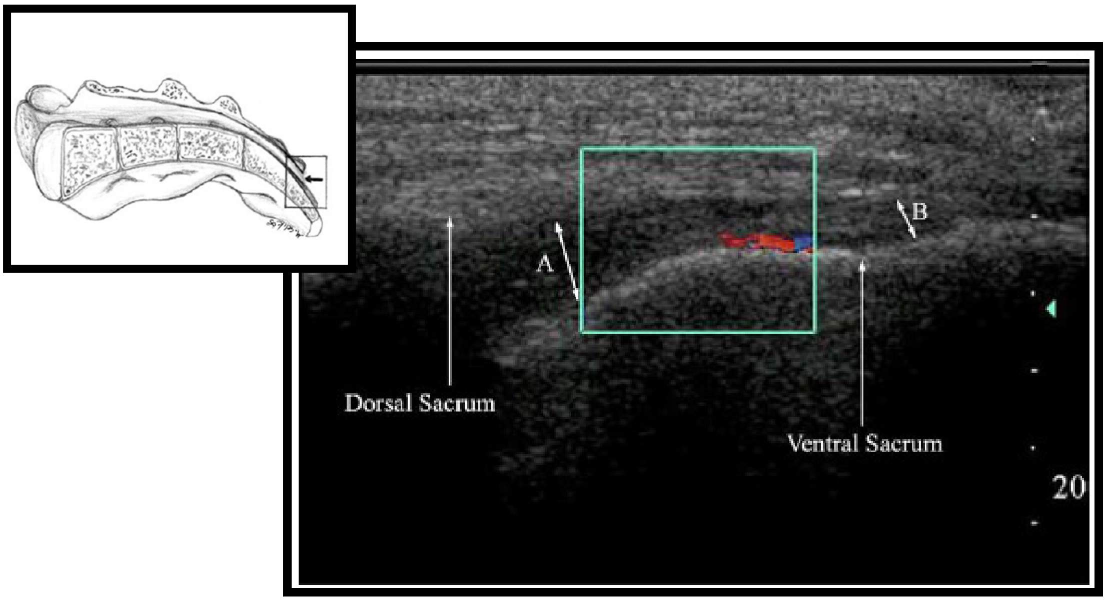

Figure 2.4: Colour Doppler ultrasonography, midsagittal view of the sacrum.

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.

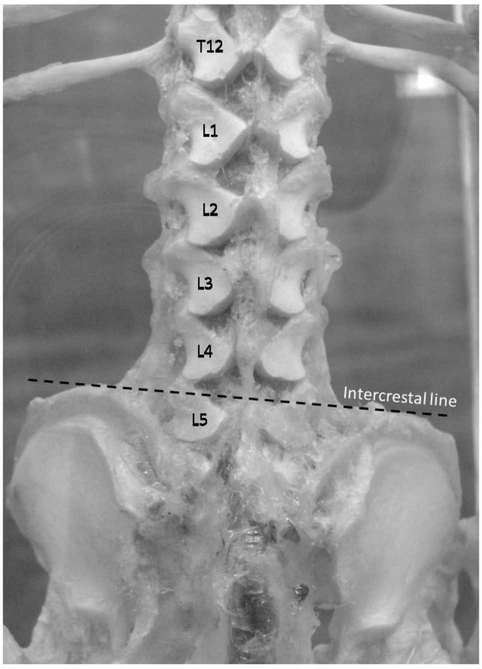

Figure 2.5: Posterior view of the neonatal vertebral column and iliac crests.

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).

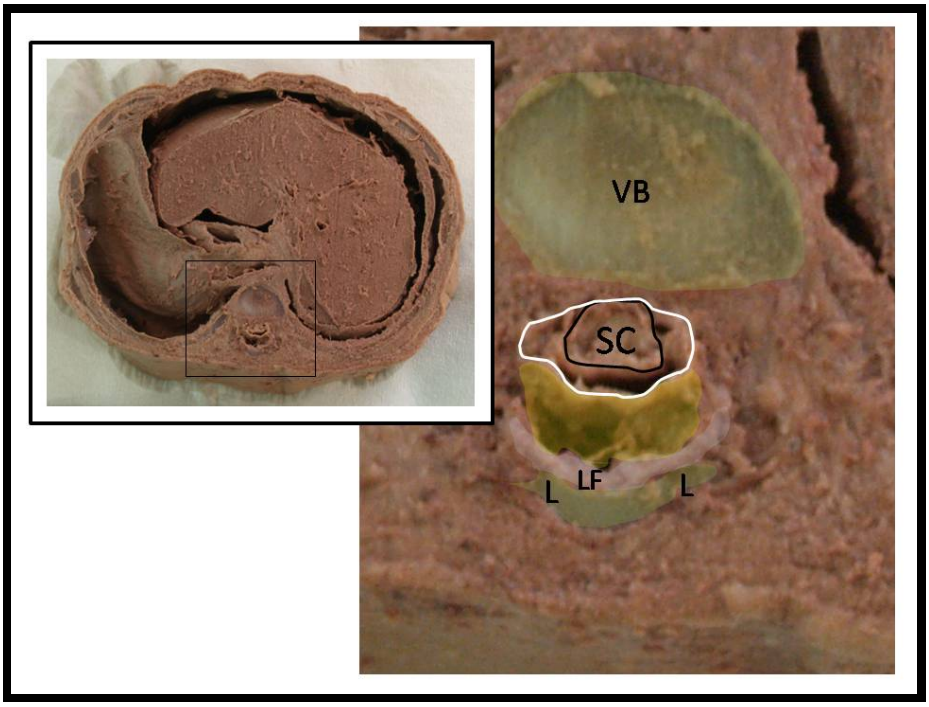

Figure 2.6: Transverse section through the L1 vertebra (highlighted in green) of a neonatal cadaver.

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).

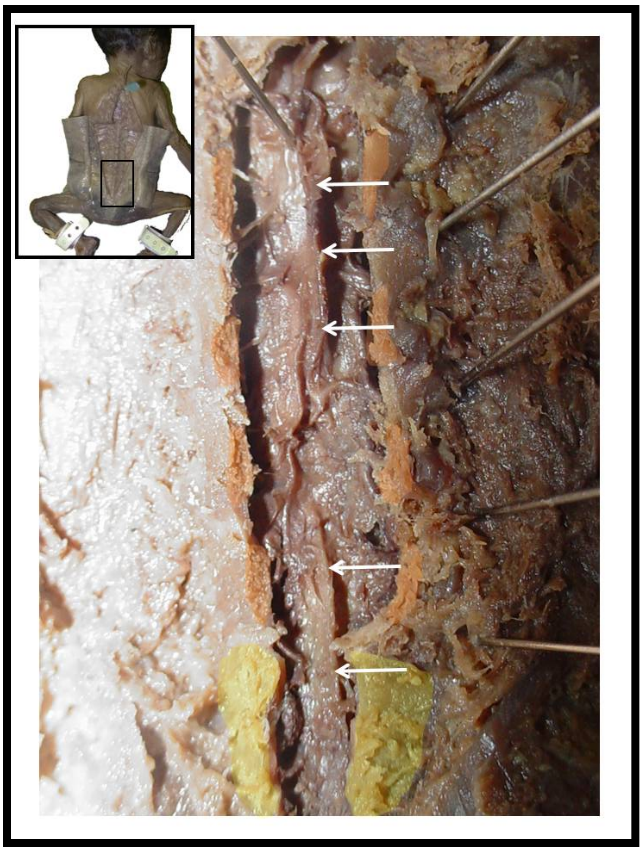

Figure 2.9: Dissection of a neonatal vertebral column.

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).

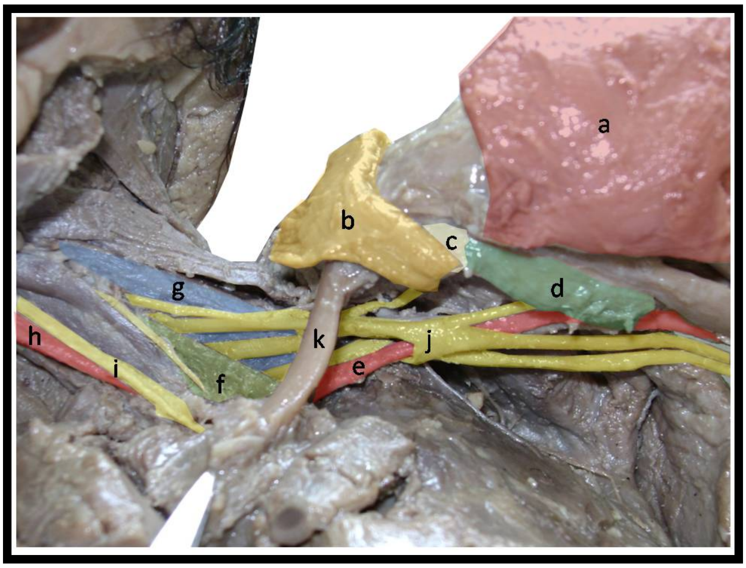

Figure 2.10: Brachial plexus and related structures within the axilla and at the root of the neck.

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).

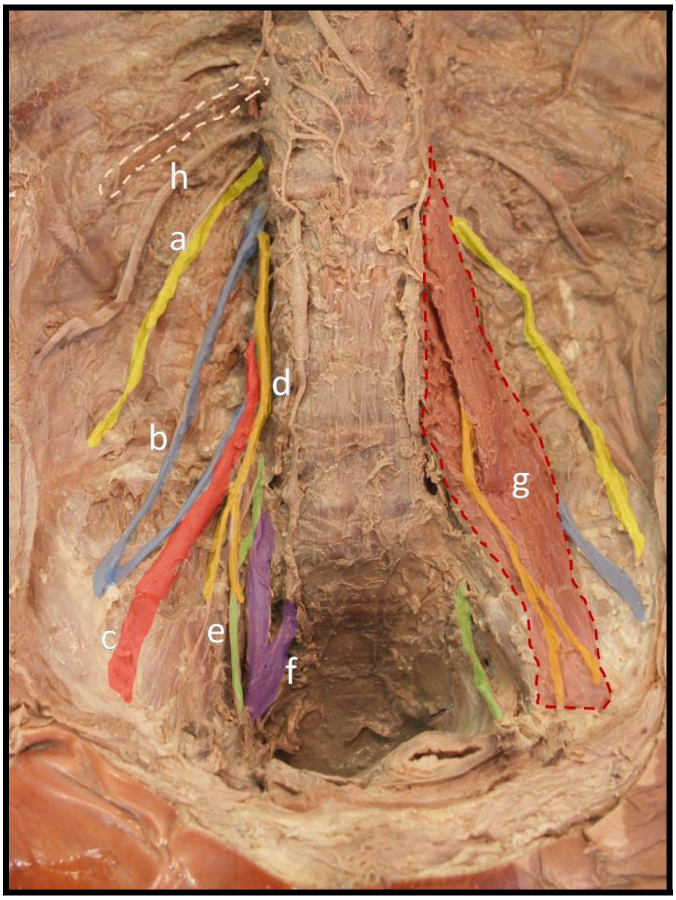


Figure 2.11: The lumbar plexus of a neonate.

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.

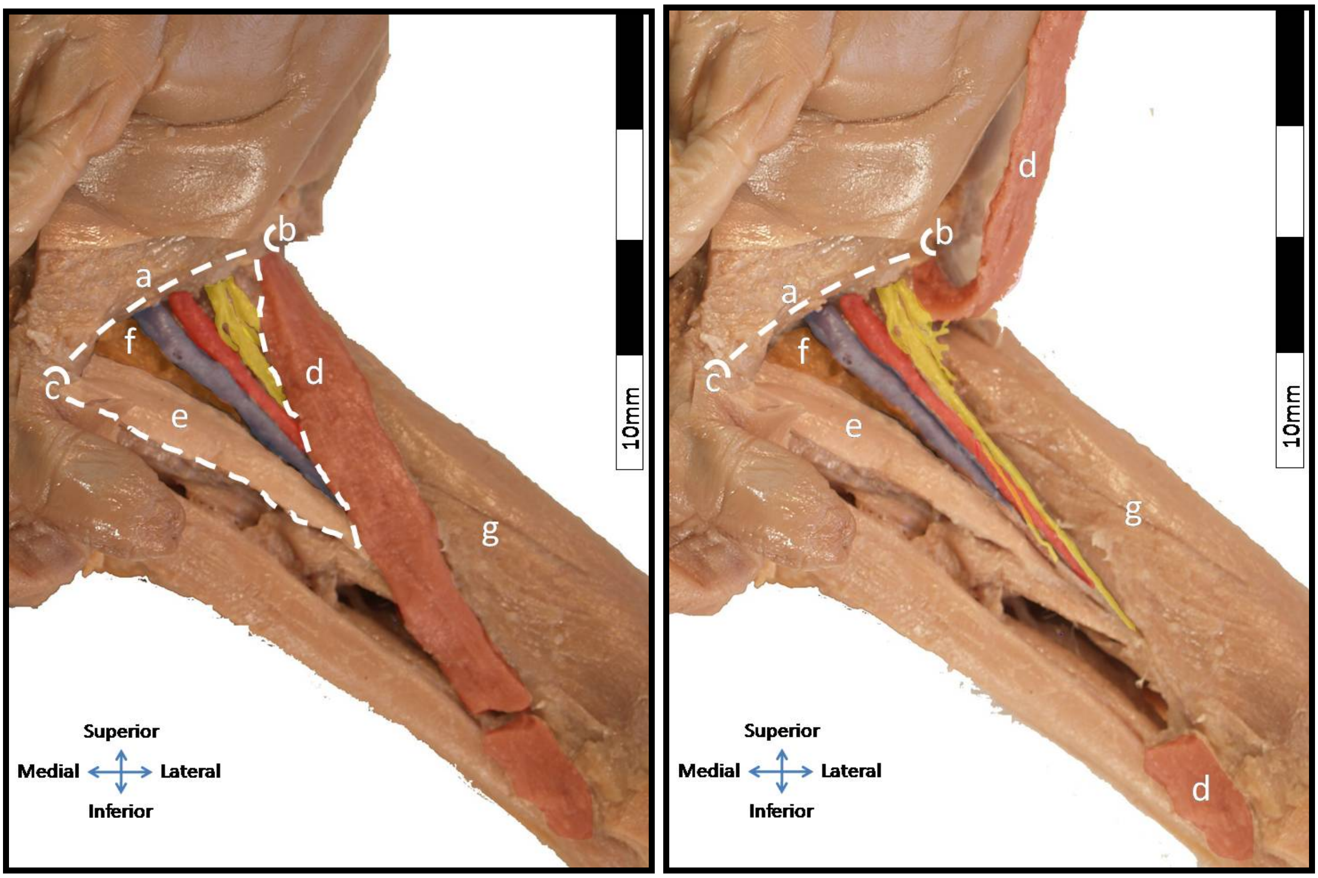
The upper parts of the plexus (T12-L1 spinal nerves) gives rise to nerves supplying the pelvis, the iliohypogastric and ilio-inguinal nerves (fibres from the L1 spinal nerve), the genitofemoral nerve (L1-L2), the branches supplying motor innervation to the quadratus lumborum (T12-L4), psoas minor (L1),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

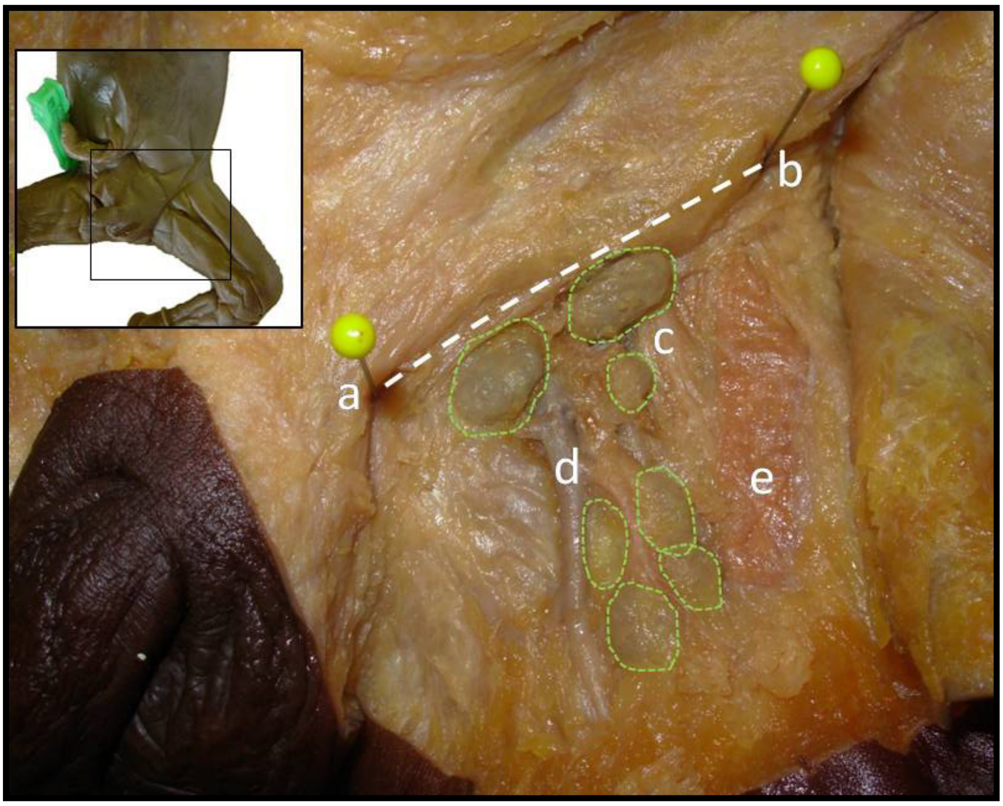


Figure 2.13: Superficial dissection of a neonatal femoral triangle with enlarged superficial inguinal lymph nodes.

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).

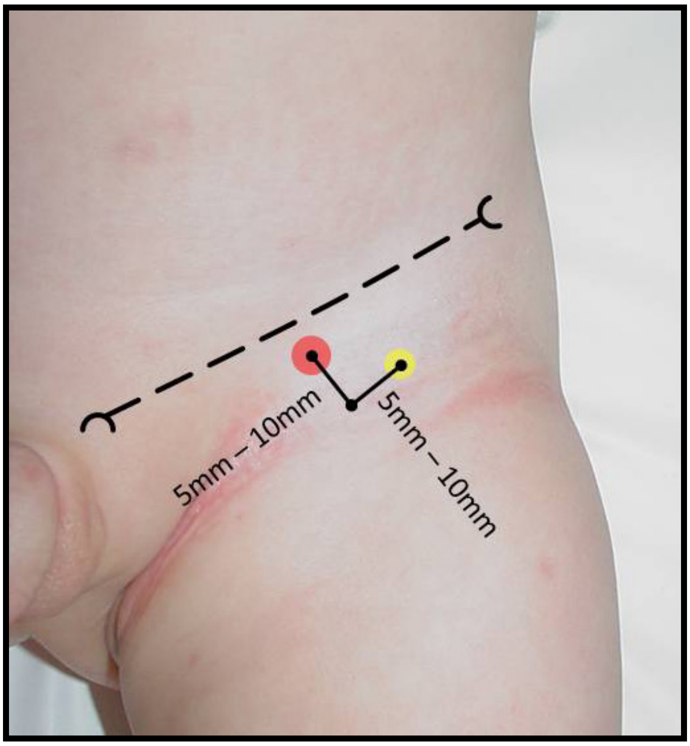


Figure 2.14: Classical femoral nerve block technique on an infant.

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 12^{th} 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)

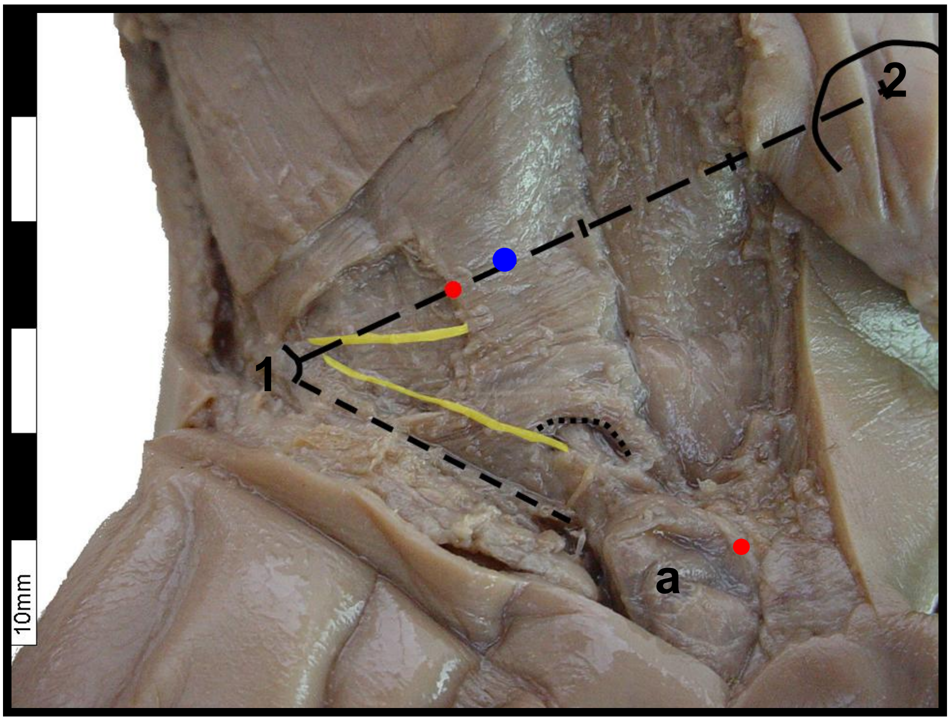


Figure 2.15: Technique described by Von Bahr (1979).

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).

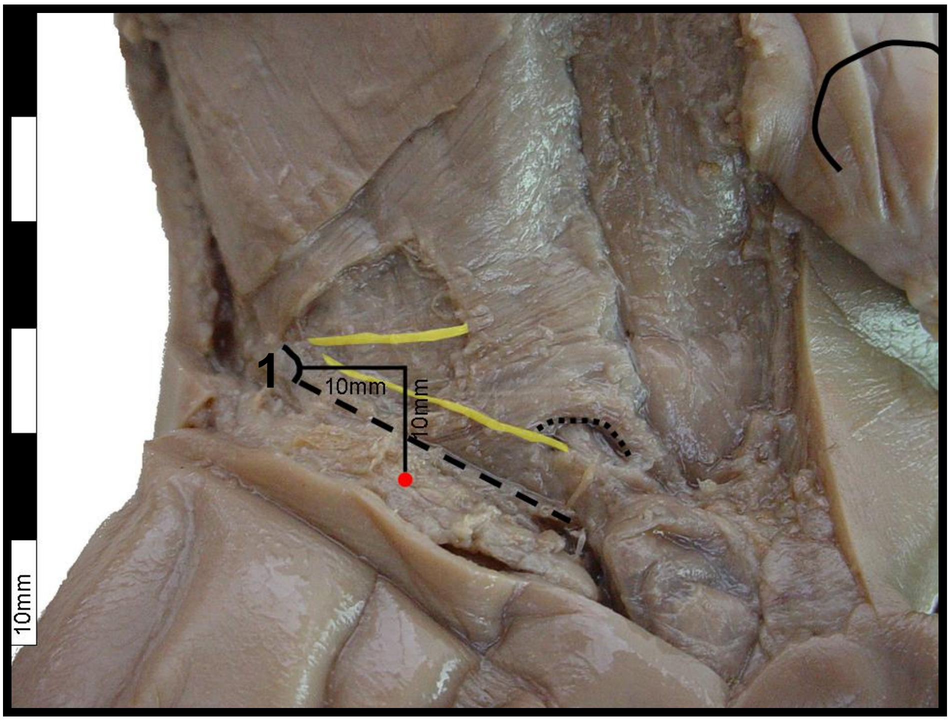


Figure 2.16: Technique described by Sethna and Berde (1989).

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).

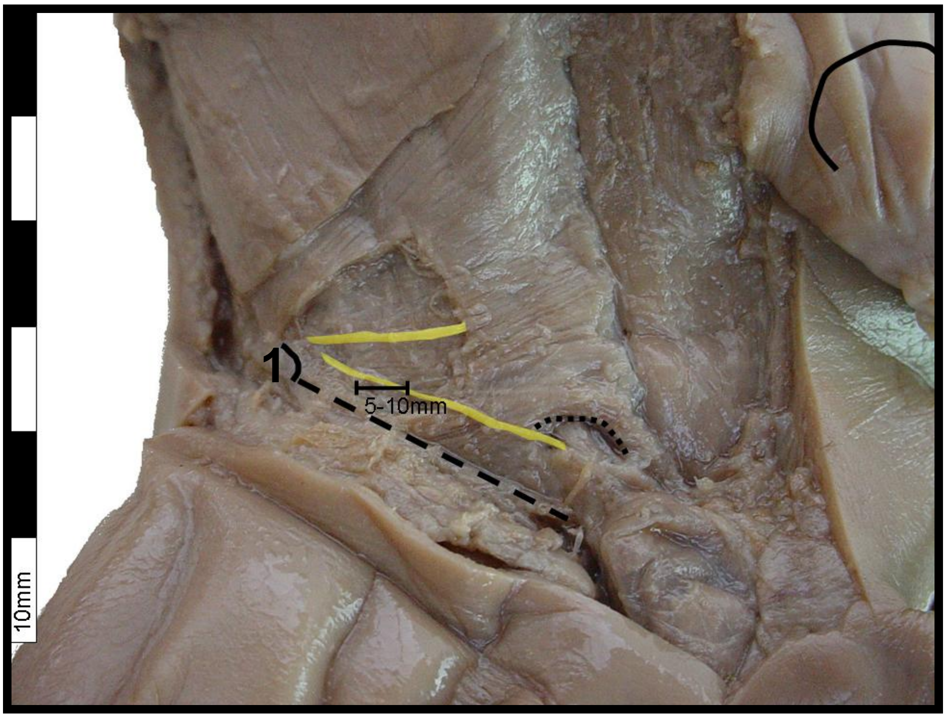


Figure 2.17: Technique described by Schulte-Steinberg (1990).

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 10^{th} 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.

Chapter 3: Aims of the thesis

3.1) Paediatric caudal epidural block

3.1.1 Dimensions of the neonatal sacrococcygeal membrane

Although the caudal epidural block is commonly performed, some anaesthesiologists find it difficult to determine the correct anatomical location of the sacral hiatus and the caudal epidural space (see Appendix C). Therefore, in order to perform caudal epidural blocks one must first be able to locate the sacral hiatus and also have an understanding of the anatomy of the sacrococcygeal membrane that covers it. This understanding of the landmarks and related structures enables anaesthesiologists to identify the correct point of needle insertion and in turn may increase the success rate of the procedure (Senoglu *et al.,* 2005).

The aim was to record the dimensions of the sacrococcygeal membrane in a sample of neonatal cadavers. Measurements that were taken include the distance between the two sacral cornuae (intercornual distance) and the surface area of the sacrococcygeal membrane.

3.1.2 The distance of the lumbar interlaminar spaces from the apex of the sacrococcygeal membrane in a neonatal sample

An advantage of placing caudal epidural catheters in young children is the fact that it is easier to advance the epidural catheter within the vertebral canal, which can allow for higher positioning of the catheter. This was demonstrated by Bosenberg *et al.* (1988) who, via the caudal route, successfully threaded a catheter to the thoracic levels 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 lumber epidural spaces in small infants. In order to select the correct length of the catheter when threading it to higher vertebral levels, anaesthesiologists should be aware of the possible distances of the apex of the sacrococcygeal membrane (where the catheter is inserted) to the various vertebral levels.

The aims were firstly to measure the distance of the apex of the sacrococcygeal membrane to the inferior border of the interlaminar spaces found between the lumbar vertebrae (L1/L2; L2/L3; L3/L4; L4/L5; and L5/S1) of neonatal cadavers in both a prone and flexed position. Secondly, to determine the percentage change in the distances obtained in the previous aim between the neonate in a prone and flexed position.

3.1.3 The vertebral level of termination and distance from the apex of the sacrococcygeal membrane to the dural sac

Before attempting to perform a caudal epidural block, or inserting a continuous caudal epidural catheter in a paediatric patient, one must have a good understanding of the relevant anatomy of the sacrum and caudal space, as well as the level at which the dural sac ends and the distance from the sacral hiatus (insertion point) to the dural sac. This knowledge is extremely important for anaesthesiologists as it provides an awareness regarding the position of the dural sac when inserting a catheter/needle. The knowledge of the anatomy in turn will increase the level of confidence of the anaesthesiologist performing the block as well as decrease the risk of possible complications, such as dural puncture.

The aim was to measure the distance from the apex of the sacrococcygeal membrane to the dural sac in a sample of neonatal cadavers in a prone position. The vertebral level at which the dural sac ends was also determined by using sagittal MR images of patients ranging from neonates to young adults.

3.2) Paediatric lumbar epidural block

3.2.1 The value of Tuffier's or the intercrestal line in neonates

Using Tuffier's line is the most common method of identifying the correct lumbar interlaminar space when performing lumbar epidural blocks on adults. In infants, this line has been described as crossing the midline at the level of L5/S1 (Jankovic & Wells 2001). Tame and Burstal (2003) evaluated the vertebral level of Tuffier's line in MR images of 35 children less than ten years old and found that Tuffier's line intersected the L5 vertebra. These MR images were evaluated with the children in a neutral position (no flexion of the trunk).

The aims were to determine the vertebral level of Tuffier's line in neonates in a prone position as well as to establish the change in the vertebral level of Tuffier's line when the same sample of neonatal cadavers was flexed.

3.2.2 The dimensions of the lumbar interlaminar spaces in neonates in both a prone and flexed position

Research regarding the dimensions of the interlaminar space is limited. Boon and co-workers (2003) found, from measuring the dimensions of the adult lumbar vertebrae, that the L3/L4, L4/L5, and L5/S1 interlaminar spaces becomes significantly smaller with increased age. All measurements were taken on articulated vertebral columns in an erect position. A search of the available literature showed no mention of the dimensions of the lumbar interlaminar spaces in neonates. This knowledge could be of benefit to anaesthesiologists performing lumbar epidural blocks or spinal anaesthesias on neonates or physicians doing lumbar punctures on neonates to obtain CSF samples.

The aims were to determine the surface area of the interlaminar spaces between vertebral levels L1/L2, L2/L3, L3/L4, L4/L5, and L5/S1 in neonatal cadavers in both a prone and flexed position, and secondly, to determine the percentage change that occurs in the measurements between the neonate in a prone and flexed position.

3.2.3 The vertebral level and distance from the apex of the sacrococcygeal membrane of the conus medullaris

Knowledge of the position of the end of the spinal cord or conus medullaris in both children and adults is of utmost importance for anaesthesiologists performing neuraxial or central blocks and physicians performing lumbar punctures. Direct trauma to the spinal cord may occur if the needle is inserted too deeply, at higher vertebral levels. Although this is a rare complication, as most punctures are carried out inferior to the conus medullaris (Jankovic & Wells, 2001), insufficient knowledge of neonatal anatomy and incorrect identification of the needle insertion point may cause trauma to the spinal cord. Neurological disorders may result from the insertion of the tip of the needle into the spinal cord, especially if the local anaesthetic solution is injected. This could tear the nerve fibres and/or produce compression lesions, possibly with severe consequences (Dalens, 1995).

The aims were therefore to first ascertain at which vertebral level the spinal cord terminates (conus medullaris) in a sample of (a) neonatal cadavers and (b) sagittal MR images. Secondly, to determine the distance of the apex of the sacrococcygeal membrane to the conus medullaris on neonatal cadavers.

3.3) Paediatric infraclavicular approach to the brachial plexus

3.3.1 Anatomical considerations of the neonatal infraclavicular brachial plexus block

Most anatomical research is based on investigations and techniques originally performed on adults. Although the success rate of these studies were good, either a nerve stimulator or other expensive imaging modalities were used to identify the brachial plexus. The use of these modalities has shown to increase the success rate of these regional blocks dramatically (Rapp & Grau, 2004; Minville *et al.*, 2005; Bloc *et al.*, 2006; McCormack & Malherbe, 2008; Aziz *et al.,* 2009). Even with the aid of nerve stimulators or CT guidance, no regional anaesthetic technique could truly be called simple, safe and consistent until the anatomy has been closely examined (Winnie *et al.*, 1975). After an extensive search of the literature regarding brachial plexus blocks in a paediatric population, it is clear that there is surprisingly little research available on the anatomy of the paediatric brachial plexus and how it relates to the different infraclavicular block techniques.

The first aim was to determine the relationship of the brachial plexus (and its components), within the axilla, to the coracoid process. The second aim was to use the data obtained to determine an improved needle insertion site for the infraclavicular brachial plexus block using the coracoid process and the xiphisternal joint as easily identifiable bony landmarks. The final aim was to determine the distance of the inserted needle from the parietal pleura when performing the infraclavicular approach on a neonatal cadaver population in order to ascertain the risk of pneumothorax.

3.3.2 Anatomical considerations of the infraclavicular brachial plexus block–comparison between neonatal and adult data

A search of the literature revealed that very little information regarding the anatomy of the brachial plexus is available. 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". Even using modern imaging, Birchansky & Altman (2000) could not accurately describe the brachial plexus in paediatric patients and ultimately concluded that "imaging the plexii and peripheral nerves of infants and children are a challenging endeavour, which is at the cutting edge of current MR imaging technology". As a result anaesthesiologists have applied their knowledge of adult anatomy, which is far more readily available, when performing brachial plexus blocks in neonates and young infants. This is clearly summarised in Table 3.1.

Table 3.1: Summary of cases where the infraclavicular brachial plexus blocks were performed on paediatric patients.

Author	Sample size	Age of sample	Technique used	Original sample
De Jose Maria & Tielens, 2004	55	5–17	Kilka *et al.*, 1995	Adults
Fisher *et al.*, 2006	1	10	Fisher *et al.*, 2006	Child
Dadure *et al.*, 2003	2	6 & 11	Jandard *et al.*, 2002	Adults
Fleischmann *et al.*, 2003	40	1–10	Kapral *et al.*,1996	Adults
Zimmermann *et al.*, 2002	1	8	Kilka *et al.*, 1995	Adults
Marhofer *et al.*, 2004	40	1-10	Fleischmann *et al.*, 2003 (Kapral *et al.*, 1996)*	Adults*

* Marhofer *et al.* (2004) used the infraclavicular block technique described by Fleischmann *et al*. 2006, which was originally developed by Kapral *et al.*, 1996.

If the assertions made by Katz (1993) are correct, then performing procedures on paediatric patients that was originally designed on adults shouldn't be a problem. One cannot just assume that this is the case. There is very little scientific evidence to prove that there are no differences between the position of and relationship between the structures found in the axilla when comparing paediatric and adult populations.

The aims were therefore to firstly determine the relationship of the brachial plexus (and its components), within the axilla, to the coracoid process. The second aim was to use the data obtained to determine an improved needle insertion site for the infraclavicular brachial plexus block using the coracoid process and the xiphisternal joint as easily identifiable bony landmarks. The third aim was to determine the distance of the inserted needle from the parietal pleura when performing the infraclavicular approach on an adult cadaver population in order to determine the risk of pneumothorax when performing this procedure. The final aim was to compare the data obtained in the adult sample to that found in the neonatal sample (see *5.3.1: Anatomical considerations of the neonatal infraclavicular brachial plexus block*).

3.4) Paediatric femoral nerve block

3.4.1 Anatomical considerations of the neonatal femoral nerve block

Although there is no mystery regarding the femoral nerve and its position within the femoral triangle, there are still relatively few studies of the anatomy of the nerve in children, especially neonates. Classical anatomical literature describes the femoral artery as entering the femoral triangle, posterior to the inguinal ligament, at the mid-inguinal point. The femoral nerve can then be found between 5mm–10mm lateral to the artery in children (Dalens, 2003). This is despite the fact that no anatomical studies have been conducted on a paediatric sample to verify this.

The aim was therefore to determine the accurate position of the femoral nerve, in relation to the femoral artery and the ASIS and PT, within the femoral triangle of a neonatal sample.

3.4.2 Anatomical considerations of the femoral nerve block– comparison between neonatal and adult data

Femoral nerve blocks are well established as a peripheral nerve block in adult patients. To immediately assume that the position of the contents of the femoral triangle will be exactly the same in neonates as in adults would be a mistake.

Therefore, the aim was to compare the position of the neonatal femoral nerve and artery, within the femoral triangle, to the position of the adult nerve and artery. This was accomplished by conducting a similar study as described in *5.4.1: Anatomical considerations of the neonatal femoral nerve block* on an adult population.

3.5) Paediatric ilio-inguinal/ iliohypogastric nerve block

3.5.1 Anatomical considerations of the neonatal ilio-inguinal/ iliohypogastric nerve block

Although inguinal hernia repair is one of the most common surgical procedures performed on neonates and premature infants, the precise anatomical positions of both the ilio-inguinal and the iliohypogastric nerves have not been identified in this age group. Knowledge of the exact anatomical location of these nerves would enhance the success of this block, which carries a relatively high failure rate in this age group (Trotter *et al.*, 1995; Eichenberger *et al.*, 2006).

The primary aim was to establish the anatomical position of the ilio-inguinal and iliohypogastric nerves in relation to an easily identifiable bony landmark, the ASIS, and the secondary aim was to evaluate three techniques - described in the literature - from an anatomical perspective.

3.6) Problem statement

It is inadvisable to use data obtained from adult studies and use it on neonates, infants and even toddlers. This is due to the fact that the relationship of the targeted nerve to surrounding anatomical landmarks differs significantly from that of adults. It would therefore be more appropriate to use data obtained from neonatal samples and extrapolate “up” when performing regional nerve blocks on infants and even toddlers.

Chapter 4: Materials & Methods

4.1) Paediatric caudal epidural block

4.1.1 Dimensions of the neonatal sacrococcygeal membrane

The sacrococcygeal membrane, as well as the sacral cornuae was carefully exposed in a sample of 40 neonatal cadavers (mean length: 0.42m ± 0.07m; mean weight: 1.59kg ± 0.85kg). Both sacral cornuae and the apex of the sacrococcygeal membrane, or the upper margin of the sacral hiatus, were identified and pins were placed into each of these landmarks. High quality digital photographs were then taken of the sacral area. A scale of known distance was placed on top of the dissected area (without covering any of the relevant structures) in order to make digital measurements of the photograph possible. The photographs were then imported into *UTHSCSA* Image Tool V3.0, which was used to analyse the photographs. Using the *Calibrate Spatial Measurements* function, the known scale found on each photograph was converted into a pixel format. This allows for accurate measurement of the photographs by means of the *Distance* function, which converts the length of a straight line – drawn between two points on the photograph – into mm. These measurements were then inserted into an MS Excel™ worksheet and subsequent statistical analysis of the data was done.

The digital photographs were used to measure (a) the distance between the sacral cornuae, (b) the length of the sacrococcygeal membrane (distance between an imaginary line drawn between the two sacral cornuae and the apex of the sacrococcygeal membrane). The *Area* function was used to determine the surface area of the sacrococcygeal membrane, which consisted of a triangular area between the two sacral cornuae (base) and the apex of the sacral hiatus (see Figure 2.1).

4.1.2 The distance of the lumbar interlaminar spaces from the apex of the sacrococcygeal membrane in a neonatal sample

The lumbar and sacral regions of 40 neonatal cadavers (mean length: 0.42m ± 0.07m; mean weight: 1.59kg ± 0.85kg) were carefully dissected in order to expose the laminae and spinous processes of the lumbar vertebrae and sacrum.

With the exposure of the lumbar vertebrae and sacrum a pin was inserted into the apex of the sacrococcygeal membrane as well as the inferior border of the interlaminar spaces found between L1/L2; L2/L3; L3/4; L4/L5 and L5/S1 (see Figure 4.1).

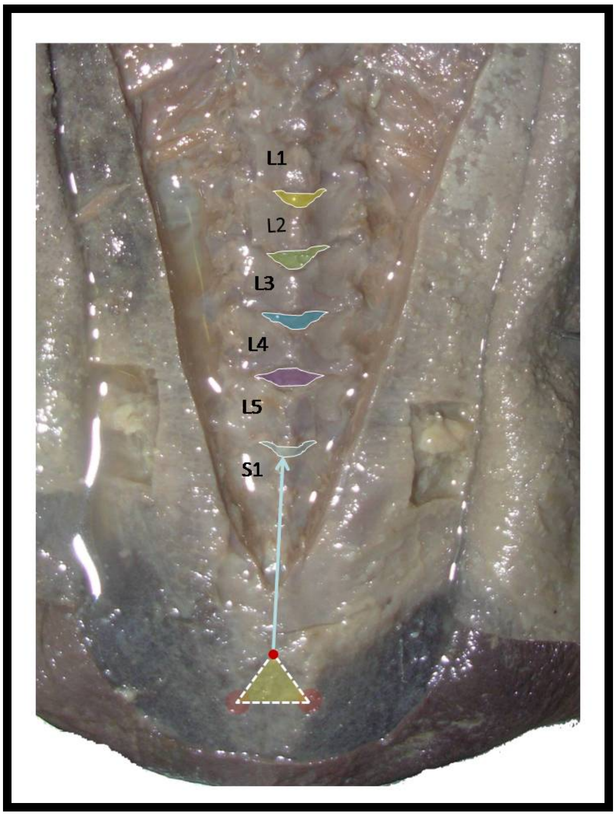


Figure 4.1: Exposed lumbar vertebrae and apex of sacrococcygeal membrane (yellow triangle) of a neonate in the prone position.

Measurements were taken from the apex (red circle) to the inferior border of the interlaminar spaces between each of the lumbar vertebrae (highlighted in colour). Dissection above shows measurement from the apex to the inferior border of the L5/S1 interlaminar space.

Digital photographs were taken with the neonate placed in a prone position as well as with the neonate flexed between 40^{o}-50^{o} over a wooden block. These photographs were then imported into UTHSCSA Image Tool V3.0 to measure the distance of the apex of the sacrococcygeal membrane to the inferior borders of the interlaminar spaces of L1/L2; L2/L3; L3/4; L4/L5 and L5/S1 in both a prone and flexed position.for analysis.

The data obtained from the neonate in both a prone and flexed position was then inserted into a MS Excel™ worksheet in order to determine the change that occurs in these measurements between the neonate in a prone and flexed position. The percentage change of the distance of the apex of the sacrococcygeal membrane to the inferior border of the interlaminar spaces between the lumbar vertebrae was determined for each neonate in both a prone and flexed position. The distances in a prone position (α) was divided by the distances in the same neonate in a flexed position (β) and then multiplied by a hundred to obtain a percentage (θ). This percentage was then subtracted from a hundred in order to obtain the percentage change between the two positions. Thus, **θ = (α / β) x 100** and then the **% change = 100 – θ**

For example:
θ = (17.04mm / 19.13mm) x 100
θ = 0.8907 x 100
θ = 89.07% change = 100 – 89.07
Therefore, % change = 10.93%

4.1.3 The vertebral level of termination and distance from the apex of the sacrococcygeal membrane to the dural sac

Firstly, the lumbar and sacral regions of 40 neonatal cadavers (mean length: 0.42m ± 0.07m; mean weight: 1.59kg ± 0.85kg) were carefully dissected in order to expose the laminae and spinous processes of the lumbar vertebrae and sacrum. Prior to dissecting the laminae, a pin was placed at the apex of the sacrococcygeal membrane and care was taken not to disturb it during the dissection.

Using a scalpel, both the laminae of the sacrum and the lumbar vertebrae were cut and the spinous processes were carefully removed, effectively exposing the dural sac within the vertebral canal (see Figure 4.2). A second pin was placed at the point were the dural sac ended.

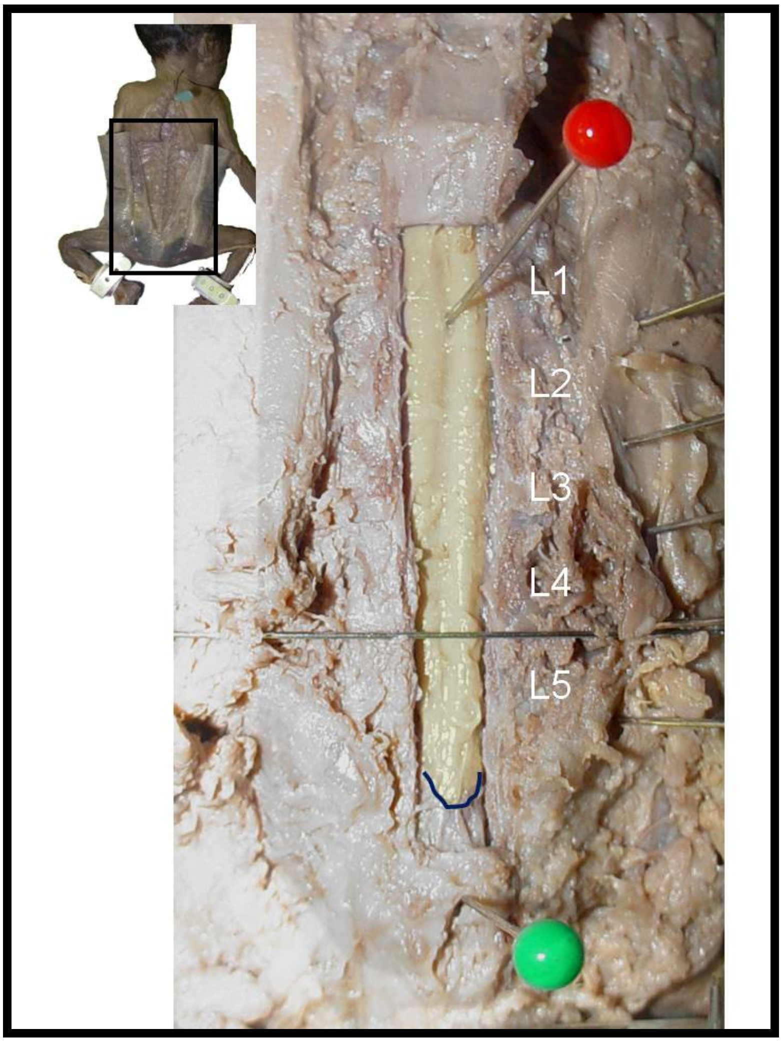


Figure 4.2: Content of the vertebral canal

The laminae and spinous processes were removed in order to show the dural sac (highlighted in yellow). The green pin has been placed into the apex of the sacrococcygeal membrane, while the red pin was placed into the L1/L2 interlaminar space prior to removal of the laminae and spinous process of the lumbar vertebrae. The end of the dural sac is indicated by the curved black line.

High quality digital photographs were taken of the exposed dural sac and were then imported into UTHSCSA Image Tool V3.0 to determine the distance of the apex of the sacrococcygeal membrane (marked by the green pin) to the end of the dural sac.

In order to determine the vertebral level where the dural sac ends, a series of 102 midsagittal T2-weighted MR images of the lumbar and sacral regions (patients' ages ranging between 1 day to 29 years old) was analysed.

Each vertebra on the MR image was divided into thirds and each third, as well as each intervertebral disc was given a corresponding number, i.e., the upper third of T12 was "1", the middle third of T12 was "2", the lower third of T12 was "3" and the T12/L1 intervertebral disc was "4". Numbering then continued from the upper border of L1 (which was "5") to the lower third of S3 (which was number "35") (see Figure 4.3). The level at which the dural sac ended was noted on the MR images and given a corresponding number.

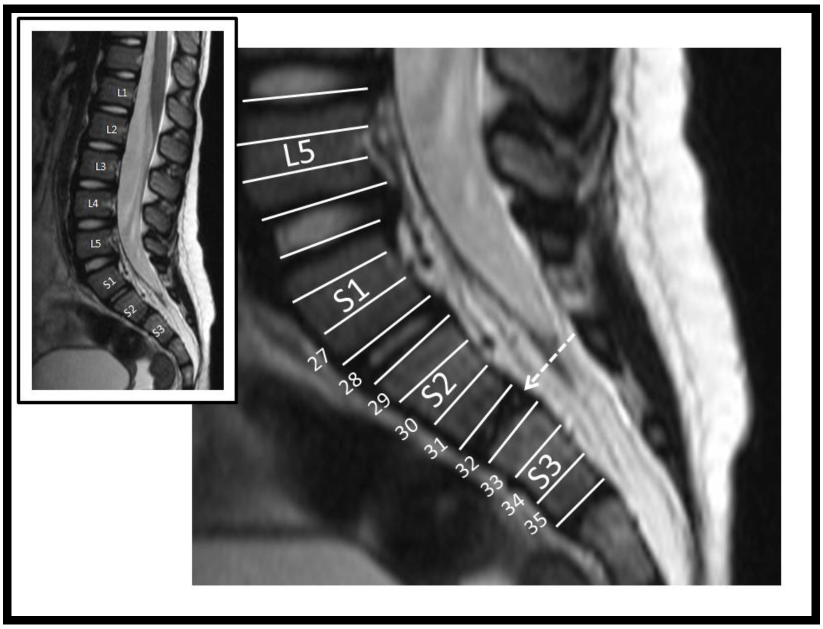


Figure 4.3: MR image of a 2 year old showing how the vertebrae were divided into thirds.

Each third as well as the intervertebral disc was then given a corresponding number. The end of the dural sac (indicated by the white, dashed arrow).

4.2) Paediatric lumbar epidural block

4.2.1 The value of Tuffier's or the intercrestal line in neonates

The lumbar and sacral regions of 40 neonatal cadavers (mean length: 0.42m ± 0.07m; mean weight: 1.59kg ± 0.85kg) were carefully dissected in order to expose the laminae and spinous processes of the lumbar vertebrae. During dissection, the two iliac crests were also exposed and the most superior border of each iliac crest was marked. Each vertebra was divided into thirds. Each third, as well as each interlaminar space, was given a corresponding number, i.e., the upper third of T12 was "1", the middle third of T12 was "2", the lower third of T12 was "3" and the T12/L1 intervertebral disc was "4". Numbering then continued from the upper border of L1 (which was "5") to the L5/S1 intervertebral disc (which was number "24"). High quality digital photographs were taken of the dissected vertebral column in both a prone and a flexed position. Using imaging software, a straight line was drawn between the two marked iliac crests. The vertebral level (indicated by a corresponding number) where this line intersected the vertebral column was then noted in both positions (see Figure 4.4).

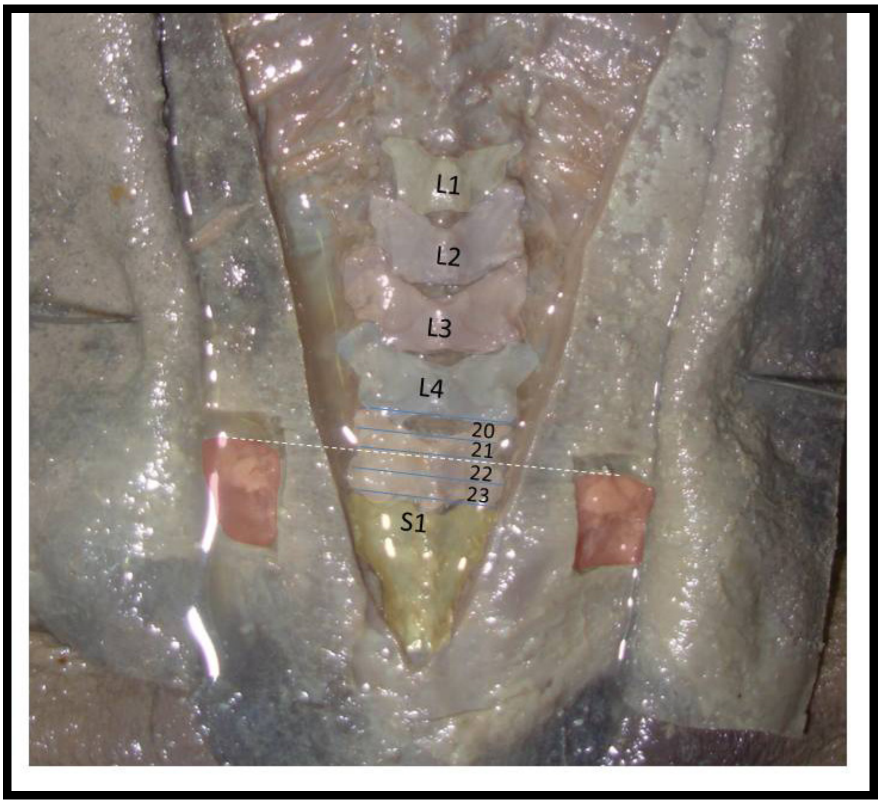


Figure 4.4: The exposed lumbar vertebrae of a neonatal cadaver in a prone position.

The vertebral bodies (divided into thirds) and interlaminar space was each given a corresponding number (in the picture above the L4/L5 interlaminar space and L5 vertebral body is divided and numbered 20-23). The two iliac crests were also exposed and a line was drawn between these two bony landmarks (indicated by the white dashed line).

The photographs were imported into *UTHSCSA* Image Tool V3.0 to determine the distance of the apex of the sacrococcygeal membrane (marked by a pin) to Tuffier's line in both a prone and a flexed position.

The percentage change of the distance of the apex of the sacrococcygeal membrane to Tuffier's line was determined for each neonate in both positions by using the principle discussed in *4.1.2: The distance of the lumbar interlaminar spaces from the apex of the sacrococcygeal membrane in a neonatal sample.*

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4.2.2 The dimensions of the lumbar interlaminar spaces in neonates in both a prone and flexed position

The lumbar and sacral regions of 40 neonatal cadavers (mean length: 0.42m ± 0.07m; mean weight: 1.59kg ± 0.85kg) were carefully dissected in order to expose the interlaminar spaces of the lumbar vertebrae. High quality digital photographs were taken of the dissected vertebral column of the neonatal sample, in both a prone and a flexed position, and were then imported into UTHSCSA Image Tool V3.0 for analysis. This allowed for accurate measurements of the surface area of the interlaminar spaces between L1/L2, L2/L3, L3/L4, L4/L5 and L5/S1.

The percentage change of the surface area of the interlaminar space of a neonate in a prone and flexed position was then determined by using the principles discussed in *4.1.2: The distance of the lumbar interlaminar spaces from the apex of the sacrococcygeal membrane in a neonatal sample.*

4.2.3 The vertebral level and distance from the apex of the sacrococcygeal membrane of the conus medullaris

4.2.3.1 Neonatal cadavers

The lumbar and sacral regions of 40 neonatal cadavers (mean length: 0.42m ± 0.07m; mean weight: 1.59kg ± 0.85kg) were carefully dissected in order to expose the laminae and spinous processes of the lumbar vertebrae and sacrum. Prior to dissecting the laminae, a pin was placed at the apex of the sacrococcygeal membrane and care was taken not to disturb it during the dissection. The lumbar vertebrae were carefully marked for future reference.

Using a scalpel, both the laminae of the sacrum and the lumbar vertebrae were cut and the spinous processes carefully removed, effectively exposing the dural sac within the vertebral canal (see Figure 4.2). A midline incision was made through the dural sac and the two halves of the now transected dural sac was reflected laterally in order to expose the spinal cord and cauda equina (see Figure 4.5).

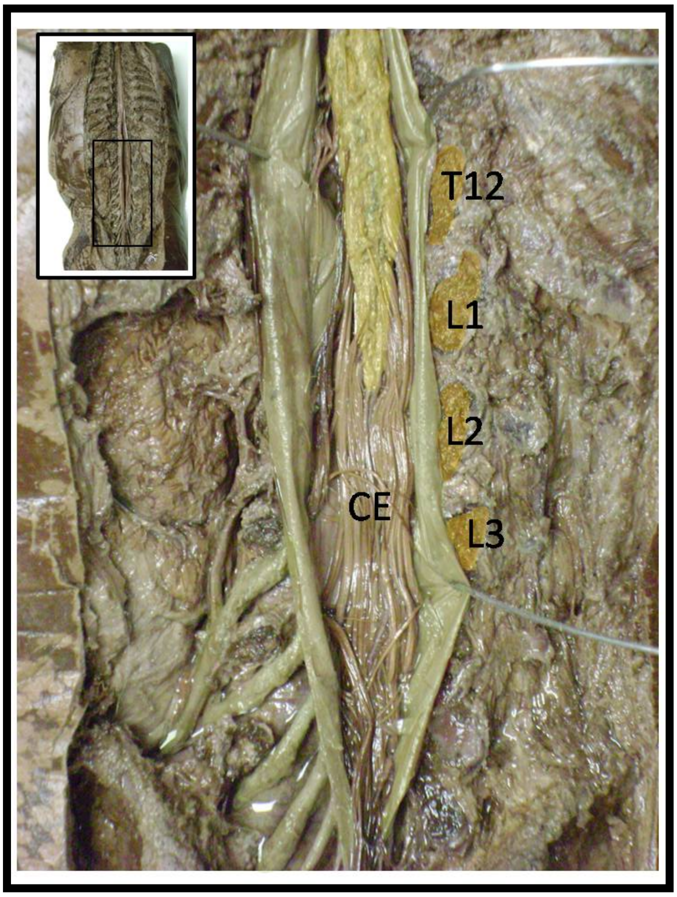


Figure 4.5: An exposed spinal cord (highlighted in yellow) of a neonatal cadaver.

The T12-L3 vertebrae (highlighted in orange) are also indicated. The dura mater (highlighted in green was sectioned and reflected in order to show the spinal cord and cauda equina (CE).

High quality digital photographs were taken of the dissected vertebral columns of the neonatal sample, in both a prone and a flexed position, and were then imported into UTHSCSA Image Tool V3.0 to determine the distance from the apex of the sacrococcygeal membrane (marked by a pin) to the conus medullaris in both positions.

The percentage change of the distance of the apex of the sacrococcygeal membrane to the conus medullaris was determined for each neonate in both a prone and flexed position, by using the principles discussed in *4.1.2: The distance of the lumbar interlaminar spaces from the apex of the sacrococcygeal membrane in a neonatal sample.*

Each vertebra was also divided into thirds and each third as well as each intervertebral disc was given a corresponding number similar to that shown in Figure 4.6. After exposing the spinal cord, a pin was placed at the level of termination of the conus medullaris, the vertebral level was noted and a corresponding number was given. This was done on 39 neonatal cadavers, all in the prone or neutral position.

4.2.3.2 MR images

In order to determine the vertebral level where the spinal cord ends, a series of 108 midsagittal T2-weighted MR images of the lumbar and sacral regions (patients' ages ranging between 1 day to 29 years old) was obtained, with the appropriate ethical clearance, from Burger Radiologists, UNITAS hospital and the Department of Radiology, Steve Biko Academic Hospital.

Each vertebra on the MR image was divided into thirds and each third as well as each intervertebral disc was given a corresponding number as can be seen in *4.1.3: The vertebral level of termination and distance from the apex of the sacrococcygeal membrane to the dural sac.*

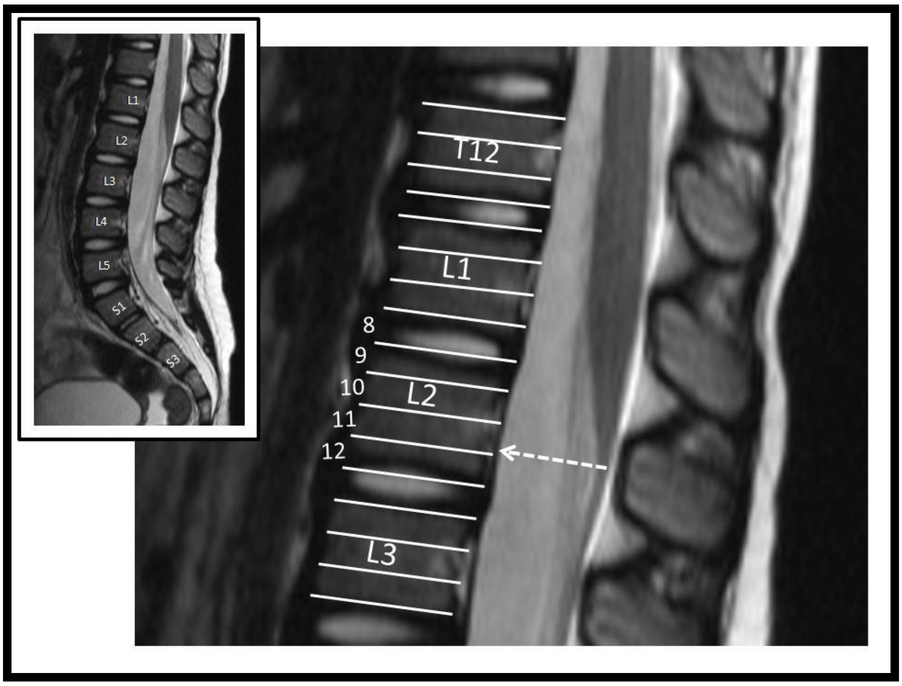


Figure 4.6: MR image of a 2 year old showing how the vertebrae were divided into thirds.

Each third as well as the intervertebral disc was then given a corresponding number. The end of the spinal cord (indicated by the white, dashed arrow) was then given a number corresponding with the vertebral level of termination.

4.3) Paediatric infraclavicular approach to the brachial plexus

4.3.1 Anatomical considerations of the neonatal infraclavicular brachial plexus block

The content of the axilla was carefully exposed in a sample of 52 neonatal cadavers (52 left and 50 right axillae; mean length: 0.43m ± 0.08m; mean weight: 1.94kg ± 1.62kg). The skin over the pectoral region was first removed in order to expose the pectoralis major muscle (see Figure 4.7), and subsequently reflect it in order to expose the underlying pectoralis minor muscle (see Figure 4.8).

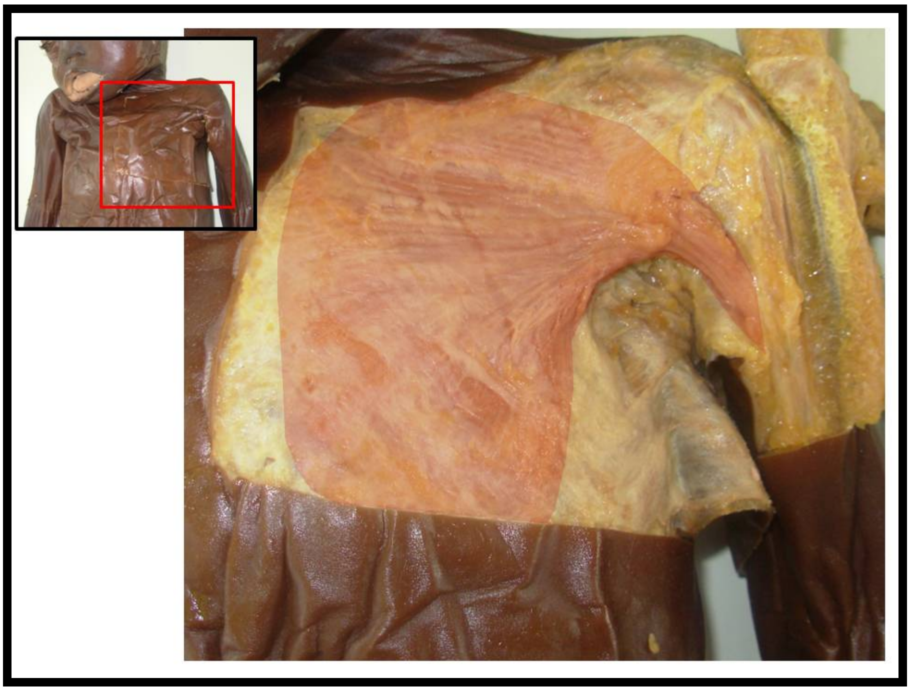


Figure 4.7: Skin reflected from the pectoral region of a neonatal cadaver in order to expose the pectoralis major muscle.

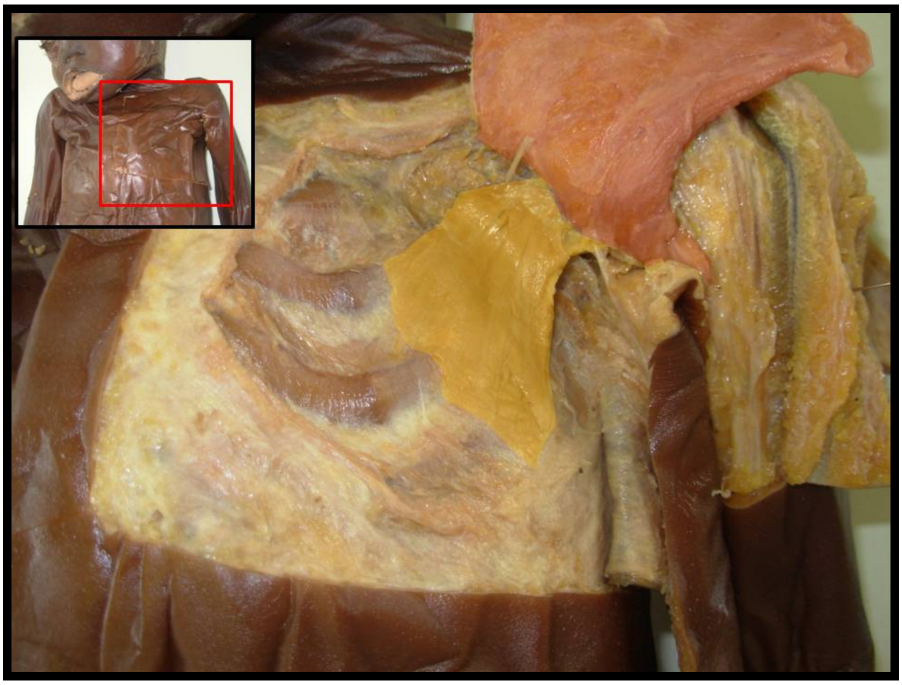
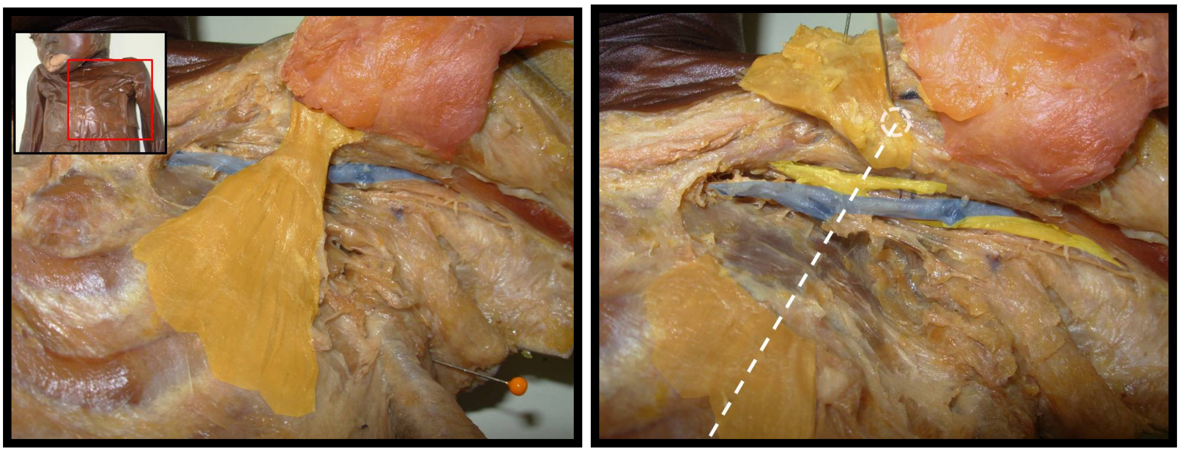


Figure 4.8: Pectoralis major muscle (highlighted in red) reflected in order to expose the pectoralis minor muscle (highlighted in orange).

Care was taken not to disturb the structures within the axillary sheath when the pectoralis minor was reflected (see Figure 4.9a & b). The axillary vein was carefully removed in order to better visualise the structures of the axilla. All measurements were done with the cadavers' arms adducted and supinated, lying against the trunk. The distance between (a) the coracoid process and the xiphisternal joint (CP-XS line) was measured using a mechanical dial sliding calliper (accuracy of 0.01mm).



(a) (b)

Figure 4.9a: Pectoralis minor muscle.

Pectoralis major muscle (highlighted in red) reflected in order to expose the pectoralis minor muscle (highlighted in orange) with content of the axilla traversing posterior to it. The axillary vein, the most superficial structure in the axillary sheath, is highlighted in blue.

Figure 4.9b: Content of the axilla.

Both the pectoralis major muscle (highlighted in red) and the pectoralis minor muscle (highlighted in orange) has been reflected in order to expose the axillary sheath. The axillary vein and brachial plexus (lateral cord and some terminal branches are visible) are highlighted in blue and yellow respectively. The position of the coracoid process is indicated by the dashed circle, while the CP–XS line is indicated by the white dashed line.

The distances of the coracoid process to (b) the lateral cord of the brachial plexus (LBP) and (c) medial cord of the brachial plexus (MBP) were then measured on the CP-XS line, as well as (d) the distance between the LBP and MBP. These distances were then converted to a percentage of the

CP-XS line distance and recorded in an MS Excel™ worksheet where further statistical analysis was done, i.e., distance of the coracoid process to the LBP (%)=100(measurement **b** / measurement **a**) and the distance of the MBP (%)=100(measurement **c** / measurement **a**). The midpoint of between the LBP and MBP, along the CP-XS line was also determined as this should be the ideal point of needle insertion. Therefore the point of needle insertion should be (e) the measurement **b** + ½ measurement **d** (see Figure 4.10).

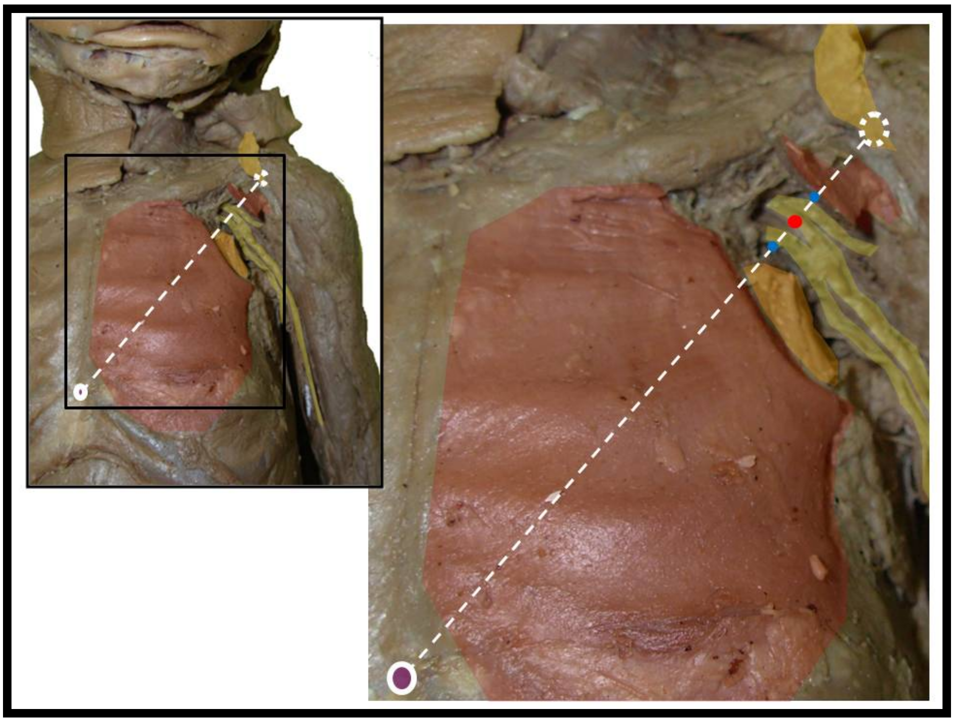


Figure 4.10: Schematic of measurements taken on exposed brachial plexus.

Both the pectoralis major and minor muscles (highlighted in red and orange respectively) have been reflected in a neonatal cadaver in order to expose the brachial plexus (highlighted in yellow). The red circle indicates the ideal site for needle insertion, or the point halfway between the LBP and MBP (blue circles) on the CP–XS line (white dashed line, between the coracoid process (dashed circle) and the xiphisternal joint (purple circle with white border).

A paired *t*-test was performed to compare the all the results from the right side of the adult sample to that of the left side.

A Pearson's correlation coefficient test (correlation coefficient or R) was conducted to determine correlation coefficient or the strength of the correlation between the dependent and independent variables. In this study the dependent variables were (a) the distance from the coracoid process to the point of needle insertion and (b) the distance from the coracoid process to the point of needle insertion as a percentage of the CP–XS line distance. The independent variables were the length, weight and CP–XS line distances of the sample.

In the cases where a strong correlation existed between two variables ($R > 0.7$), the coefficient of determination (or R^2) was determined, which is a statistical measure of how well the regression line approximates the real data points. In these cases, a linear regression formula was developed with the distance from the CP to the point of needle insertion along the CP–XS line, as the *dependant variable* and the CP–XS line distance (mm) as the *independent variable*.

The distance of (f) the MBP to the closest rib was also measured to determine the closest distance between the possible position of the needle and the thoracic wall, and subsequently the pleural cavity. All measurements were done with the cadavers' arms adducted and supinated, lying against the trunk.

4.3.2 Anatomical considerations of the infraclavicular brachial plexus block–comparison between neonatal and adult data

Similar to *4.3.1: Anatomical considerations of the neonatal infraclavicular brachial plexus block*, the content of the axilla was carefully exposed in a sample of 81 adult cadavers (74 left and 70 right axillae; mean length: 1.70m ± 0.09m; mean weight: 57.57kg ± 14.95kg) and measurements were taken with a mechanical dial sliding calliper (accuracy of 0.01mm).

In order to compare the results of the neonatal sample (see *5.3.1: Anatomical considerations of the neonatal infraclavicular brachial plexus block)* with the above adult sample, a paired *t*-test was performed on measurements (b)–(d). Only the values given as a percentage of the CP-XS line distance were compared as the distances in millimetres quite clearly shows a difference between neonates and adults, due to the large size differences and not because of differences of the position of the brachial plexus within the axilla.

4.4) Paediatric femoral nerve block

4.4.1 Anatomical considerations of the neonatal femoral nerve block

In order to visualise the specific anatomical structures, i.e., femoral artery, nerve, PT and ASIS, the skin and subcutaneous fat covering the anterior abdominal wall and femoral triangle was reflected in both sides of 54 neonatal cadavers (50 left and 50 right; mean length: 0.44m ± 0.08m; mean weight: 1.96kg ± 1.57kg). Needles were then inserted into the specific bony landmarks (ASIS and PT), as well as into the centre of the femoral artery and femoral nerve (at a point immediately inferior to the inguinal ligament) (see Figure 4.11). Four separate measurements (i–iv) were then made on both the left and right sides of each cadaver using a mechanical dial sliding calliper. Measurements were taken from (i) the ASIS to the PT, (ii) the ASIS to the femoral nerve, (iii) the ASIS to the femoral artery, and (iv) the femoral artery to the femoral nerve.

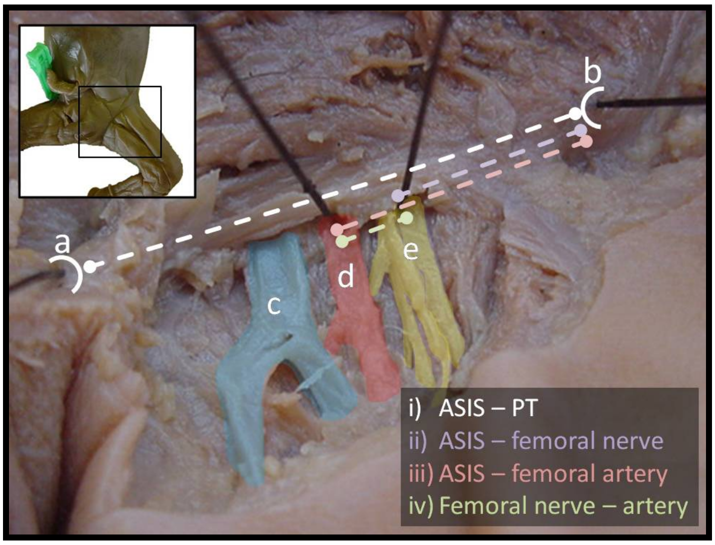


Figure 4.11: Neonatal femoral triangle.

Needles were placed into the (a) PT, (b) ASIS, (c) femoral vein, (d) femoral artery and (d) femoral nerve. The dashed lines indicate the measurements that were taken.

After all measurements were taken, the distances of the femoral nerve (ii) and artery (iii) was converted to a percentage of the ASIS-PT line distance (i), i.e., femoral nerve (%) = 100(ii / i) and the femoral artery (%) = 100(iii / i). This would allow for determining at what point (as a percentage of the ASIS-PT line distance) the femoral nerve and artery passes posterior to the inguinal ligament to enter the femoral triangle.

A paired *t*-test was performed to compare all the results from the two sides.

A Pearson's correlation coefficient test (correlation coefficient or R) was conducted to determine the correlation coefficient or the strength of the correlation between the dependent variables, i.e., the distance from the ASIS to the femoral nerve in mm and as a % of the ASIS-PT line distance, and the independent variables, the length, weight and ASIS-PT line distance (i) of the sample.

In the cases where a strong correlation ($R > 0.7$) existed between the two variables, a linear regression formula together with the coefficient of determination (or R^2) was determined.

4.4.2 Anatomical considerations of the femoral nerve block– comparison between neonatal and adult data

The skin and subcutaneous fat covering the anterior abdominal wall and femoral triangle was reflected on each side of 77 adult cadavers. Similar to that of the neonatal sample (see *4.4.1 Anatomical considerations of the neonatal femoral nerve block*), measurements and statistical analyses were done on the adult sample.

The data obtained from the adult sample was then compared to the data obtained in the neonatal sample (see *5.4.1: Anatomical considerations of the neonatal femoral nerve block)* using a paired *t*-test.

4.5) Paediatric ilio-inguinal/ iliohypogastric nerve block

4.5.1 Anatomical considerations of the neonatal ilio-inguinal/ iliohypogastric nerve block

A midline incision through the skin stretching from the umbilicus to the pubic symphysis as well as two horizontal incisions laterally from the umbilicus and pubic symphysis was made bilaterally in a sample of 54 neonatal cadavers (51 left and 53 right sides; mean length: 0.43m±0.06m; mean weight: 1.64kg±0.72kg). The skin was then reflected laterally, leaving the superficial fascia of the anterior abdominal wall intact. The superficial fat layer was carefully removed to expose the superficial muscles and the rectus sheath of the anterior abdominal wall (see Figure 4.12).

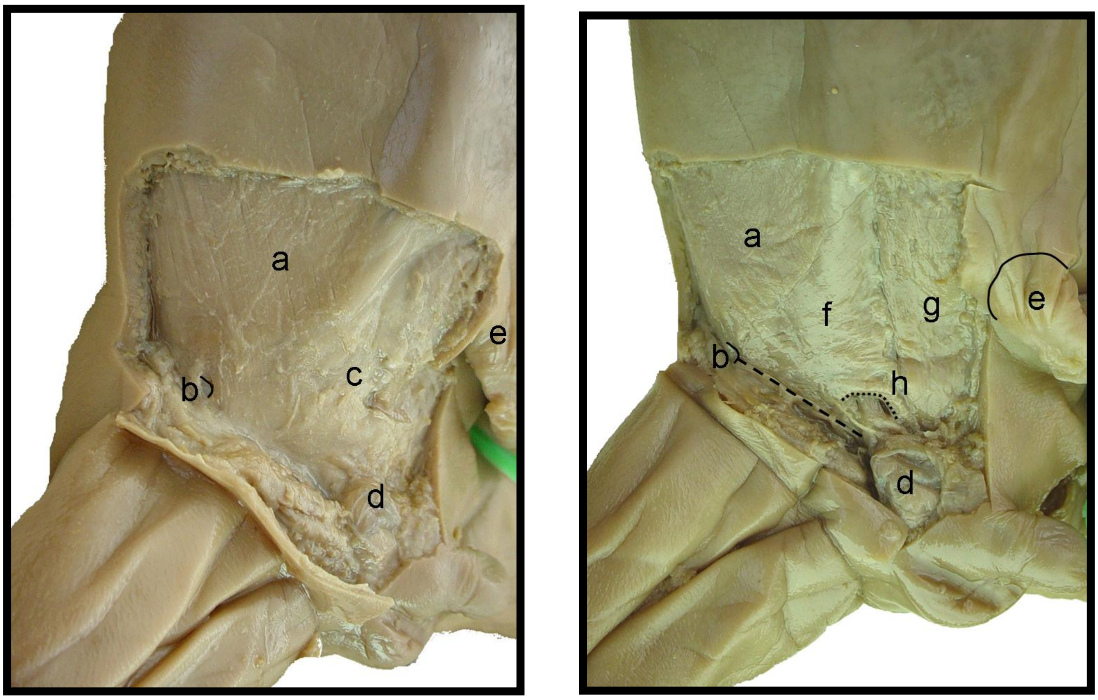


Figure 4.12: Superficial and deeper dissections of the anterior abdominal wall of a neonatal cadaver.

Structures that are visible include the external oblique muscle (a), the ASIS (b), the rectus sheath (c), testis (d), the umbilicus (e), internal oblique muscle (f), rectus abdominis muscle (g), and the conjoint tendon (h) (also indicated with the smaller, curved dotted line). The inguinal ligament is indicated with a dashed line.

A midline incision was made through the external oblique muscle and then carefully reflected laterally to expose the underlying internal oblique muscle. The ilio-inguinal nerve was then identified as it coursed through the deeper layers and travelled within the inguinal canal (see Figure 4.13). The nerve was then followed superolaterally to the point where it penetrates the internal oblique muscle. The latter was then carefully removed in sections to expose the course of the ilio-inguinal nerve back to a point superolateral to the ASIS. The iliohypogastric nerve, which courses superior to the ilio-inguinal nerve, was exposed in a similar manner (see Figure 4.14).

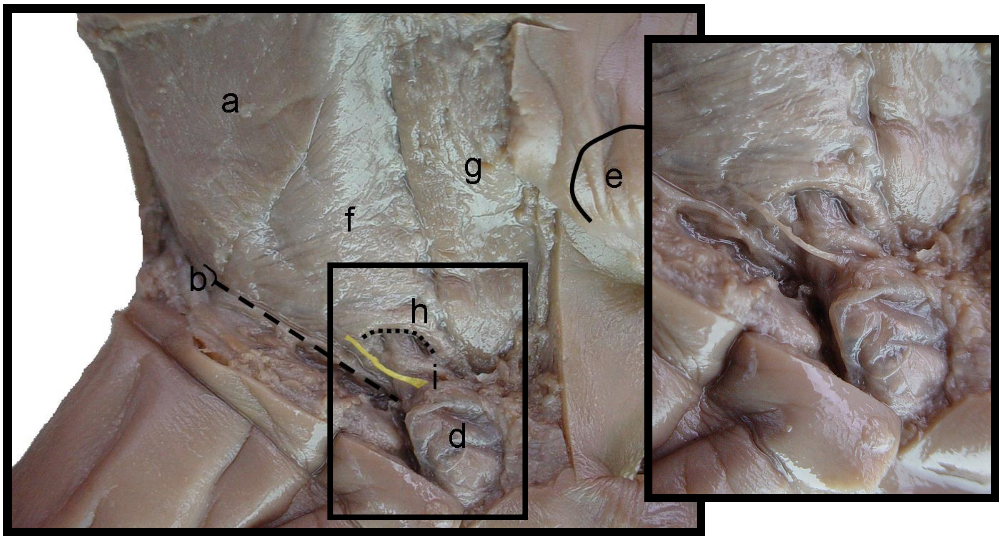


Figure 4.13: Dissection of anterior abdominal wall and the ilio-inguinal nerve.

The nerve can be seen piercing the internal oblique muscle (f) running with the spermatic cord towards the testis (d). Other structures include the external oblique muscle (a), ASIS (b), umbilicus (e), rectus abdominis muscle (g), conjoint tendon (h) (also indicated with the smaller, curved dotted line), and the ilio-inguinal nerve (i).

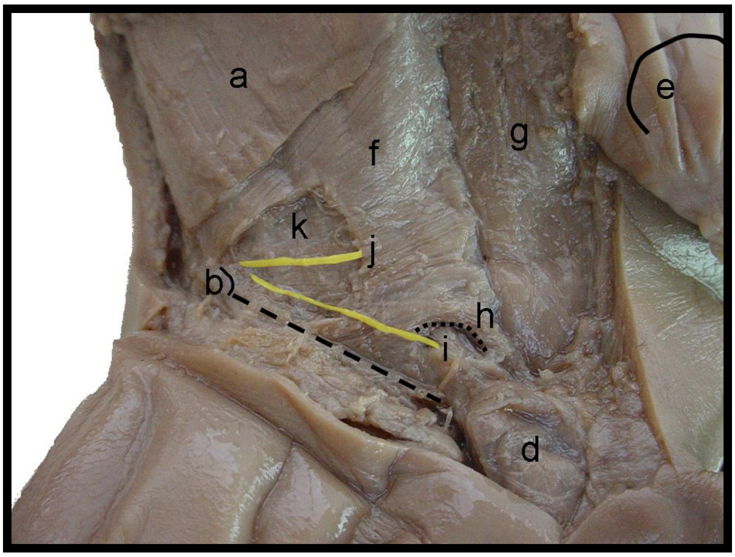


Figure 4.14: Dissection of the anterior abdominal wall and the ilio-inguinal and iliohypogastric nerves.

As the nerves pass inferomedial past the ASIS (b), they are still running in the plane between the transversus abdominis (k) muscle and internal oblique muscle (f). Other structures include the external oblique muscle (a), testis (d), umbilicus (e), rectus abdominis muscle (g), conjoint tendon (h) (also indicated with the smaller, curved dotted line), the ilio-inguinal nerve (i) and iliohypogastric nerve (j).

The ASIS was identified on both sides and the distance of both nerves from the ASIS - on a line connecting the ASIS to the umbilicus - was measured with a mechanical dial sliding calliper (accuracy of 0.01mm).

After complete dissection and identification of the nerves, a needle was then inserted according to the methods described by Von Bahr (1979) (see Figure 2.15), Sethna and Berde (1989) (see Figure 2.16) and Schulte-Steinberg (1990) (see Figure 2.17). The respective positions of the needle and its relationship to the nerves were documented for each specimen dissected.

Statistical analysis included a comparison between the left and right sides by using a paired *t*-test.

A Pearson's correlation coefficient test (correlation coefficient or R) was conducted to determine the correlation coefficient or the strength of the correlation between the dependent variables, i.e., the distance of the ilio-inguinal and iliohypogastric nerves from the ASIS and the distance of the point of needle insertion from the ASIS, and the independent variables, the length and weight of the sample population.

In the cases where a strong or high, moderate correlation (R > 0.6) between the dependent and independent variables was found, the coefficient of determination (or R^2) was determined. This is a statistical measure of how well the regression line, that was also determined, approximates the real data points.

4.6) Sample size and selection

In order to obtain the relevant data, three separate sample populations were used. These were: (a) neonatal cadavers, (b) adult cadavers, and (c) MR images.

4.6.1 Neonatal sample

A total of 69 neonatal and two infant cadavers, stored in the Department of Anatomy of the University of Pretoria (n = 60) and University of the Witwatersrand (n = 11), were selected for this study. The ages of the cadavers ranged from stillborn babies to 2-month-old. The mean weight of the neonatal sample was 1.77kg and it included very low birth weight cadavers (less than 1.5kg), low birth weight cadavers (less than 2.5kg) and normal birth weight cadavers (more than 2.5kg). The mean length of the cadavers was 0.43m ± 0.07m (mean ± SD). The University of the Witwatersrand's sample of cadavers were only used for the femoral nerve and ilio-inguinal/ iliohypogastric nerve blocks.

4.6.2 Adult sample

A total of 90 adult cadavers, stored at the Department of Anatomy of the University of Pretoria, were used as a basis for comparison with the neonatal data. The mean age of the adult sample was 61 years ± 20 years. The samples age ranged between 23 years and 94 years. The mean weight of the sample was 57.53kg ± 15.49kg and the mean length was 1.70m ± 0.09m.

The adult sample was used in the femoral nerve and infraclavicular blocks to compare with the data obtained from the neonatal sample.

4.6.3 MRI scans

A total of 108 T-2 weighted midsagittal lumbar MR images were obtained from Burger Radiologists, UNITAS hospital and the Department of Radiology, Steve Biko Academic Hospital. The MRI scans were used for the lumbar and caudal epidural blocks.

4.7) Ethical considerations

Ethical approval to conduct this study was obtained from the Ethics Committee of the University of Pretoria. All dissections of the neonatal and adult cadavers were performed in accordance with the Human Tissue act 65 of 1983 (Government Gazette, 1983).

Permission to access MR images was obtained from Burger Radiologists, UNITAS Hospital and the Department of Radiology, Steve Biko Academic Hospital.

4.8) Statistical analysis

All measurements were entered into MS Excel™. Statistical analysis of all the measurements and subsequent comparisons of these measurements with the demographic profile of both the sample of neonatal cadavers and MRI scans were performed using Statistix™ Ver. 8.0 for Windows.

In certain cases where a linear correlation between two variables are expected (i.e., distance to a nerve will increase with the length of the patient), a Pearson's correlation coefficient test (correlation coefficient or R) was conducted to determine the strength of the correlation between the dependent variable and the independent variables. This test determines the strength of the linear relationship between two variables ($R < 0.3$ is considered to be a weak correlation, $R = 0.3 – 0.7$ is considered to be a moderate correlation, and $R > 0.7$ is considered to be a strong correlation between the variables). In the cases where a moderate or strong correlation was found, a linear regression formula was determined.

Linear regression is a method of estimating the conditional expected value of one variable (dependent variable) when the values of another variable or variables (independent variables) are known. The dependant and independent variables will be discussed in more detail in each separate Chapter.

The coefficient of determination (or R^2) was determined for any linear regression model with a strong or high, moderate correlation between the dependant and independent variables. R^2 is a statistical measure of how well the regression line "fits"; in other words, how well the dependant variable is "explained" by the independent variables in the model. For example, a value such as $R^2 = 0.7$ may be interpreted that approximately seventy percent of the variation in the dependent variable can be explained by the independent variable. The remaining thirty percent can be explained by unknown variables or inherent variability.

4.9) Limitations of the study

The small sample size and the fact that mostly neonatal cadavers were used are directly related to the scarcity of paediatric cadavers of different age groups. Data on neonatal cadavers is however equally rare and therefore immensely valuable.

Shrinkage is a common artefact and occurs during preservation of cadavers. Although the shrinkage is minimal, it should nevertheless be taken into account when data is obtained from the neonatal cadavers.

Chapter 5: Results

5.1) Paediatric caudal epidural block

5.1.1 Dimensions of the neonatal sacrococcygeal membrane

Results obtained from the measurements taken from the forty sacrococcygeal membranes of the neonatal cadavers are summarised in Table 5.1.

Table 5.1: Summary of the measurements take on the neonatal sacrococcygeal membrane

	ISC	SC Height	SC Area
N	**40**		
Mean	8.70	3.90	18.27
SD	2.70	1.28	10.67
CI 95%	0.84	0.40	3.35
Lower	7.86	3.50	14.92
Upper	9.53	4.29	21.62

Key:

ISC: Distance between the two sacral cornuae
SC Height: Height of the sacrococcygeal membrane
SC Area: Surface area of the sacrococcygeal membrane
CI 95%: Confidence interval with a 95% confidence level
Lower: Lower range of the Confidence interval with a level of confidence of 95%
Upper: Upper range of the Confidence interval with a level of confidence of 95%

The average distance between the two sacral cornuae for the neonatal sample was 8.70mm (range: 7.86mm – 9.53mm; all measurements with a 95% confidence level) while the average height of the sacrococcygeal membrane was only about 3.90mm (range: 3.50mm – 4.29mm). The average surface area of the membrane was found to be 18.27mm^2 (range: 14.92mm^2 – 21.62mm^2).

5.1.2 The distance of the lumbar interlaminar spaces from the apex of the sacrococcygeal membrane in a neonatal sample

With the neonate in a prone position measurements were taken from the apex of the sacrococcygeal membrane to the interlaminar spaces between L1/L2; L2/L3; L3/4; L4/L5 and L5/S1. These measurements are summarised in Table 5.2.

Table 5.2: Measurements of the apex of the sacrococcygeal membrane to the neonatal lumbar interlaminar spaces.

	Cadavers in prone position				
	L5/S1	L4/L5	L3/L4	L2/L3	L1/L2
n	**40**				
Mean	16.09	22.43	29.17	37.85	45.61
SD	3.97	5.14	7.70	7.67	9.07
CI 95%	1.28	1.65	2.45	2.44	2.92
Lower	14.81	20.78	26.72	35.41	42.69
Upper	17.37	24.09	31.62	40.29	48.54

Key:

CI 95%: Confidence interval with a 95% confidence level
Lower: Lower range of the Confidence interval with a level of confidence of 95%
Upper: Upper range of the Confidence interval with a level of confidence of 95%

The same measurements were taken from the apex of the sacrococcygeal membrane, but with the neonates flexed over a wooden block. These measurements are summarised in Table 5.3.

Table 5.3: Measurements of the apex of the sacrococcygeal membrane to the neonatal lumbar interlaminar spaces.

	Cadavers in flexed position				
	L5/S1	L4/L5	L3/L4	L2/L3	L1/L2
n	40				
Mean	17.80	25.45	33.93	42.93	51.21
SD	4.30	5.49	6.96	8.00	9.02
CI 95%	1.37	1.75	2.18	2.51	2.87
Lower	16.43	23.71	31.75	40.42	48.35
Upper	19.17	27.20	36.12	45.44	54.08

Key:

CI 95%: Confidence interval with a 95% confidence level
Lower: Lower range of the Confidence interval with a level of confidence of 95%
Upper: Upper range of the Confidence interval with a level of confidence of 95%

The measurements obtained from the cadavers in a prone position and the same cadavers in a flexed position can best be summarised in Figure 5.1.

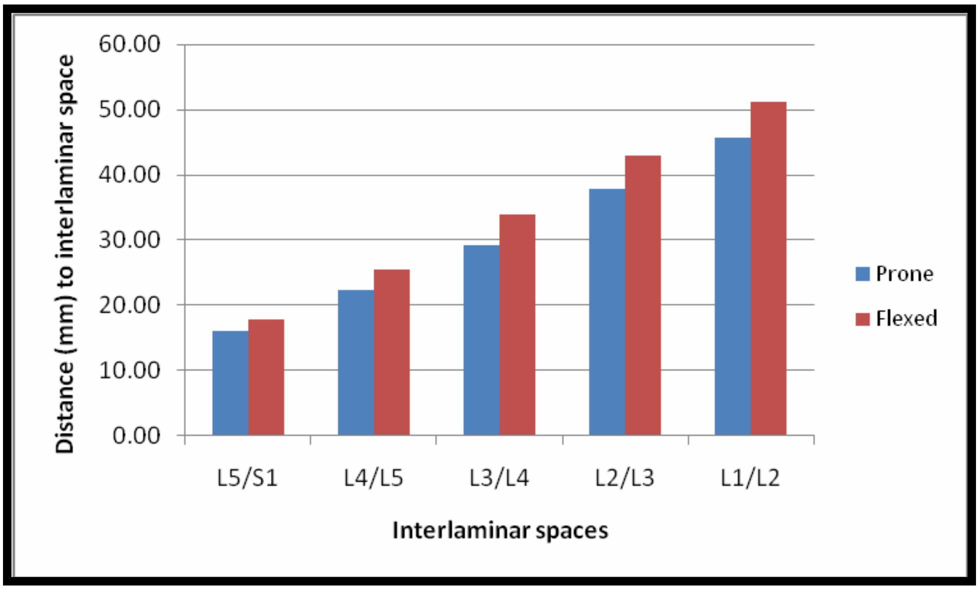


Figure 5.1: Distances from the apex of the sacrococcygeal membrane to the neonatal lumbar epidural spaces.

With the cadaver in the prone position, the distance (95% confidence level) from the apex of the sacrococcygeal membrane to the inferior border of the L1/L2; L2/L3; L3/4; L4/L5 and L5/S1 interlaminar spaces was: 45.61mm ± 1.91mm (mean ± CI 95%); 37.85mm ± 3.17mm;

29.17mm ± 3.84mm; 22.43mm ± 2.03mm; and 16.09mm ± 1.37mm, respectively. While the same measurements for the cadavers in a flexed position were: 51.21mm ± 1.35mm; 42.93mm ± 1.37mm; 33.93mm ± 1.04mm; 25.45mm ± 0.93mm; and 17.80mm ± 0.75mm, respectively.

The percentage change of these measurements between the prone and flexed positions was then calculated and is summarised in Figure 5.2.

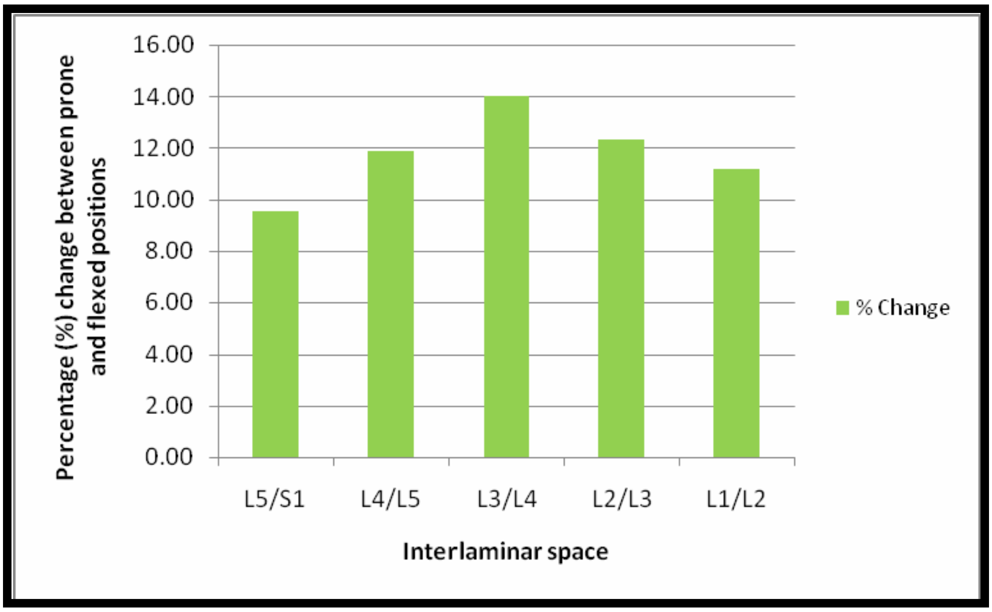


Figure 5.2: Percentage change of the distance from the apex of the sacrococcygeal membrane to the neonatal lumbar epidural spaces.

A paired *t*-test compared the distances between the measurements taken with the cadavers in a prone position with those of the cadavers in a flexed position. There was a significant difference between the distances with the cadaver in a prone and flexed position.

On average, there is an 11.20% change from the prone to flexed position for the distance from the apex of the sacrococcygeal membrane to the interlaminar space of L1/L2. The percentage change of the distance to the interlaminar spaces of L2/L3; L3/L4; L4/5; and L5/S1 are 12.35%, 14.01%, 11.89%, and 9.54% respectively.

5.1.3 The vertebral level of termination and distance from the apex of the sacrococcygeal membrane to the dural sac

In the sample of forty neonatal cadavers, the mean distance from the apex of the sacrococcygeal membrane to the dural sac was 10.45mm ± 3.99mm (mean ± SD). There is a 95% confidence level that in a neonatal sample, the dural sac can be found between 8.88mm – 11.79mm from the apex of the sacrococcygeal membrane.

The MR images were divided into two groups; patients less than 6 years old (n = 13) and patients older than 6 and younger than 30 years old (n = 89). The vertebral level where the dural sac ends, for both the groups as well as the total sample, is summarised in Table 5.4.

Table 5.4: Vertebral level of dural sac termination on MR images. The corresponding number of each division is given in brackets.

Age	n	Mean	Lower 95% CI	Upper 95% CI
< 6	13	S1/S2 **(28)**	Lower third S1 **(27)**	Middle third S2 **(30)**
6-29	89	Upper third S2 **(29)**	Upper third S2 **(29)**	Upper third S2 **(29)**
Total	102	Upper third S2 **(29)**	S1/S2 **(28)**	Upper third S2 **(29)**

Key:

Lower: Lower range of the Confidence interval with a level of confidence of 95%
Upper: Upper range of the Confidence interval with a level of confidence of 95%
CI 95%: Confidence interval with a 95% confidence level

In children younger than six years, the dural sac ends on average at the vertebral level corresponding with the S1/S2 interlaminar space. The range is between the lower third of the S1 vertebra and the middle third of the S2 vertebra (95% confidence level). In patients older than six years, the dural sac appears to end at the upper third of the S2 vertebrae. There is very little variation of this level as there is a 95% confidence level that the dural sac ends at the upper third of the S2 vertebra.

5.2) Paediatric lumbar epidural block

5.2.1 The value of Tuffier's or the intercrestal line in neonates

The corresponding number of the vertebral level where Tuffier's line intersects the lumbar vertebral column is summarised in Table 5.5.

Table 5.5: Average level of Tuffier's line in a neonatal sample in both a prone and flexed position. The corresponding number of each division is given in brackets.

	Vertebral level of Tuffier's line		**Change from prone to flexed**
	Prone	**Flexed**	
Mean	L4/L5 **(20)**	Upper third L5 **(21)**	0.97*
SD	1.87*	1.81*	0.67*
Lower	Lower third L4 **(19)**	L4/L5 **(20)**	0.76*
Upper	L4/L5 **(20)**	Upper third L5 **(21)**	1.18*

Key:

Lower: Lower range of the Confidence interval with a level of confidence of 95%
Upper: Upper range of the Confidence interval with a level of confidence of 95%
CI 95%: Confidence interval with a 95% confidence level

* These numbers represent the divisions of the vertebral column (the vertebral bodies into thirds with a subsequent interlaminar space). Therefore a 1* would for example represent a change from the upper third of L5 to the middle third of L5.

It is clear from this sample that, when in a prone (or neutral position, Tuffier's line crosses through the L4/L5 interlaminar space (95% confidence level, range between the lower third of L4 and the L4/L5 interlaminar space). During flexion this level moves caudally by an average of one number position (0.97 ± 0.67) to the upper third of the L5 vertebra (95% confidence level, range between the L4/L5 interlaminar space and the upper third of the L5 vertebra).

The distance from the apex of the sacrococcygeal membrane to Tuffier's line in both a prone and flexed position was also measured using Image Tool and the results are summarised in Table 5.6.

Table 5.6: Measurement of the apex of the sacrococcygeal membrane to Tuffier's line on a neonatal sample in both a prone and flexed position.

	Distance in mm		% Change
	Prone	Flexed	
Mean	23.64	25.47	
SD	5.65	5.63	
CI 95%	1.77	1.77	
Lower	21.86	23.71	3.10
Upper	25.41	27.24	11.10

Key:

Lower: Lower range of the Confidence interval with a level of confidence of 95%
Upper: Upper range of the Confidence interval with a level of confidence of 95%
CI 95%: Confidence interval with a 95% confidence level

While the vertebral level of Tuffier's line moves caudally during flexion, the distance from the apex of the sacrococcygeal membrane to Tuffier's line increases significantly ($p = 0.0061$) from 23.64mm ± 5.65mm (mean ± SD) (95% confidence level; range: 21.86mm – 25.41mm) to 25.47mm ± 5.63mm (95% confidence level; range 23.71mm – 27.25mm). This constitutes a percentage change that ranges from 3.10% to 11.10% (95% confidence level) in the distance between the apex of the sacrococcygeal membrane and Tuffier's line).

5.2.2 The dimensions of the lumbar interlaminar spaces in neonates in both a prone and flexed position

Using the *Area* function of Image Tool, the surface area of the interlaminar spaces between L1/L2; L2/L3; L3/4; L4/L5 and L5/S1 were determined. These measurements are summarised in Table 5.7.

Table 5.7: Surface area measurements of the neonatal lumbar interlaminar spaces.

	Cadavers in prone position (measurements in mm^2)				
	L5/S1	**L4/L5**	**L3/L4**	**L2/L3**	**L1/L2**
n	**40**				
Mean	9.87	10.66	11.40	11.42	9.82
SD	3.93	4.10	4.26	4.63	3.89
CI 95%	1.27	1.32	1.35	1.47	1.25
Lower	8.60	9.33	10.05	9.95	8.57
Upper	11.14	11.98	12.76	12.89	11.07

Key:

CI 95%: Confidence interval with a 95% confidence level
Lower: Lower range of the Confidence interval with a level of confidence of 95%
Upper: Upper range of the Confidence interval with a level of confidence of 95%

The same surface area measurements of the interlaminar spaces were taken with the neonatal cadaver flexed over a wooden block. These measurements are summarised in Table 5.8.

Table 5.8: Surface area measurements of the neonatal lumbar interlaminar spaces.

	Cadavers in flexed position (40°-50°) (measurements in mm^2)				
	L5/S1	L4/L5	L3/L4	L2/L3	L1/L2
n	40				
Mean	12.81	14.45	15.33	13.91	11.94
SD	4.97	5.54	6.42	5.58	4.16
CI 95%	1.58	1.76	2.02	1.75	1.32
Lower	11.23	12.69	13.31	12.16	10.62
Upper	14.39	16.21	17.35	15.66	13.27

Key:

CI 95%: Confidence interval with a 95% confidence level
Lower: Lower range of the Confidence interval with a level of confidence of 95%
Upper: Upper range of the Confidence interval with a level of confidence of 95%

The surface area of the interlaminar spaces of the neonatal cadavers in a prone position and the same sample of cadavers in a flexed position can best be summarised in Figure 5.3.

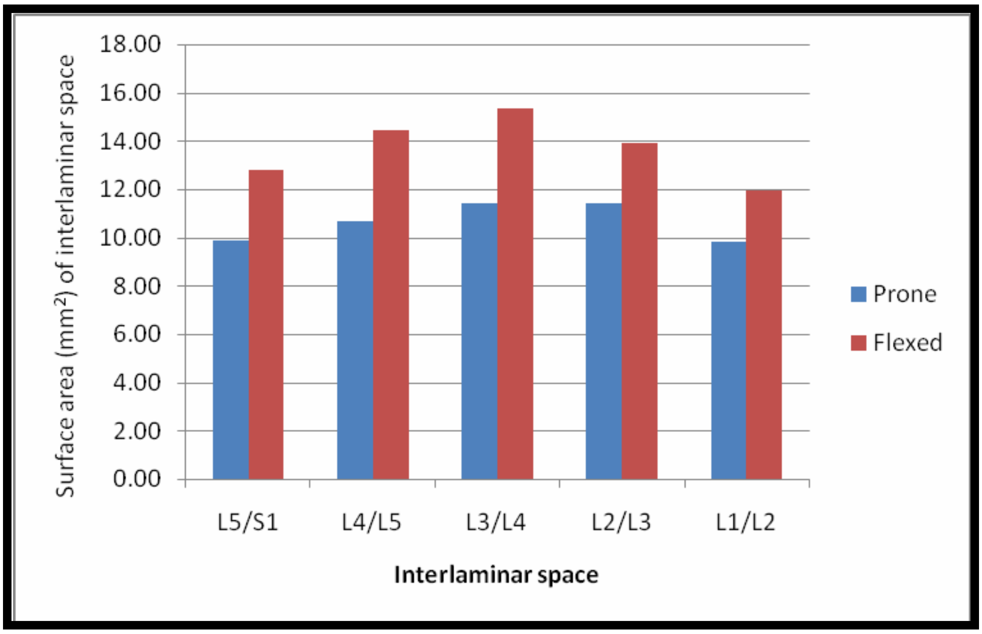


Figure 5.3: Surface area of neonatal lumbar interlaminar spaces.

Average surface area for both samples are shown (blue and red blocks respectively).

With the cadaver in the prone position, the average surface area of the L1/L2; L2/L3; L3/4; L4/L5 and L5/S1 interlaminar spaces was: 9.82mm ± 3.89mm (mean ± SD), 11.42mm ± 4.63mm, 11.40mm ± 1.67mm, 10.66mm ± 4.10mm, and 9.87mm ± 3.93mm, respectively. While the same measurements for the cadavers in a flexed position were: 11.94mm ± 4.16mm, 13.91mm ± 5.58mm, 15.33mm ± 6.42mm, 14.45mm ± 5.54mm, and 12.81mm ± 4.97mm, respectively.

The percentage change of the surface area between the interlaminar spaces of the cadavers in a prone and flexed position was then calculated and is summarised in Figure 5.4.

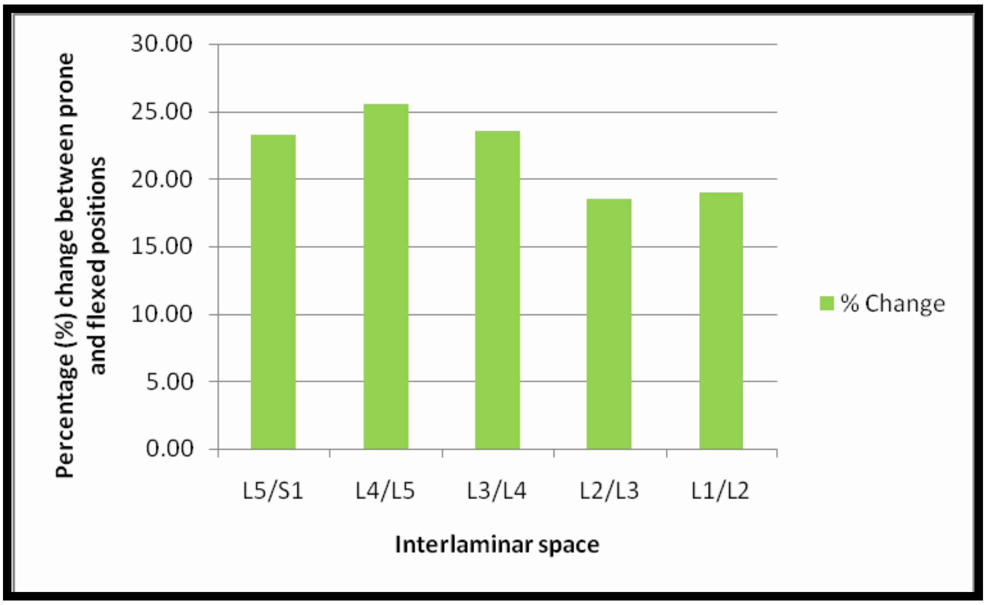


Figure 5.4: Percentage change of the surface area measurements of the neonatal lumbar interlaminar spaces.

A paired *t*-test compared the surface area measurements of the interlaminar spaces with the cadavers in a prone position with those in a flexed position. There was a significant difference ($p = 0.00001$) between all the surface area measurements taken with the cadaver in prone and flexed position.

On average, there is a 19.01% change in the surface area of the L1/L2 interlaminar space from a prone to a flexed position. The percentage change of the surface area of the L2/L3; L3/L4; L4/5; and L5/S1 interlaminar spaces is 18.56%, 23.52%, 25.53%, and 23.23% respectively.

5.2.3 The vertebral level and distance from the apex of the sacrococcygeal membrane of the conus medullaris

5.2.3.1 Neonatal cadavers

The distance of the sacrococcygeal membrane to the conus medullaris was measured in a sample of 39 neonatal cadavers after carefully exposing the above-mentioned structures. The measurements are summarised in Table 5.9.

Table 5.9: Summary of the distance from the apex of the sacrococcygeal membrane to the conus medullaris.

	Distance in mm		% Change
	Prone	Flexed	
n	40		
Mean	40.62	45.76	11.43
SD	11.67	12.16	7.56
CI 95%	3.66	3.82	2.37
Lower	36.96	41.94	9.06
Upper	44.29	49.57	13.80

Key:

CI 95%: Confidence interval with a 95% confidence level
Lower: Lower range of the Confidence interval with a level of confidence of 95%
Upper: Upper range of the Confidence interval with a level of confidence of 95%

In the sample of 39 neonatal cadavers, the mean distance from the apex of the sacrococcygeal membrane to the conus medullaris was 40.62mm ± 11.67mm (mean ± SD). There is a 95% confidence level that in a neonatal sample, the conus medullaris lies between 36.96mm – 44.29mm from the apex of the sacrococcygeal membrane in a neonate lying in the prone position. When flexed, the distance from the apex of the sacrococcygeal membrane to the conus medullaris increases to 45.76mm ± 12.16mm (95% confidence level; range: 41.94mm – 49.57mm).

This distance changes between 9.06% - 13.80% (95% confidence level) when the neonate is flexed.

The vertebral level of the termination of the spinal cord was noted on the neonatal sample (n = 39) and is summarised in Table 5.10.

Table 5.10: Vertebral level of spinal cord termination in the neonatal cadaver sample. The corresponding number is given in brackets.

Age	n	Mean	Lower 95% CI	Upper 95% CI
< 1	39	Upper third L2 **(9)**	L1/L2 **(8)**	Middle third L2 **(10)**

Key:

Lower: Lower range of the Confidence interval with a level of confidence of 95%
Upper: Upper range of the Confidence interval with a level of confidence of 95%
CI 95%: Confidence interval with a 95% confidence level

5.2.3.2 MR images

The MR images were divided into two groups; patients 1 year old or less (n = 7) and patients older than 1 and younger than 30 years old (n = 101). The vertebral level where the spinal cord ends, for both the groups as well as the total sample, is summarised in Table 5.11.

Table 5.11: Vertebral level of spinal cord termination on MR images. The corresponding number is given in brackets.

Age	n	Mean	Lower 95% CI	Upper 95% CI
1-29	101	Middle third L1 **(6)**	Middle third L1 **(6)**	Middle third L1 **(6)**

Key:

Lower: Lower range of the Confidence interval with a level of confidence of 95%
Upper: Upper range of the Confidence interval with a level of confidence of 95%
CI 95%: Confidence interval with a 95% confidence level

In patients older than one year old the spinal cord appears to end at the middle third of the L1 vertebra.

5.3) Paediatric infraclavicular approach to the brachial plexus

5.3.1 Anatomical considerations of the neonatal infraclavicular brachial plexus block

The data obtained for the right and left sides of all the neonatal cadavers is summarised in Tables 5.12 & 5.13.

Table 5.12: Distances of the neonatal brachial plexus from the coracoid process, on the right side.

	Height	Weight	Right							
			CP – XS (mm)	CP – LBP (mm)	CP – LBP (%)	CP – MBP (mm)	CP – MBP (%)	LBP – MBP (mm)	LBP – MBP (%)	MBP – Rib (mm)
N	53		50							
Mean	0.43	1.94	58.45	5.26	8.94	10.10	17.25	4.81	8.29	4.89
SD	0.08	1.62	11.63	1.86	2.26	2.86	3.34	1.46	2.20	2.17
Min.	0.32	0.60	36.53	2.38	5.71	5.29	11.53	2.45	5.14	1.78
Max.	0.76	9.10	91.88	12.34	14.27	18.57	29.22	8.32	15.84	12.99
CI 95%			3.22	0.52	0.63	0.79	0.93	0.40	0.61	0.60
Lower			55.22	4.75	8.31	9.30	16.32	4.40	7.67	4.29
Upper			61.67	5.78	9.56	10.89	18.17	5.21	8.90	5.49

Key:

CP-XS: Distance (mm) between the coracoid process and the xiphisternal joint
CP-LBP: Distance (mm) from the coracoid process to the LBP
CP-LBP %: Distance from the coracoid process to the LBP as a percentage of the CP-XS line distance
CP-MBP: Distance (mm) from the coracoid process to the MBP
CP-MBP %: Distance from the coracoid process to the MBP as a percentage of the CP-XS line distance
LBP-MBP: Distance (mm) between the LBP and MBP
LBP-MBP %: Distance between the LBP and MBP as a percentage of the CP-XS line distance
MBP-Rib: Distance between the MBP and the closest rib
CI 95%: Confidence interval with a 95% confidence level
Lower: Lower range of the Confidence interval with a level of confidence of 95%
Upper: Upper range of the Confidence interval with a level of confidence of 95%

Table 5.13: Distances of the neonatal brachial plexus from the coracoid process, on the left side.

	Height	Weight	Left							
			CP – XS (mm)	CP – LBP (mm)	CP – LBP (%)	CP – MBP (mm)	CP – MBP (%)	LBP – MBP (mm)	LBP – MBP (%)	MBP – Rib (mm)
N	53		52							
Mean	0.43	1.94	59.14	5.26	8.86	10.00	16.91	4.78	8.08	4.77
SD	0.08	1.62	11.42	1.61	2.01	2.49	2.75	1.29	1.55	2.52
Min.	0.32	0.60	38.91	2.77	5.59	5.50	12.01	2.32	4.94	2.37
Max.	0.76	9.10	90.44	9.49	14.29	16.48	23.31	8.53	12.04	19.37
CI 95%			3.10	0.44	0.55	0.68	0.75	0.35	0.42	0.68
Lower			56.04	4.82	8.32	9.32	16.16	4.43	7.66	4.09
Upper			62.24	5.70	9.41	10.67	17.66	5.13	8.51	5.45

The confidence interval was determined for all the measurements, with a 95% confidence level. Looking at the results of the right and left sides it can be seen that, as a percentage of the CP–XS line distance, the LBP lies between 8.31%–9.56% (mean distance: 4.75mm–5.78mm) of the total CP–XS line distance away from the coracoid process on the right and between 8.32%–9.41% (mean distance: 4.82mm–5.70mm) from the coracoid process on the left. The right MBP can be found a total of 16.32%–18.71% (mean distance: 9.30mm–10.89mm) of the CP–XS line distance along the line connecting the coracoid process and xiphisternal joint, while the left MBP can be found between 16.16%–17.66% (mean distance: 9.32mm–10.67mm) along the CP–XS line. The distance between the LBP and MBP on the right is between 4.40mm–5.21mm and between 4.43mm–5.13mm on the left. Finally, the mean distance between the MBP and the closest rib (the shortest distance between the possible location of the needle and the thoracic wall and subsequent parietal pleura) is 4.29mm–5.49mm on the right and 4.09mm–5.45mm on the left.

Using the paired *t*-test, no significant difference were found between the left and right sides when comparing the coracoid process to LBP line distance in mm (p=0.3813) or as a % of the CP-XS line distance (p=0.3853), coracoid process to MBP distance in mm (p=0.3970) or as a % of the CP-XS line distance (p=0.3559), LBP to MBP distance (p=0.9543), or the distance from the MBP to the closest rib (p=0.7998). Because no statistically significant difference were obtained for any of the measurements, the right and left sides were combined to increase the sample to 102 axillae. The measurements of the total sample is summarised in Table 5.14.

Table 5.14: Distances of the brachial plexus, of the total neonatal population from the coracoid process.

	Height	Weight	Total							
			CP – XS (mm)	CP – LBP (mm)	CP – LBP (%)	CP – MBP (mm)	CP – MBP (%)	LBP – MBP (mm)	LBP – MBP (%)	MBP – Rib (mm)
N	102									
Mean	0.43	1.88	58.80	5.26	8.90	10.05	17.07	4.79	8.18	4.83
SD	0.08	1.48	11.47	1.73	2.12	2.67	3.04	1.37	1.89	2.34
Min.	0.32	0.60	36.53	2.38	5.59	5.29	11.53	2.32	4.94	1.78
Max.	0.76	9.10	91.88	12.34	14.29	18.57	29.22	8.53	15.84	19.37
CI 95%			2.23	0.34	0.41	0.52	0.59	0.27	0.37	0.45
Lower			56.57	4.93	8.49	9.53	16.48	4.53	7.82	4.38
Upper			61.02	5.60	9.31	10.56	17.67	5.06	8.55	5.28

In the total sample (n=102) the LBP can be found between 8.49% and 9.31% (95% confidence level; mean distance: 4.93mm–5.60mm) from the coracoid process, along a line drawn between the coracoid process and xiphisternal joint. The MBP can be found between 16.48% and 17.67% (mean distance: 9.53mm–10.56mm) from the coracoid process. The distance between the lateral and medial cords is between 4.53mm and 5.06mm. From the MBP there is a safe distance of between 4.38mm and 5.25mm before reaching the closest rib.

The point of needle insertion, in this case, is defined as the point midway between the LBP and MBP (see Figure 4.10). The needle insertion points, as well as the previously mentioned distance as a percentage of the CP–XS line distance, is summarised in Table 5.15.

Table 5.15: Point of needle insertion for the right, left, and total neonatal sample.

	Right	Left	Total	Right	Left	Total
	Needle insertion (mm)	**Needle insertion (mm)**	**Needle insertion (mm)**	**Needle insertion (%)**	**Needle insertion (%)**	**Needle insertion (%)**
N	50	52	102	50	52	102
Mean	7.67	7.65	7.66	13.08	12.91	12.99
SD	2.30	2.04	2.16	2.68	2.25	2.46
Min.	3.89	4.35	3.89	8.75	8.61	8.61
Max.	15.52	12.71	15.52	20.02	17.93	20.02
CI 95%	0.64	0.55	0.42	0.74	0.61	0.48
Lower	7.03	7.09	7.24	12.34	12.29	12.51
Upper	8.30	8.20	8.08	13.82	13.52	13.47

On the right, the point of needle insertion in the neonatal sample (n=50 on the right and 52 on the left) can be found with 95% confidence between 12.34%–13.52% (mean distance: 7.03mm–8.30mm) of the CP–XS line distance from the coracoid process. The needle insertion point on the left can be found between 12.29% and 13.52% of the CP–XS line distance (mean distance: 7.09mm–8.20mm). A paired *t*-test also revealed no significant difference between the right and left sides of the sample when comparing both the distance from the coracoid process to the point of needle insertion (mm) (p=0.4569) or the distance of the point of needle insertion as a percentage of the CP –XS line distance (p=0.3818). For the total sample (n=102) the point of needle insertion can be found between 12.29% and 13.47% (mean distance: 7.24mm–8.08mm) from the coracoid process.

The Pearson's correlation revealed that there exists a very weak correlation between the distance of the needle insertion point as a percentage of the CP–XS line distance (*dependent variable*) and the length of the sample (R=0.1850), the weight of the sample (R=0.1640) and the CP–XS line distance (R=0.0712) (*independent variables*). When correlating the distance (mm) of the point of needle insertion from the coracoid process with the independent variables, one can see that there is a moderate correlation with the length (R=0.6810) and weight (R=0.6171) of the sample. A strong correlation exists between the point of needle insertion (mm) and the CP–XS line distance (R=0.7460) of the sample. Because of this strong correlation, a linear regression formula was developed for the neonatal sample with the distance of the point of needle insertion from the coracoid process (in mm) as the dependent variable and the distance between the CP and XS (in mm) as the independent variable (see Figure 5.5). The coefficient of determination for this linear regression formula revealed that there is a moderate "fit" (R^2=0.557) between the distance of the point of needle insertion and the CP–XS line distance.

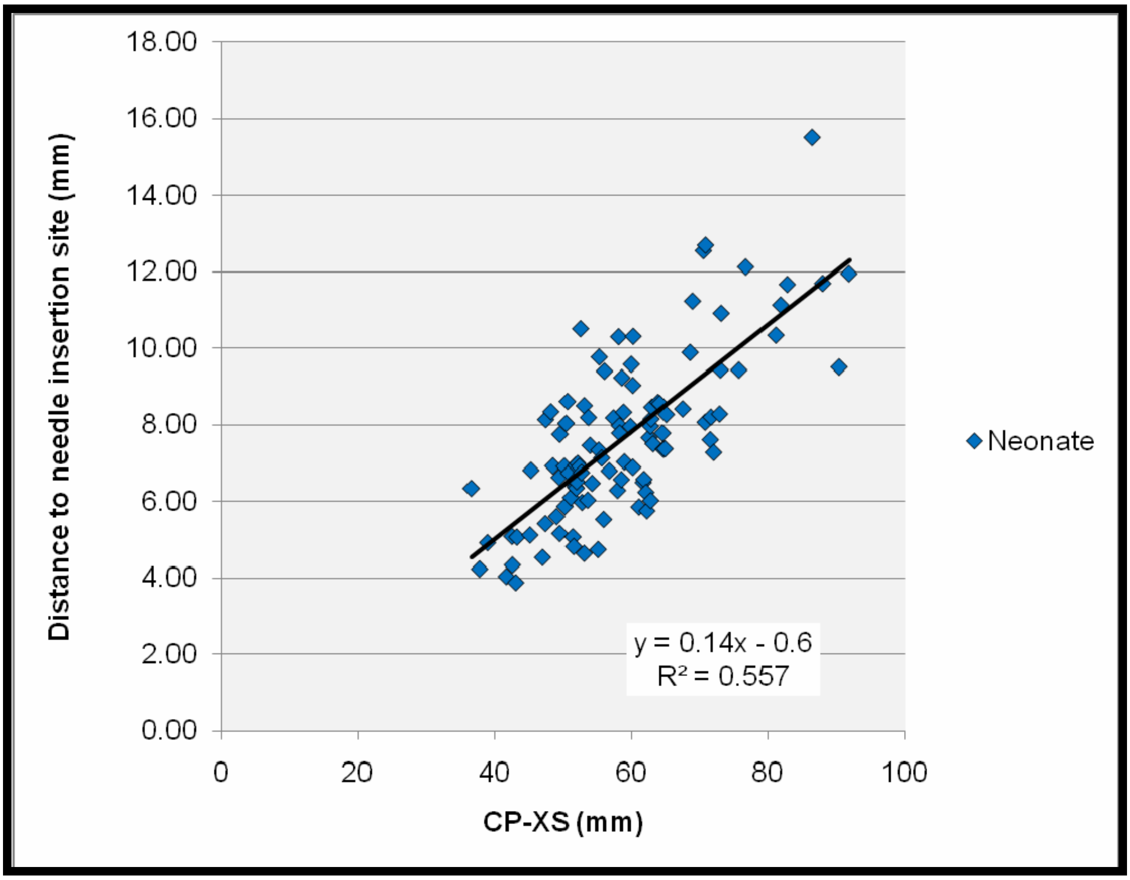


Figure 5.5: Linear regression formula for the distance of the point of needle insertion in neonates

The CP–XS line distance is the independent variable.

When comparing the measured distance to the point of needle insertion from the line (*true distance*) with the distance obtained when using the neonatal linear regression model (*formulated distance*) there is no statistically significant difference (p=0.8432) and also a strong correlation (R=0.7460) between the true and formulated distances.

5.3.2 Anatomical considerations of the infraclavicular brachial plexus block–comparison between neonatal and adult data

The data obtained for the right and left sides of all the adult cadavers is summarised in Tables 5.16 & 5.17.

Table 5.16: Distances of the adult brachial plexus from the right coracoid process.

	Height	Weight	Right							
			CP – XS (mm)	CP – LBP (mm)	CP – LBP (%)	CP – MBP (mm)	CP – MBP (%)	LBP – MBP (mm)	LBP – MBP (%)	MBP – Rib (mm)
N	**81**		**70**							
Mean	1.70	57.57	231.36	24.02	10.20	36.79	15.73	14.00	6.06	16.55
SD	0.09	14.95	31.27	8.54	2.76	10.47	3.09	3.27	1.17	4.56
Min.	1.47	31.70	164.05	10.47	5.26	13.42	5.77	7.90	3.63	8.90
Max.	1.92	97.40	289.96	46.69	17.34	65.26	23.54	23.68	8.54	32.53
CI 95%			7.33	2.00	0.65	2.45	0.72	0.77	0.27	1.07
Lower			224.03	22.02	9.56	34.29	15.01	13.23	5.79	15.48
Upper			238.68	26.04	10.85	39.24	16.46	14.76	6.33	17.61

Key:

CP-XS: Distance (mm) between the coracoid process and the xiphisternal joint
CP-LBP: Distance (mm) from the coracoid process to the LBP
CP-LBP %: Distance from the coracoid process to the LBP as a percentage of the CP-XS line distance
CP-MBP: Distance (mm) from the coracoid process to the MBP
CP-MBP %: Distance from the coracoid process to the MBP as a percentage of the CP-XS line distance
LBP-MBP: Distance (mm) between the LBP and MBP
LBP-MBP %: Distance between the LBP and MBP as a percentage of the CP-XS line distance
MBP-Rib: Distance between the MBP and the closest rib
CI 95%: Confidence interval with a 95% confidence level
Lower: Lower range of the Confidence interval with a level of confidence of 95%
Upper: Upper range of the Confidence interval with a level of confidence of 95%

Table 5.17: Distances of the adult brachial plexus from the left coracoid process.

	Height	Weight	Left							
			CP – XS (mm)	CP – LBP (mm)	CP – LBP (%)	CP – MBP (mm)	CP – MBP (%)	LBP – MBP (mm)	LBP – MBP (%)	MBP – Rib (mm)
N	81		74							
Mean	1.70	57.57	232.96	23.04	9.73	36.10	15.33	13.75	5.90	16.99
SD	0.09	14.95	26.71	8.40	2.79	9.94	3.00	3.09	1.09	4.98
Min.	1.47	31.70	187.32	9.38	4.77	18.01	9.16	7.86	3.61	7.77
Max.	1.92	97.40	296.57	46.35	17.05	65.15	22.89	22.94	9.50	28.90
CI 95%			6.09	1.91	0.64	2.27	0.68	0.70	0.25	1.13
Lower			226.88	21.12	9.09	33.83	14.64	13.05	5.65	15.86
Upper			239.05	24.95	10.36	38.37	16.01	14.46	6.14	18.13

The confidence interval was determined for all the measurements, with a 95% confidence level. Looking at the results of the right and left sides it can be seen that, as a percentage of the CP–XS line distance, the LBP lies between 9.56%–10.85 (mean distance: 22.02mm–26.02mm) of the total CP–XS line distance away from the coracoid process on the right and between 9.09%–10.36% (mean distance: 33.83mm–38.37mm) from the coracoid process on the left. The right MBP can be found a total of 15.01%–16.46% (mean distance: 34.34mm–39.24mm) of the CP–XS line distance along the line connecting the coracoid process and xiphisternal joint, while the left MBP can be found between 14.64%–16.01% (mean distance: 33.83mm–38.37mm) along the CP–XS line. The distance between the LBP and MBP on the right is between 13.23mm–14.76mm and between 13.05mm–14.46mm on the left. Finally the mean distance between the MBP and the closest rib (the shortest distance between the possible location of the needle and the thoracic wall and subsequent parietal pleura) is 15.48mm–17.61mm on the right and 15.86mm–18.13mm on the left.

Using the paired *t*-test no significant difference was found between the left and right sides, when comparing the coracoid process to LBP distance in mm (p=0.2501), or as a % of the CP-XS line distance (p=0.1488), coracoid process to MBP distance in mm (p=0.4349) or as a % of the CP-XS line distance (p=0.2207), the distance between the LBP and MBP in mm (p=0.6228) or the distance from the MBP to the closest rib (p=0.1890). Because no statistically significant difference were obtained for any of the measurements, the right and left sides were combined to increase the sample to 144 axillae. The measurements of the total sample is summarised in Table 5.18.

Table 5.18: Distances of the brachial plexus of the total adult population from the coracoid process.

	Height	Weight	Total							
			CP – XS (mm)	CP – LBP (mm)	CP – LBP (%)	CP – MBP (mm)	CP – MBP (%)	LBP – MBP (mm)	LBP – MBP (%)	MBP – Rib (mm)
N	144									
Mean	1.70	57.57	232.18	23.51	9.96	36.44	15.52	13.87	5.98	16.78
SD	0.09	14.95	28.93	8.45	2.77	10.18	3.04	3.17	1.12	4.77
Min.	1.47	31.70	164.05	9.38	4.77	13.42	5.77	7.86	3.61	7.77
Max.	1.92	97.40	296.57	46.69	17.34	65.26	23.54	23.68	9.50	32.53
CI 95%			4.72	1.38	0.45	1.66	0.50	0.52	0.18	0.78
Lower			227.46	22.13	9.51	34.77	15.03	13.35	5.79	16.00
Upper			236.91	24.89	10.41	38.10	16.02	14.39	6.16	17.55

In the total sample (n=144) the LBP can be found between 9.51% and 10.41% (95% confidence level; mean distance: 22.13mm–24.89mm) from the coracoid process, along a line drawn between the coracoid process and xiphisternal joint. The MBP can be found between 15.03% and 16.02% (mean distance: 34.77mm–38.10mm) from the coracoid process. The distance between the lateral and medial cords is between 13.35mm and 14.39mm.

From the MBP there is a safe distance of between 16.00mm and 17.55mm before reaching the closest rib.

The point of needle insertion, in this case, is defined as the point midway between the LBP and MBP. The needle insertion points, as well as the previously mentioned distance as a percentage of the CP–XS line distance, is summarised in Table 5.19.

Table 5.19: Point of needle insertion for the right, left, and total adult sample.

	Right	Left	Total	Right	Left	Total
	Needle insertion (mm)	Needle insertion (mm)	Needle insertion (mm)	Needle insertion (%)	Needle insertion (%)	Needle insertion (%)
N	70	74	144	70	74	144
Mean	31.02	29.91	30.45	13.23	12.68	12.95
SD	9.30	9.01	9.14	2.77	2.82	2.80
Min.	16.28	13.31	13.31	8.11	6.77	6.77
Max.	57.96	54.45	57.96	20.91	19.91	20.91
CI 95%	2.18	2.05	1.49	0.65	0.64	0.46
Lower	28.84	27.86	28.96	12.59	12.03	12.49
Upper	33.19	31.96	31.94	13.88	13.32	13.40

On the right, the point of needle insertion in the adult sample (n=70 on the right and 74 on the left) can be found with 95% confidence between 12.59%–13.88% (mean distance: 28.84mm–33.19mm) of the CP–XS line distance from the coracoid process. The needle insertion point on the left can be found between 12.03% and 13.32% of the CP–XS line distance (mean distance: 27.86mm–31.96mm). A paired *t*-test also revealed no significant difference between the right and left sides of the sample when comparing both the distance from the coracoid process to the point of needle insertion (in mm) (p=0.2165) or the distance of the point of needle insertion as a percentage of the CP –XS distance (p=0.0893). For the total sample (n=144) the point of needle insertion can be found between 12.49%–13.40% (mean distance: 12.03mm–13.32mm).

The Pearson's correlation revealed that a very weak correlation exist between the distance of the needle insertion point as a percentage of the CP–XS line distance (*dependent variable*) and the length of the sample (R=0.2339). There is a weak negative correlation with the weight of the sample (R=-0.0841) and a moderate correlation with the CP–XS line distance (R=0.4804) (*independent variables*). When correlating the distance of the point of needle insertion from the coracoid process (in mm) with the independent variables, one can see that there is a weak positive correlation with the length (R=0.3359) and a weak negative correlation with the weight (R=-0.0449) of the sample. A strong correlation exists between the point of needle insertion (in mm) and the CP–XS line distance (in mm) (R=0.7693) of the sample. Because of this strong correlation, a linear regression formula was developed for the neonatal sample with the distance to the point of needle insertion from the coracoid process as the dependent variable and the distance between the coracoid process and xiphisternal joint as the independent variable (see Figure 5.6). The coefficient of determination for this linear regression formula revealed that there is a moderate "fit" (R^2=0.592) between the distance of the point of needle insertion and the CP–XS line distance.

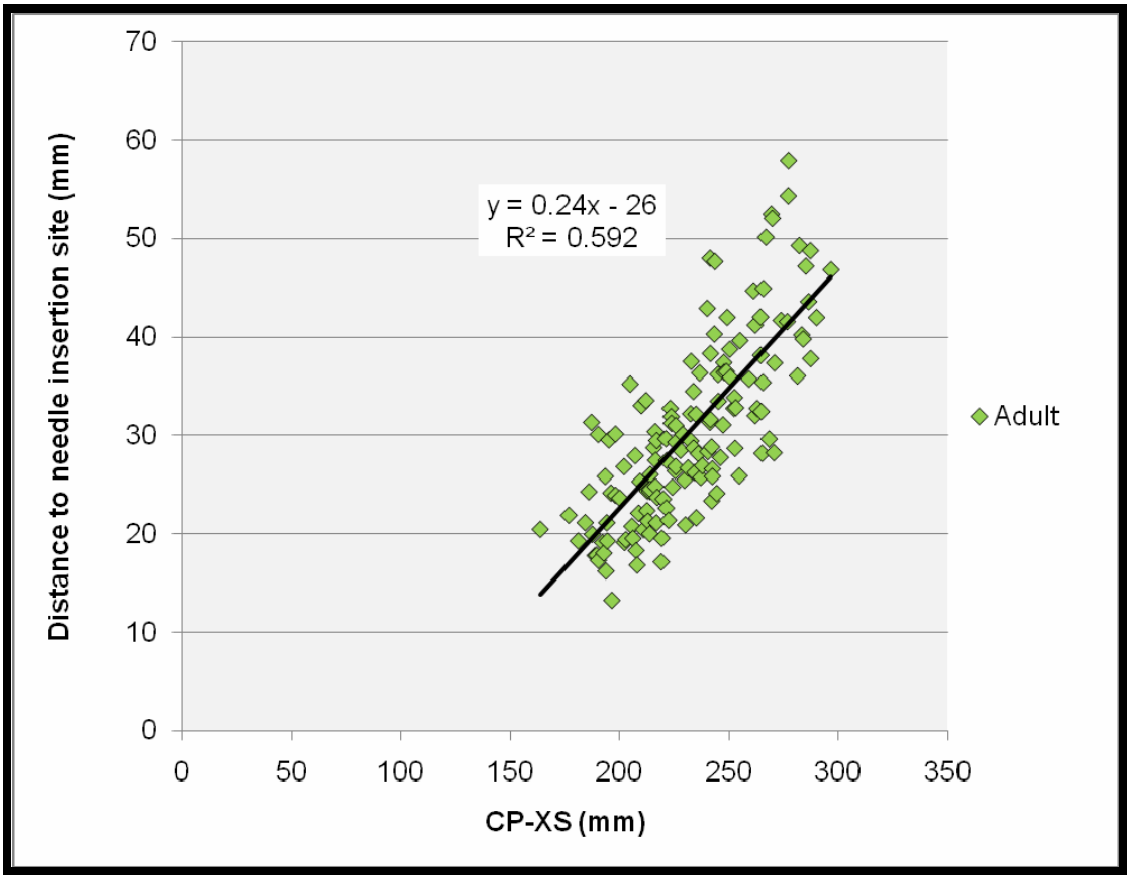


Figure 5.6: Linear regression formula for the distance of the point of needle insertion in adults.

The CP–XS line distance is the independent variable.

When comparing the measured distance to the point of needle insertion from the line (*true distance*) with the distance obtained when using the neonatal linear regression model (*formulated distance*) there is no statistically significant difference (p=0.1678) and also a strong correlation between the true and formulated distances (R=0.7692).

5.3.2.1 Comparison between adult and neonatal data

Converting the measurements from the coracoid process to the LBP and MBP, as well as the distance between the LBP and MBP, to a percentage of the total CP–XS line distance means that these percentages could be compared between adults (where the distances in millimetres were understandably much greater than the neonatal distances). The percentages along the CP–XS line where the LBP and MBP lie within the axilla, the distance between the LBP and MBP (as a percentage of the CP–XS line distance), as well as the percentage along the CP–XS line were the optimal needle insertion site can be found (midpoint between the LBP and MBP) of both the adult and neonatal data, were compared using a paired t-test. A statistically significant difference was found between the percentages of the distance of the coracoid process to the MBP (p=0.0000), distance between the LBP and MBP (p=0.000) and the distance of the point of needle insertion from the coracoid process (p=0.0179). There was however no statistical difference between the distance from the coracoid process to the LBP (p=0.3264). This could indicate that the position of the lateral cord of the brachial plexus, in relation to the coracoid process, remains in a more constant position within the axilla, throughout development.

Because there is a statistically significant difference of the point of needle insertion between the neonatal and adult data, two separate linear regression formulae should be used when attempting to determine the distance of the point of needle insertion as a percentage of the CP–XS line distance. The two separate linear regression formulae, determined for both the neonatal and adult sample, can be seen in Figure 5.7.

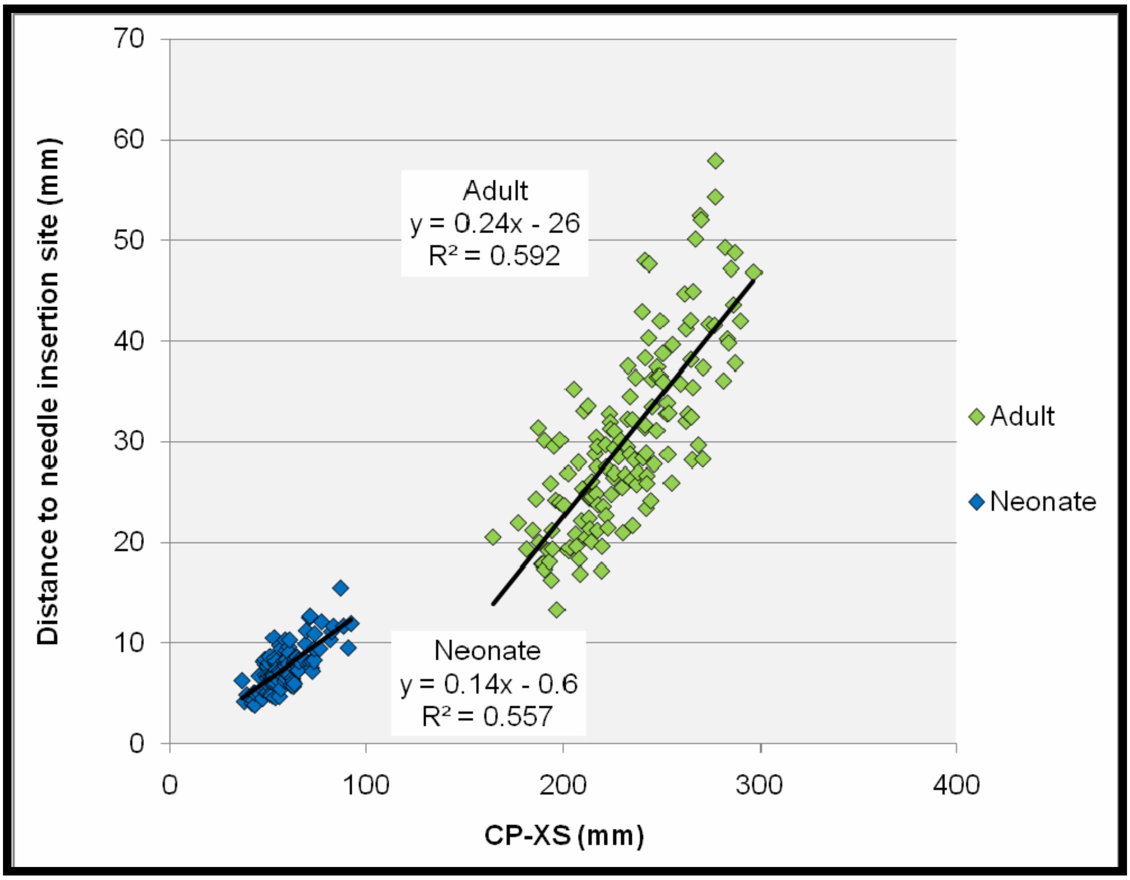


Figure 5.7: Linear regression formulae, for both the neonatal and adult samples.

The distance to the point of needle insertion from the CP is the dependent variable and the CP–XS distance is the independent variable.

5.4) Paediatric femoral nerve block

5.4.1 Anatomical considerations of the neonatal femoral nerve block

The data obtained for the right and left sides of all the neonatal cadavers is summarised in Tables 5.20 & 5.21.

Table 5.20: Distances of the neonatal femoral nerve and artery from the ASIS, on the right side.

	Height	Weight	Right					
			ASIS-PT	ASIS-N	ASIS-N %	ASIS-A	ASIS-A %	A-N
N	50							
Mean	0.44	1.96	31.01	11.17	35.94	14.85	47.86	3.36
SD	0.08	1.57	7.46	3.61	6.84	4.22	6.52	1.51
Min.	0.32	0.60	20.35	5.46	20.61	8.56	32.31	0.54
Max.	0.76	9.10	59.35	22.83	51.23	30.60	63.52	7.77
CI 95%			2.07	1.00	1.90	1.17	1.81	0.42
Lower			28.94	10.17	34.05	13.68	46.05	2.94
Upper			33.08	12.17	37.84	16.01	49.67	3.78

Key:

ASIS-PT: Distance (mm) between the ASIS and the PT
ASIS-N: Distance (mm) from the ASIS to the femoral nerve
ASIS-N %: Distance from the ASIS to the femoral nerve in a percentage of the ASIS-PT distance
ASIS-A: Distance (mm) from the ASIS to the femoral artery
ASIS-A%: Distance from the ASIS to the femoral artery in a percentage of the ASIS-PT distance
A-N: Distance (mm) between the femoral nerve and the femoral artery
CI 95%: Confidence interval with a 95% confidence level
Lower: Lower range of the Confidence interval with a level of confidence of 95%
Upper: Upper range of the Confidence interval with a level of confidence of 95%

Table 5.21: Distances of the neonatal femoral nerve and artery from the ASIS, on the left side.

	Height	Weight	Left					
			ASIS-PT	ASIS-N	ASIS-N %	ASIS-A	ASIS-A %	A-N
n	50							
Mean	0.44	1.96	30.87	10.93	33.73	14.94	48.79	4.08
SD	0.08	1.57	7.55	3.29	7.91	3.90	6.97	1.80
Min.	0.32	0.60	16.69	5.71	16.87	9.28	34.87	0.93
Max.	0.76	9.10	54.80	19.79	51.38	27.00	64.32	9.53
CI 95%			2.09	0.91	2.19	1.08	1.93	0.50
Lower			28.78	10.02	31.54	13.85	46.85	3.58
Upper			32.96	11.84	35.92	16.02	50.72	4.58

The confidence interval was determined for all the measurements, with a 95% confidence level. Looking at the results of the right and left sides it can be seen that, as a percentage of the ASIS-PT line distance, the femoral nerve enters the femoral triangle, posterior to the inguinal ligament between 34.05%

and 37.84% of the ASIS-PT line distance on the right and between 31.54% and 35.92% on the left. The femoral artery is at a point 46.05% and 49.67% along the inguinal ligament on the right and between 46.85% and 50.72% on the left. The distance between the femoral nerve and artery is 2.94mm to 3.78mm on the right and 3.58mm to 4.58mm on the left.

Using the paired *t*-test, no significant difference was found between the left and right sides when comparing the ASIS-PT line distance (p=0.5746), ASIS to femoral nerve distance (p=0.5636), ASIS to femoral nerve distance (as a % of the ASIS-PT line distance) (p=0. 1478), ASIS to femoral artery distance (p=0.8226), ASIS to femoral artery distance (as a % of the ASIS-PT line distance) (p=0.1478), or the femoral artery to femoral nerve distance (p=0.0687). Because no statistically significant difference were obtained for any of the measurements, the right and left sides were combined to increase the sample to a total of 100 femoral triangles. The measurements of the total sample are summarised in Table 5.22 and shown in Figure 5.8.

Table 5.22: Distances of the femoral nerve and artery from the ASIS for the total neonatal sample.

	Height	Weight	Total sample					
			ASIS-PT	ASIS-N	ASIS-N %	ASIS-A	ASIS-A %	A-N
n	100							
Mean	0.44	1.96	30.94	11.05	34.84	14.89	48.32	3.72
SD	0.08	1.57	7.47	3.44	7.44	4.04	6.73	1.70
Min.	0.32	0.60	16.69	5.46	16.87	8.56	32.31	0.54
Max.	0.76	9.10	59.35	22.83	51.38	30.60	64.32	9.53
CI 95%			1.46	0.67	1.46	0.79	1.32	0.33
Lower			29.48	10.38	33.38	14.10	47.00	3.39
Upper			32.41	11.73	36.30	15.68	49.64	4.06

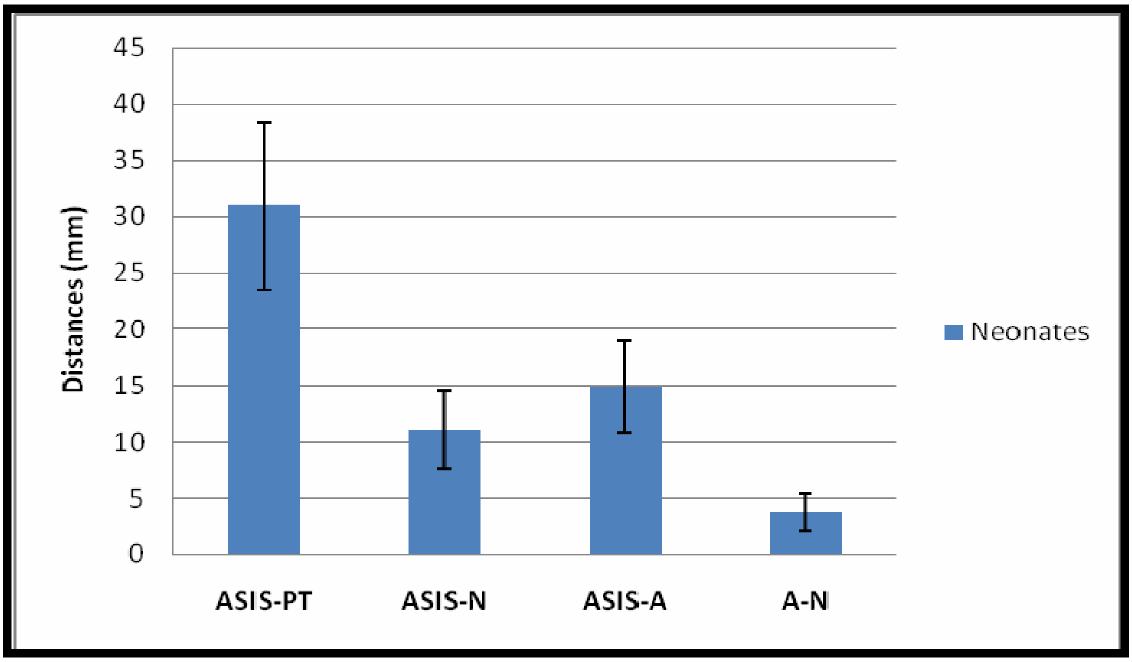


Figure 5.8: Measurements for total sample of neonatal cadavers.

In the total sample (n=100), on average the femoral nerve can be found 34.84% (range: 33.38%-36.30%; 95% confidence level) from the ASIS, along the inguinal ligament. The femoral artery can be found 48.32 (range: 47.00%-49.64%) from the ASIS, along the inguinal ligament. The distance between the femoral nerve and artery is on average 3.72mm (range: 3.39mm-4.06mm).

There is also a 95% level of confidence that, the femoral nerve can be found inferior to the inguinal ligament, between 10.38mm and 11.73mm (average distance = 11.05mm ± 3.44mm) from the ASIS. The femoral artery can be found inferior to the inguinal ligament, between 14.10mm and 15.68mm (average distance = 14.89mm ± 4.04mm) from the ASIS.

The Pearson's correlation revealed that a very weak negative correlation exists between the ASIS to femoral nerve distance (as a % of the ASIS-PT line distance) (dependent variable) and the length of the sample (R=-0.1458) and ASIS-PT line distance (R=-0.0376), and a very weak correlation between the % value and the weight of the sample (R=0.0269) (independent variables). There is also a moderate correlation between the ASIS to femoral nerve distance and the length (R=0.5470) and weight

(R=0.6068) of the sample. A strong correlation exists between the ASIS to femoral nerve distance and the ASIS-PT line distance (R=0.8058) of the sample. Because of this strong correlation, a linear regression formula was developed for the neonatal sample with the distance of the femoral nerve from the ipsilateral ASIS as the dependent variable and the ASIS to PT distance as the independent variable (see Figure 5.9). The coefficient of determination for this linear regression formula revealed that there is a moderate "fit" (R^2=0.6493) between the distance of the ASIS to the femoral nerve and the ASIS–PT distance.

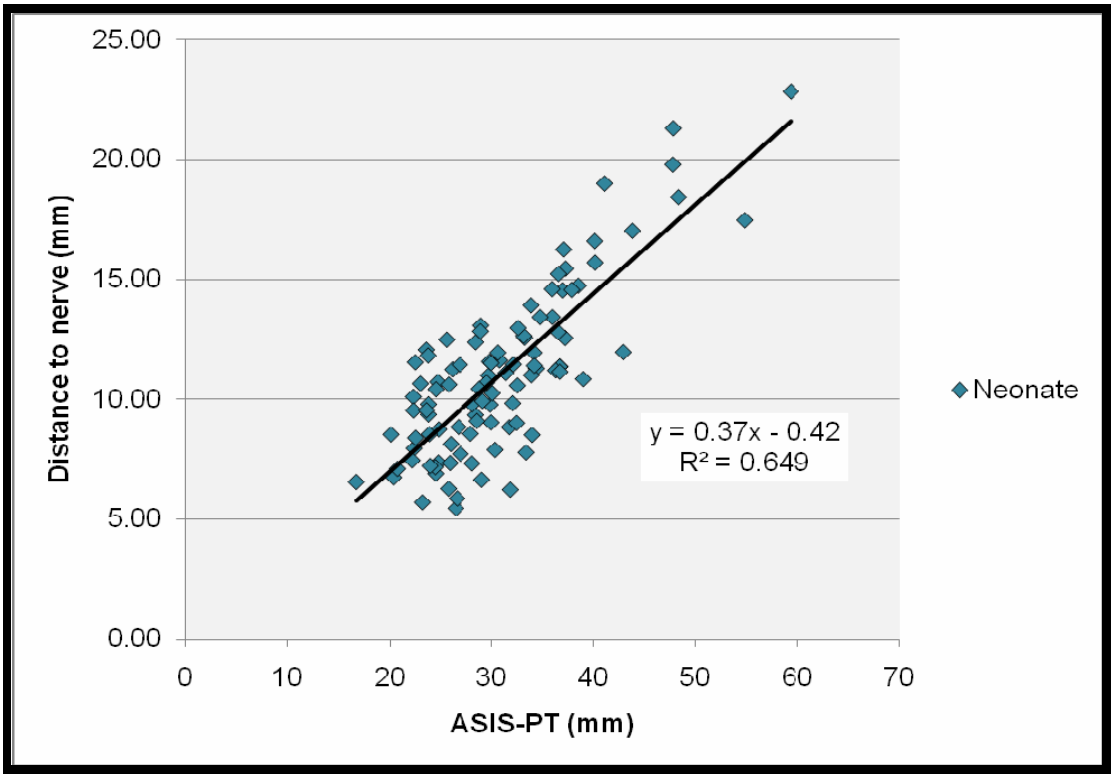


Figure 5.9: Linear regression formula for the distance of the neonatal femoral nerve from the ASIS.

The ASIS-PT line distance is the independent.

When comparing the measured distance of the femoral nerve from the ASIS (*true distance*) with the distance obtained when using the neonatal linear regression formula, i.e., femoral nerve distance in mm=0.37(ASIS–PT line distance)–0.42 (*formulated distance*), there is no statistically significant differences (p=0.5164) and also a strong correlation (R=0.8058) between the true and formulated distances.

5.4.2 Anatomical considerations of the femoral nerve block– comparison between neonatal and adult data

The data obtained for the right and left sides of all the adult cadavers is summarised in Tables 5.23 & 5.24.

Table 5.23: Distances of the adult femoral nerve and artery from the ASIS on the right side.

	Height	Weight	Right					
			ASIS-PT	ASIS-N	ASIS-N %	ASIS-A	ASIS-A %	A-N
n	68							
Mean	1.69	56.43	116.12	56.58	48.50	67.91	58.37	11.81
SD	0.09	15.53	13.85	10.88	5.61	10.72	4.89	3.49
Min.	1.47	31.70	91.47	34.47	35.43	46.26	43.44	4.69
Max.	1.92	104.70	164.85	89.81	61.70	99.78	69.30	21.81
CI 95%			3.29	2.59	1.33	2.55	1.16	0.83
Lower			112.83	53.99	47.17	65.36	57.21	10.98
Upper			119.41	59.16	49.83	70.46	59.53	12.64

Key:

ASIS-PT: Distance (mm) between the ASIS and the PT
ASIS-N: Distance (mm) from the ASIS to the femoral nerve
ASIS-N %: Distance from the ASIS to the femoral nerve in a percentage of the ASIS-PT distance
ASIS-A: Distance (mm) from the ASIS to the femoral artery
ASIS-A%: Distance from the ASIS to the femoral artery in a percentage of the ASIS-PT distance
A-N: Distance (mm) of the femoral nerve from the femoral artery
CI 95%: Confidence interval with a 95% confidence level
Lower: Lower range of the Confidence interval with a level of confidence of 95%
Upper: Upper range of the Confidence interval with a level of confidence of 95%

Table 5.24: Distances of the adult femoral nerve and artery from the ASIS on the left side.

	Height	Weight	Left					
			ASIS-PT	ASIS-N	ASIS-N %	ASIS-A	ASIS-A %	A-N
n	70							
Mean	1.69	56.43	118.03	58.47	49.51	70.03	59.35	11.86
SD	0.09	15.53	14.60	10.10	5.74	10.73	5.61	3.56
Min.	1.47	31.70	84.63	31.71	29.81	48.65	46.12	4.31
Max.	1.92	104.70	153.59	85.04	69.30	100.79	76.64	22.97
CI 95%			3.42	2.37	1.35	2.51	1.32	0.83
Lower			114.61	56.10	48.16	67.52	58.04	11.03
Upper			121.45	60.84	50.85	72.55	60.67	12.70

The confidence interval was determined for all the measurements, with a 95% confidence level. Looking at the results of the right and left sides it can be seen that, as a percentage of the ASIS-PT line distance, and with a 95% confidence level, the femoral nerve enters the femoral triangle, posterior to the inguinal ligament between 47.17% and 49.83% of the ASIS-PT line distance on the right and between 48.16% and 50.85% on the left. The femoral artery is at a point 57.21% to 59.53% (95% confidence level) along the inguinal ligament on the right and between 58.04% and 60.67% on the left. The distance between the femoral nerve and artery ranges between 10.98mm and 12.64mm on the right and 11.03mm and 12.70mm on the left.

Using the paired *t*-test, no significant difference was found between the left and right sides when comparing the ASIS-PT line distance (p=0.3232), ASIS to femoral nerve distance in mm (p=0.1043), or as a % of the ASIS-PT line distance (p=0.1235). There were also no significant differences for the ASIS to femoral artery distance in mm (p=0.1316, as a % of the ASIS-PT line distance (p=0.1859), or the femoral artery to femoral nerve distance (p=0.5154). Because no statistically significant difference were obtained for any of the measurements, the right and left sides were combined to increase the sample to 138 femoral triangles. The measurements of the total sample are summarised in Table 5.25 and visible in Figure 5.10.

Table 5.25: Distances of the adult femoral nerve and artery from the ASIS for the total adult sample.

	Height	Weight	Total sample					
			ASIS-PT	ASIS-N	ASIS-N %	ASIS-A	ASIS-A %	A-N
n	138							
Mean	1.69	56.22	117.09	57.54	49.01	68.99	58.87	11.84
SD	0.09	15.13	14.22	10.50	5.68	10.74	5.28	3.51
Min	1.47	31.70	84.63	31.71	29.81	46.26	43.44	4.31
Max	1.92	104.70	164.85	89.81	69.30	100.79	76.64	22.97
CI 95%			2.37	1.75	0.95	1.79	0.88	0.59
Lower			114.72	55.78	48.06	67.19	57.99	11.25
Upper			119.46	59.29	49.96	70.78	59.75	12.42

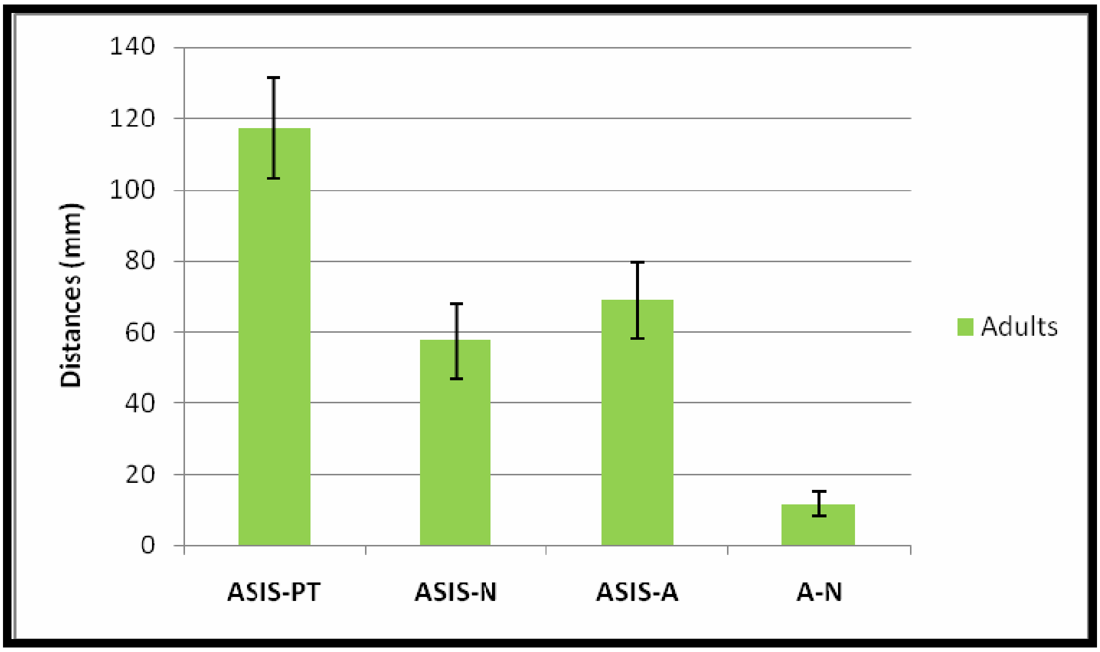


Figure 5.10: Measurements for total sample of adult cadavers.

In the total sample (n=138) the femoral nerve can be found between 48.06% and 49.96% (95% confidence level) from the ASIS, along the inguinal ligament. The femoral artery can be found between 57.99% and 59.75% from the ASIS, along the inguinal ligament. The distance between the femoral nerve and artery is between 11.25mm and 12.42mm.

There is also a 95% level of confidence that for this sample the femoral nerve can be found inferior to the inguinal ligament, between 55.78mm and 59.29mm (average distance is 57.54mm ± 10.50mm) from the ASIS. The femoral artery can be found inferior to the inguinal ligament, between 67.19mm and 70.78mm (average distance is 68.99mm ± 10.74mm) from the ASIS.

The Pearson's correlation coefficient test revealed that a weak correlation exists between the ASIS to femoral nerve distance (as a % of the ASIS-PT line distance) (dependent variable) and either the length (R=0.0895), weight (R=0.0346) or ASIS-PT line distance (R=0.1870) (independent variables) of the sample. There is also a weak correlation between the ASIS to femoral nerve distance and the length (R=0.2255) and weight (R=0.2153) of the sample. A strong correlation was found between the ASIS to femoral nerve distance and the ASIS-PT line distance (R=0.7840) of the sample. Because of this strong correlation, a linear regression formula was developed for the adult sample with the distance of the femoral nerve from the ipsilateral ASIS as the dependent variable and the ASIS to PT distance as the independent variable (see Figure 5.11). The coefficient of determination for this linear regression formula revealed that there is a moderate "fit" (R^2=0.6147) between the distance of the ASIS to the femoral nerve and the ASIS distance.

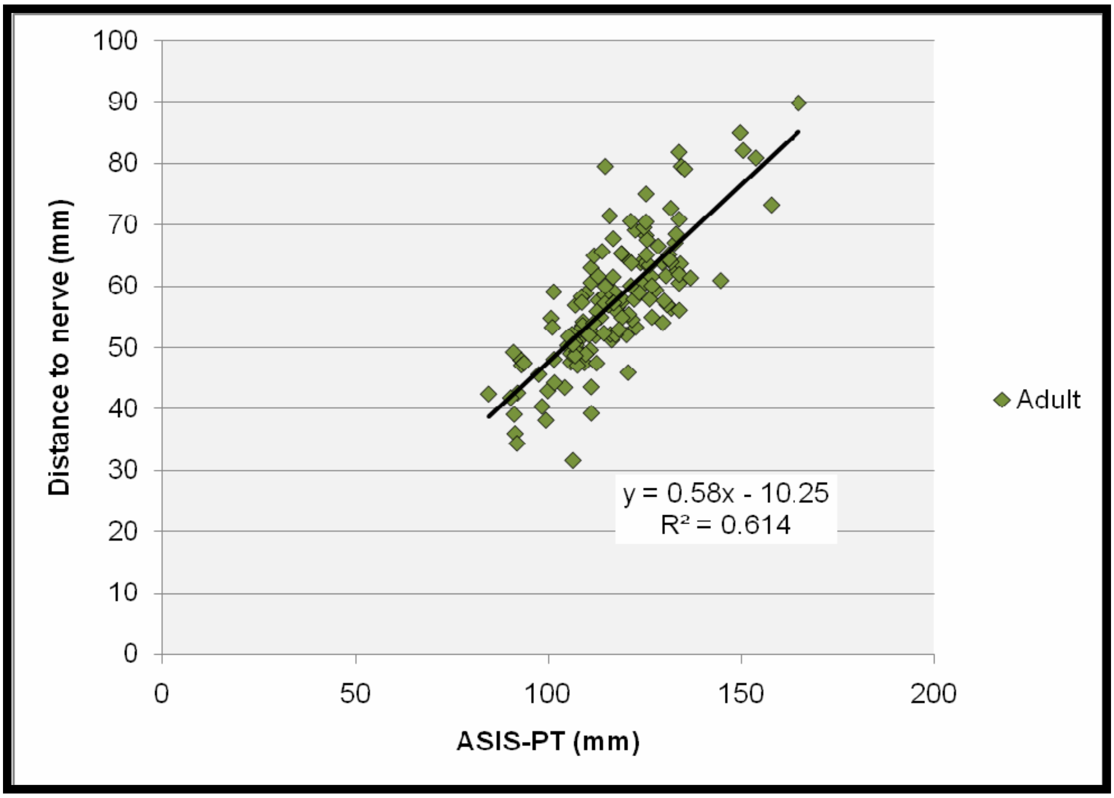


Figure 5.11: Linear regression formula for the distance of the adult femoral nerve from the ASIS.

The ASIS-PT line distance is the independent variable.

When comparing the measured distance of the femoral nerve from the ASIS (*true distance*) with the distance obtained when using the adult linear regression formula, i.e., distance of femoral nerve in mm=0.58(ASIS-PT line distance)-10.25 (*formulated distance*), there is no statistically significant differences (p=0.8216) and also a strong correlation between the true and formulated distances (R=0.7840).

5.4.2.1 Comparison between adult and neonatal data

Converting the measurements of both the distances of the femoral nerve and artery from the ASIS, to a percentage of the total ASIS-PT line distance means that these percentages could be compared between adults (where the distances in mm in adults were understandably much larger than the neonatal distances). The percentages along the inguinal ligament where the femoral nerve and artery enter the femoral triangle, of both the adult and neonatal data, were compared using a paired *t*-test. A statistically significant difference between the two samples for the position of the femoral nerve (p=0.00001) and femoral artery (p=0.00001) was found. The percentages between the neonates and adults are visible in Figure 5.12

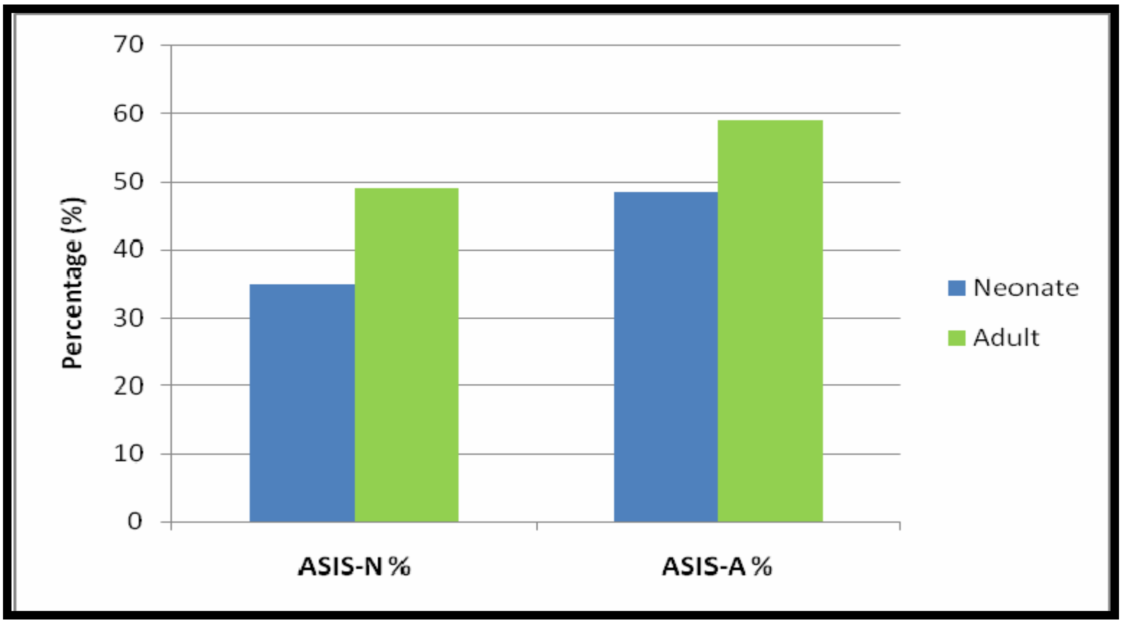


Figure 5.12: Comparison of distance of the femoral nerve (N) and femoral artery (A) from the ASIS.

Measurements are indicated as a percentage of the total ASIS-PT line distance, between neonates and adults.

Because there is a statistically significant difference between the neonatal and adult data, two separate linear regression formulae should be used when attempting to determine the distance of the femoral nerve from the ASIS. The two separate linear regression formulae, determined for both the neonatal and adult sample, can be seen in Figure 5.13.

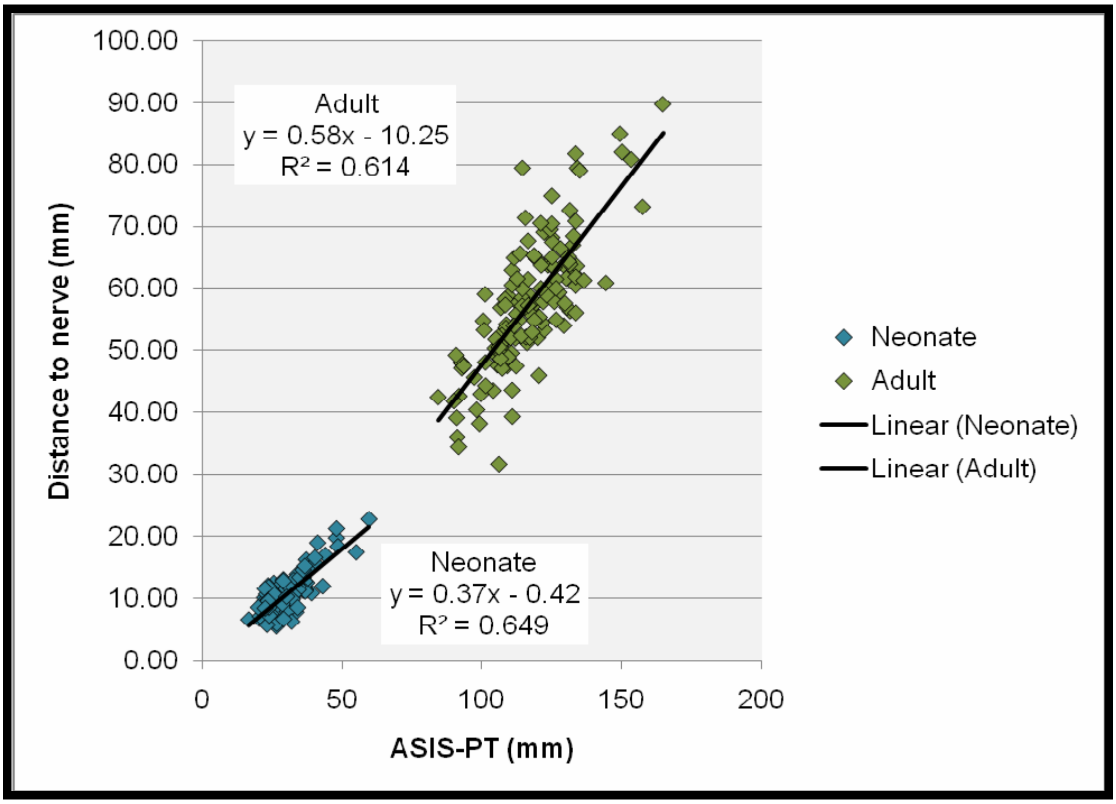


Figure 5.13: Linear regression formulae, for both the neonatal and adult sample.

The distance of the femoral nerve from the ASIS is the dependent variable and the ASIS-PT line distance is the independent variable.

5.5) Paediatric ilio-inguinal/ iliohypogastric nerve block

5.5.1 Anatomical considerations of the neonatal ilio-inguinal/ iliohypogastric nerve block

The distances from the ASIS to the ilio-inguinal and iliohypogastric nerves, on both the left and right sides of the cadavers, are shown in Table 6.1. The upper and lower ranges stated in Table 5.26 were determined with a 95% confidence level.

Table 5.26: Distances (mm) of the right and left ilio-inguinal and iliohypogastric nerves from the ASIS.

	Right			Left		
	Ilio-inguinal nerve	**Iliohypogastric nerve**	**II-IH**	**Ilio-inguinal nerve**	**Iliohypogastric nerve**	**II-IH**
n		**53**			**51**	
Mean	2.24	3.87	1.61	2.16	3.76	1.59
SD	1.19	1.27	0.52	1.16	1.38	0.64
CI 95%	0.32	0.35	0.14	0.32	0.38	0.18
Lower range*	**1.92**	**3.53**	**1.47**	**1.84**	**3.38**	**1.42**
Upper range*	**2.56**	**4.22**	**3.07**	**2.48**	**4.13**	**3.01**
Insertion site (mm)		**3.04**			**2.96**	

Key:
II–IH: Distance between the ilio-inguinal and iliohypogastric nerves
SD: Standard deviation
CI: Confidence interval
* Lower and upper ranges are obtained by subtracting and adding the CI 95% value from/to the Mean, respectively.

The mean distance from the ASIS to the right ilio-inguinal nerve was 2.24mm ± 1.19mm (95% confidence level between 1.92mm–2.56mm) while the mean distance from the ASIS to the left ilio-inguinal nerve was 2.16mm ± 1.16mm (95% confidence level between 1.84mm–2.48mm).

The mean distance from the ASIS to the right iliohypogastric nerve was 3.87mm ± 1.27mm (95% confidence level between 3.53mm–4.22mm) while the mean distance from the ASIS to the left iliohypogastric nerve was 3.76mm ± 1.38mm (95% confidence level between 3.38mm–4.13mm).

The correct distance for needle insertion was then defined to be at a point between the ilio-inguinal and iliohypogastric nerves (needle insertion = distance (mm) to ilio-inguinal nerve + ½(distance of iliohypogastric nerve–distance of ilio-inguinal nerve). The needle insertion site on the right and left sides were found to be 3.04mm and 2.96mm from the ASIS, on a line connecting the ASIS with the umbilicus, respectively.

A paired *t*-test revealed that there was no significant difference between the distance from the ASIS to the left and right ilio-inguinal (p=0.3938), iliohypogastric nerves (p=0.2109) or needle insertion site (p=0.1636). There was also no significant difference between the distance between the ilio-inguinal and iliohypogastric nerves on both sides (p=0.9758). Due to this finding, all the data were pooled together (total n=104) (see Table 5.27).

Table 5.27: Distances (mm) of the ilio-inguinal and iliohypogastric nerves from the ASIS for the total neonatal sample.

	Total		
	Ilio-inguinal nerve	**Iliohypogastric nerve**	**II-IH**
n	104	103	103
Mean	2.20	3.81	1.60
SD	1.17	1.32	0.58
CI 95%	0.22	0.25	0.11
Lower range*	**1.98**	**3.56**	**1.49**
Upper range*	**2.43**	**4.07**	**1.71**
Insertion site (mm)	**3.00**		

On average, the ilio-inguinal can be found 2.20mm±1.17mm from the ASIS, on a line connecting the ASIS to the umbilicus. More specifically, the nerve can be found between 1.98mm and 2.43mm from the ASIS in 95% of the neonatal sample. The iliohypogastric nerve can be found 3.81mm±1.32mm or between 3.56mm and 4.07mm from the ASIS (95% confidence level). The optimal needle insertion site for the sample is 3.00mm from the ASIS.

The Pearson’s correlation coefficient test revealed that there exists a moderate correlation between either the distance of the ilio-inguinal nerve (R=0.4032), iliohypogastric nerve (R=0.5161) and point of needle insertion (R=0.4776), to the ASIS (dependent variables) or the **length** of the sample (independent variables). There was however a strong correlation between the distance of the ilio-inguinal nerve (R=0.7340), iliohypogastric nerve

(R=0.7647) and point of needle insertion (R=0.7707), to the ASIS and the weight of the sample.

Because of this strong correlation, a linear regression formula was developed for the sample with the distance of the ilio-inguinal nerve (see Figure 5.14), iliohypogastric nerve (see Figure 5.15) and point of needle insertion (see Figure 5.16) from the ipsilateral ASIS, as the dependent variables, and the weight of the sample as the independent variable.

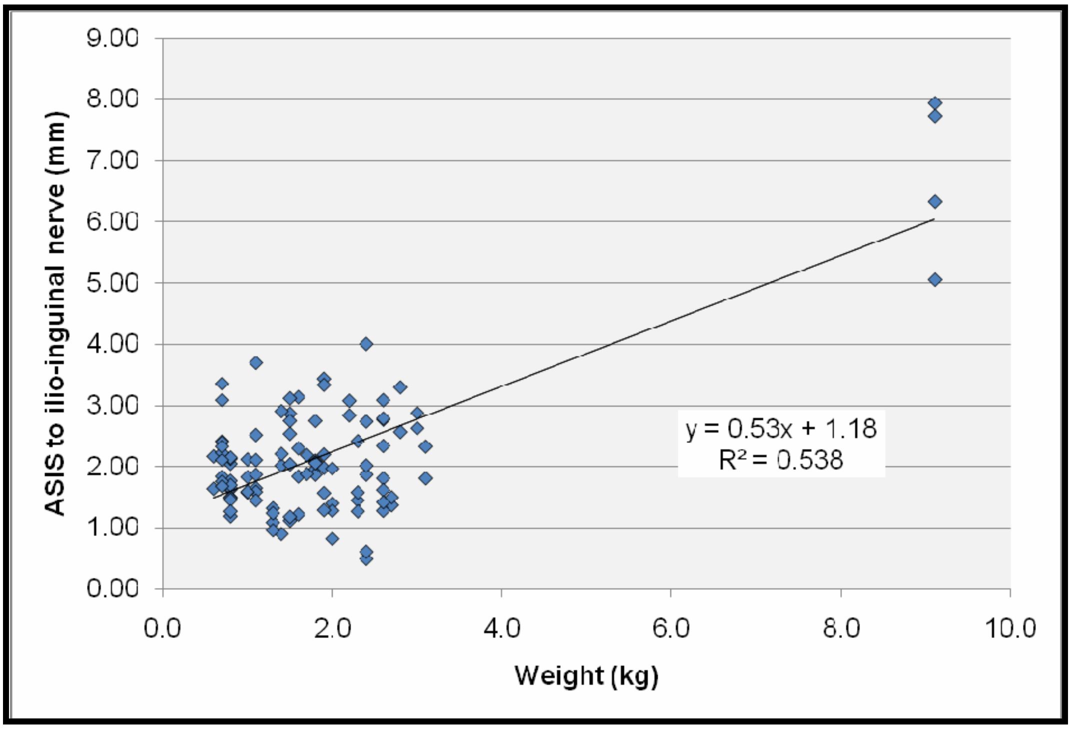


Figure 5.14: Linear regression formula for the distance of the ilio-inguinal nerve from the ASIS.

The weight of the sample is the independent variable.

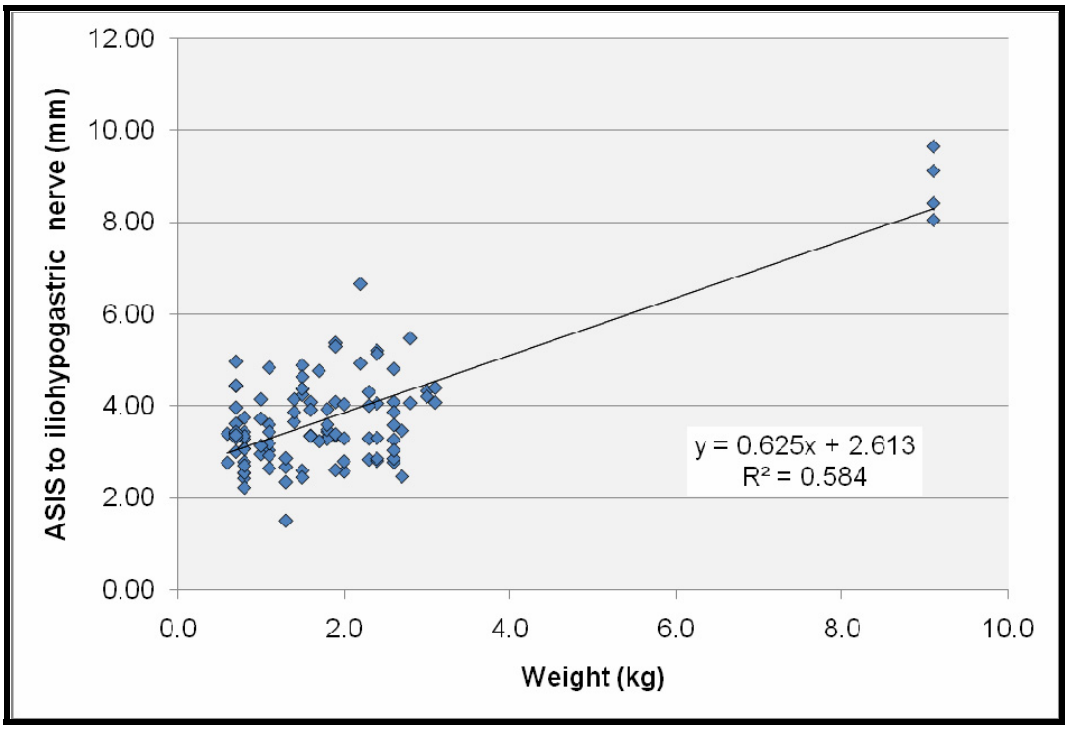


Figure 5.15: Linear regression formula for the distance of the iliohypogastric nerve from the ASIS.

The weight of the sample as the independent variable.

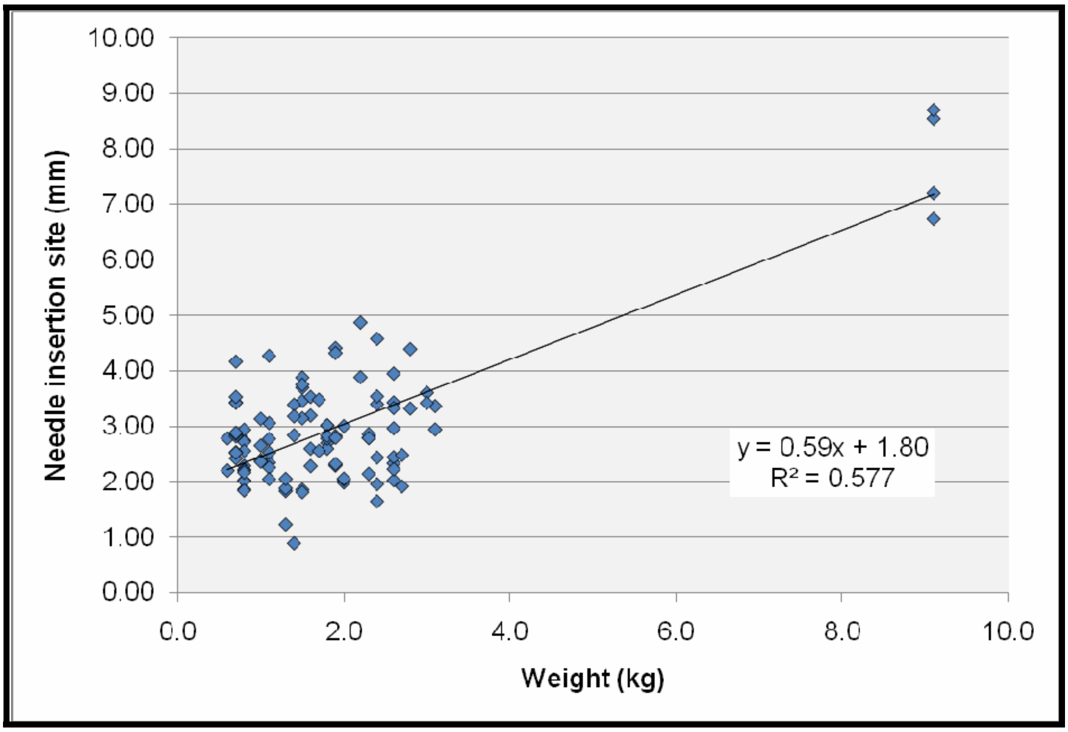


Figure 5.16: Linear regression formula for the distance of the point of needle insertion from the ASIS.

The weight of the sample as the independent variable.

The coefficient of determination for these linear regression formulae revealed that there is a moderate "fit" (R^2=0.6147) when determining the distance of the ilio-inguinal nerve (R^2=0.538), iliohypogastric nerve (R^2=0.584) and the point of needle insertion (R^2=0.577) to the ASIS.

In evaluating the different techniques described above, it is clear that they differ somewhat in respect of the needle placement. When comparing the site of placement described by these techniques, the nerve is missed in a number of cases. The insertion site described by Von Bahr (1979) was furthest away from the nerves and relies on the fan-like injection and the spread of the local anaesthetic inferiorly for an adequate block. Simulation of the technique described by Sethna and Berde (1989) placed the needle at a level inferior to the inguinal ligament in all of the neonatal cadavers. The technique described by Schulte-Steinberg (1990), appears to be the most accurate of the three techniques, provided the needle is inserted 5mm medial and inferior to the ASIS as they suggested for infants (see Figure 2.15–2.17).

Chapter 6: Discussion

6.1) Paediatric caudal epidural block

6.1.1 Dimensions of the neonatal sacrococcygeal membrane.

Correctly identifying the sacrococcygeal membrane that covers the sacral hiatus is essential for correct epidural placement of either the needle (for a single-shot caudal epidural block) or a continuous catheter (for long term and continuous epidural anaesthesia). However, in adults the sacral hiatus is only identified correctly in approximately 75% of cases where caudal epidural injections are administered (Tsui *et al.,* 1999; Lewis *et al.,* 1992; Stitz & Sommer, 1999).

The sacrum varies to differing degrees, which could contribute to difficulty in palpating the apex of the sacral hiatus, even for experienced anaesthesiologists (Senoglu *et al.,* 2005). Correctly identifying the apex of the sacral hiatus is important for successful performance of caudal epidural blocks. This study aimed to determine the dimensions of the sacrococcygeal membrane in a neonatal sample, in which caudal epidural blocks is one of the most frequently performed regional block techniques (Giaufre *et al.,* 1996).

Senoglu and co-workers (2005) examined 96 dry sacral bones in adults and determined that the triangle, formed between the apex of the sacral hiatus and the superolateral sacral crests (at the level of the S2 foramina), is an equilateral triangle. The authors suggest that because the sacral cornuae could be difficult to locate in obese adults, other bony landmarks, such as the superolateral sacral crests, could be used to determine the apex of the sacral hiatus.

Palpating the sacral cornuae should be less difficult in neonates and small children. The two sacral cornuae can be palpated as two distinct bumps, slightly inferior to the uppermost limit of the natal cleft. Based on the results from this study, the sacral cornuae are spaced 8.70mm±2.70mm (95% confidence level, range: 7.86mm–9.53mm) apart. The apex of the sacral hiatus will lie 3.90mm±1.28mm superior to the line between the two sacral cornuae. This would suggest that the surface area of the neonatal sacrococcygeal membrane (that covers the sacral hiatus) will be between 14.92mm^2 and 21.62mm^2 (95% confidence level).

Unfortunately there is a short supply of macerated neonatal pelvises, and it is difficult to accurately dissect the landmarks described by Senoglu *et al.* (2005) in neonatal cadavers. Identification of the apex of the sacral hiatus using other landmarks and describing the measurements of an equilateral triangle in the neonatal sample was difficult. Therefore, successful identification of the sacral cornuae still relies on the experience of the anaesthesiologist. This study should allow for correctly visualising the apex of the sacral hiatus as it is covered by the sacrococcygeal membrane, once the sacral cornuae have been identified. The study should also allow the anaesthesiologist to correctly identify the apex of the membrane, which is the starting point for most measurements to other structures or specific vertebral levels made in the literature. This was also used in this study

6.1.2 The distance of the lumbar interlaminar spaces from the apex of the sacrococcygeal membrane in a neonatal sample

Continuous caudal epidural blocks require threading a catheter, within the epidural space, to the desired vertebral level. If placed correctly it should provide effective anaesthesia for all spinal levels inferior to the level of the catheter. It allows for long-term surgical anaesthesia for any procedure of the upper and lower abdominal areas, the urogenital area and any procedure of the lower extremities (Bosenberg *et al.,* 2002). Bosenberg and colleagues (1988) have even demonstrated how an epidural catheter can be advanced via the caudal route to thoracic levels in neonates.

Before the catheter is inserted, it should be measured in order to be advanced to the correct vertebral level so that the desired dermatome can be blocked. A search of the literature revealed little information regarding the distances from the apex of the sacral hiatus to the individual lumbar vertebral levels, especially in neonates.

The results obtained in this study indicated that the following threading distances from the apex of the sacral hiatus are necessary for each vertebral level:

- L1/L2: 45.61mm±9.07mm
- L2/L3: 37.85mm±7.67mm
- L3/L4: 29.17mm±7.70mm
- L4/L5: 22.43mm±5.14mm and
- L5/S1: 16.09±3.97mm

It is also important to realise that the distance of the apex of the sacrococcygeal membrane to each individual vertebral level increases significantly when the patient is flexed (see Figure 5.2). These distances increase on average 11.80% with flexion. The largest increase is for the distance to the L3/L4 level where the distance between the patient lying prone and the patient flexed increases on average 14.01%.

This information can assist anaesthesiologists to determine the correct length of the catheter before threading a continuous epidural catheter into the caudal canal in neonatal patients and to realise the changes in position that occur within the vertebral canal when the patient is flexed.

6.1.3 The vertebral level of termination and distance from the apex of the sacrococcygeal membrane of the dural sac.

There have been a variety of studies to determine the level at which the dural sac terminates. The majority of these stem from early cadaver studies (Hansasuta *et al.,* 1999), conventional radiographic studies (Dunbar *et al.,* 1993), or myelography (Larsen & Olsen, 1991). These studies demonstrated a large variation in the level at which the dural sac terminates, ranging from L5/S1 to S4, with S2 being the most frequently described.

A recent MR imaging study attempted to re-evaluate the level of termination of the dural sac and to correlate its position with age and sex (Binokay *et al.,* 2006). These authors looked at 743 MR images of patients between 17 and 92 years old. Their results showed that the dural sac terminates at the upper third of the S2 vertebra (25.2%), ranging from between the level of L5/S1 to the upper border of S3. They found no significant difference between males and females. There was also no significant difference between the different age groups.

A cadaver study revealed that the average level of termination in adults was at the S1-S2 intervertebral disc, ranging between the L5/S1 to S4/S5 levels (Larsen & Olsen, 1991). Study of lumbosacral MR images indicated that the level of termination was at the middle third of the S2 vertebra, ranging between the upper border of S1 to the upper border of S4 (Crighton *et al.,* 1997; MacDonald *et al.,* 1999).

Interestingly, examination of the 89 MR images of patients between 6 and 29 years old revealed similar results to that found by Binokay *et al.* (2006). The average level of termination was at the upper third of the S2 vertebra. This level ranged between the upper third of the L5 vertebra to the middle third of S3 (see Table 6.1). With a 95% confidence level, the range of termination in this sample remained at the upper third of S2. The lowest level of dural sac termination did not extend past the middle third of the S3 vertebra. In contrast to Binokay *et al.* (2006), the most common level of termination was at the middle (25.84%) and lower third of S3 (28.09%).

Table 6.1: Frequency of termination of the dural sac

Level of termination of dural sac (ages 6-29 years)	n	%
Upper third L5	1	1.12
Middle third L5	0	0.00
Lower third L5	0	0.00
L5/S1	1	1.12
Upper third S1	2	2.25
Middle third S1	5	5.62
Lower third S1	9	10.11
S1/S2	6	6.74
Upper third S2	8	8.99
Middle third S2	23	25.84
Lower third S2	25	28.09
S2/S3	6	6.74
Upper third S3	2	2.25
Middle third S3	1	1.12

The average level of termination of the dural sac in the less than six years-old group was at S1/S2 (95% confidence level; range: lower third of S1 to middle third of S2.

Although the exact level of termination of the dural sac wasn't determined in the dissected sample of neonatal cadavers in this study, the results show that the dural sac terminates approximately 10.45mm±3.99mm from the apex of the sacrococcygeal membrane. This is important for anaesthesiologists when inserting a needle for caudal epidural blocks, or when a continuous catheter is threaded within the caudal space, as care must be taken to avoid piercing the dural sac.

Crighton and colleagues (1997) stated that in order to increase the chances of performing a successful caudal block with minimal risk of dural puncture, the most frequent termination level of the dural sac should be known. This then infers that anaesthesiologists should have a solid knowledge of the structures and their position, within the caudal and vertebral canal. Dissections done on the neonatal caudal region aimed to give specific information regarding the position of these key structures. It is essential to note the importance of correctly identifying the sacrococcygeal membrane covering the sacral hiatus, the distinct differences that occur when the patient is flexed, and the difference in the level of dural sac termination in children.

A distinct limitation of this MR component of the study, however, is the small sample size for the younger than six year old group. Further studies should be conducted in this age-group, in order to establish a normal range for the termination of the dural sac in children.

6.2) Paediatric lumbar epidural block

6.2.1 The value of Tuffier's (intercrestal) line in neonates.

Using Tuffier's line is the most common method to determine the L4/L5 vertebral level when performing procedures such as lumbar epidural blocks, spinal anaesthesia, or lumbar punctures in adults (Reynolds, 2000). The line has been described to cross the vertebral column at the level of the L4/L5 interlaminar space (Quinnell & Stockdale, 1983), or the L4 spinous process (Render, 1996). These studies were all performed without lumbar flexion and, as patients are either positioned in the lateral decubitis or sitting positions when lumbar epidural blocks are performed (see *2.2.4: Techniques*), Kim and co-workers (2003) questioned the validity of these initial findings. They conducted a study where they examined 103 lumbar spine X-rays of patients in both a neutral and flexed position. They found that Tuffier's line was in line with the L4/L5 interlaminar space in a neutral position, as well as in a fully flexed position. In relation to the vertebral column, when flexed, Tuffier's line moves cranially in 1.9%, it moved caudally in 15.5% and stayed on the same level in 82.5% of their sample.

The results of the neonates in a neutral position coincide with what Kim *et al.* (2003) found in their study. Tuffier's line intersects the L4/L5 level (95% confidence level, range: lower third of L4 to L4/L5) in 25.64% of the sample (see Table 6.2). With flexion, Tuffier's line moved caudally to the upper third of the L5 vertebra (95% confidence level, range: L4/L5 to upper third of L5), with the upper and middle thirds of L5 being the most common level where Tuffier's line transects the vertebral column (20.51%).

Table 6.2: Frequency of the level of Tuffier's line in a neonatal cadaver population.

Vertebral level of Tuffier's line in neonates	Prone		Flexed	
	n	%	n	%
Upper third L4	2	5.13	0	0.00
Middle third L4	8	20.51	2	5.13
Lower third L4	1	2.56	6	15.38
L4/L5	10	25.64	5	12.82
Upper third L5	7	17.95	8	20.51
Middle third L5	7	17.95	8	20.51
Lower third L5	2	5.13	5	12.82
L5/S1	2	5.13	4	10.26
Upper third S1	0	0.00	1	2.56

Only nine (23.08%) of the sample had no change in level when flexed, whereas the vertebral level moved caudally by one level in 22 neonates (56.41%) and two levels in eight neonates (20.51%). In this study, a level is distinguished as a third of a vertebral body or the length of an intervertebral disc.

Paediatric anaesthesia textbooks contend that Tuffier's line crosses the midline in the area of about L5 in infants and at about L5/S1 in neonates (Dalens, 1995; Jankovic & Wells 2001). 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 the 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.

In this study, Tuffier's line would appear to cross the vertebral column at the level of the L4/L5 interlaminar space in the neutral or prone position. This level does move caudally when the neonate is flexed, which is an important factor to keep in mind, even though it is not a substantial change. The most caudal level was the L5/S1 interlaminar space in the prone sample and the upper third of S1 in the flexed sample. This concurs with the findings in the literature.

Although one seldom encounters obese patients in neonates, which would make the identification of Tuffier's line difficult, accurate identification of the superior margins of the iliac crests is still very important. Anaesthesiologists aiming to use Tuffier's line should remember that the iliac crests have yet to ossify completely and still have a cartilaginous rim, which is not visible on a radiograph. This could be misleading since Tuffier's line may be seen at a level more caudad than expected. Despite this, Reynolds (2001), as well as Boon and colleagues (2004) recommended that anaesthesiologists should rather use one space lower to avoid confusion and possible complications.

6.2.2 The dimensions of the lumbar interlaminar spaces in neonates in both a prone and flexed position.

The anatomy of the lumbar spine and epidural space is of utmost importance when performing lumbar epidural blocks (Boon *et al.,* 2003). In young patients, the vertebral anatomy is well defined, relatively consistent and provides easy access to the epidural space (Kopacz *et al.,* 1996). The interlaminar space is the path of the epidural needle before entering the epidural space, either by a midline or paramedian approach (Boon *et al.,* 2003). It is therefore important to have an understanding of the dimensions of the lumbar interlaminar spaces as well as the factors, vertebral diseases or malformations, which could decrease the interlaminar spaces and make needle insertion difficult.

This study showed the surface area of the lumbar interlaminar space in neonates in the prone position to be relatively small, ranging between 9.82mm^2 and 11.42mm^2. In this position, the L2/L3 interlaminar space is the largest (11.42mm^2), followed by the L3/L4 (11.40mm^2) and L4/L5 (10.66mm^2) interlaminar spaces. By flexing the neonate, the largest increase in surface area can be seen at the L4/L5 interlaminar space, followed by the L3/L4 and L5/S1 interlaminar spaces (see Figure 5.4). This means that, when flexed, the L4/L5 (14.45mm^2) and L3/4 (15.33mm^2) interlaminar areas have the largest surface areas allowing for easiest insertion of an epidural needle at these levels. It is also sufficiently caudad to avoid inadvertent trauma to a spinal cord with a very low termination, for example, a tethered cord.

6.2.3 The vertebral level and distance from the apex of the sacrococcygeal membrane of the conus medullaris.

Knowledge of the level of spinal cord termination is vitally important when performing central blocks in patients of all age groups. This concerns not only the mean levels of termination, but also the range of levels. Although rare, trauma to the spinal cord is a very real risk for anaesthesiologists.

Many preceding cadaver studies have been conducted to determine the level of the conus medullaris (Needles, 1935; Barson, 1969; Saifuddin *et al.,* 1998). Needles (1935) studied 240 cadavers and found that the spinal cord terminated between the lower third of L1 and the upper third of L2 in 49% of the sample.

The level of the conus medullaris has also been studied in the living. Although expensive and time-consuming, MR imaging has been shown to be reliable for determining the level of the conus medullaris. Wilson and Prince (1989) reviewed a sample of 184 lumbar MR images in children of different ages and found that the range of conus levels was T12–L3 and that the adult level (L1/L2) was attained during the first few months of life. In an adult sample, Saifuddin *et al.* (1998) assessed 504 lumbar MR images and concluded that the position of the conus medullaris ranged between the middle third of T12 and the upper third of L3.

Malas *et al.* (2000) investigated the differences between the termination level of conus medullaris and the termination level of the largest part of the transverse diameter of the lumbosacral enlargement during the period of foetal development and adulthood. They dissected 25 foetuses, used ultrasonography in 25 premature babies, and MR imaging of 25 adults. They found that the conus medullaris terminated between L1 and L3 in both foetuses and premature babies, and T12 and L2 in adults.

Demiryürek *et al.* (2002) studied a large sample (n=639) of lumbar MR images to determine the range of conus medullaris levels. They found that the spinal cord terminated between the T11/T12 intervertebral disk space and the upper third of L3. These findings coincided with similar findings made by Needles (1935), Boonpirak and Apinhasmit (1994), Saifuddin *et al.* (1998), and Malas *et al.* (2000). The average level of the conus medullaris in their study was located at T12/L1 intervertebral disc space (22.38%) for the entire population.

The results of this cadaver and MR imaging studies are summarised in Table 6.3.

Table 6.3: Frequency of level of conus medullaris

Level of conus medullaris				
	0-1 years Cadavers		**1-29 years MR images**	
	n	**%**	**n**	**%**
T11/T12	0	0.00	1	0.97
Upper third T12	0	0.00	2	1.94
Middle third T12	0	0.00	0	0.00
Lower third T12	0	0.00	2	1.94
T12/L1	4	10.26	18	17.48
Upper third L1	0	0.00	13	12.62
Middle third L1	3	7.69	15	14.56
Lower third L1	1	2.56	16	15.53
L1/L2	3	7.69	21	20.39
Upper third L2	5	12.82	5	4.85
Middle third L2	6	15.38	6	5.83
Lower third L2	3	7.69	2	1.94
L2/L3	7	17.95	2	1.94
Upper third L3	3	7.69	0	0.00
Middle third L3	0	0.00	0	0.00
Lower third L3	2	5.13	0	0.00
L3/L4	2	5.13	0	0.00

The results from this study showed that in the neonatal cadaver group, the spinal cord most frequently terminates at L2/L3 (17.95%). On average it terminates at the upper third of the L2 vertebra (95% confidence level, range: L1/L2 to middle third of L2). In the 1-29 year old group the termination of the spinal cord is most frequently found at the L1/L2 level (20.39%) followed by the T12/L1 level (17.48%) and the lower third of L1 (15.53%). On average the spinal cord terminates at the middle third of the L1 vertebra.

Demiryürek *et al.* (2002) felt that it would be of clinical value to give minimum and maximum levels, as these represent possible variations that should be taken into account by anaesthesiologists performing epidural blocks. In their study, a total of 35.06% the conus medullaris was located between the lower third of T12 and the middle third L1. In this study, the conus medullaris was found between the levels, mentioned by Demiryürek *et al.* (2002), in 46.60% of the 1-29 year old group. In the majority of cases the conus medullaris was found to be between the level of T12/L1 and L1/L2 for this group (80.58%). In the neonatal cadavers, the conus medullaris was found to be somewhat lower, i.e. in 61.54% of the cases the conus medullaris was found between the levels of L1/L2 and L2/L3, when compared to the 1-29 year old group (34.95%). The conus medullaris was only found between the lower third of T12 and the middle third of L1 in only 17.95% and between T12/L1 and L1/L2 in only 28.21% of the neonates (see Table 6.4).

Table 6.4: Frequencies of spinal cord termination

Vertebral levels	0-1 years Cadavers	1-29 years MR images
T12.3-L1.2	17.95%	46.60%
T12/L1-L1/L2	28.21%	80.58%
L1/L2-L2/L3	61.54%	34.95%

The most cranial levels were found in a 23 year old where the conus medullaris was at the level of T11/T12 and two cases (28 and 29 years of age) where the conus medullaris was at the level of the upper third of T12.The most caudal level for the 1-29 year old group were two cases where the spinal cord terminated at the L2/L3 level.

The most cranial level where the conus medullaris was found in the neonatal cadavers was at the T12/L1 level (10.26%), while the most caudal level of spinal cord termination for this group was at the level of L3/L4 (5.13%). Interestingly, there were seven cases (15.91%) in the younger group where the conus medullaris was found at a level caudal to L2/L3 (upper third of L3 to L3/L4).

Wolf and colleagues (1992) studied the level of the conus medullaris in 114 healthy infants, using high resolution ultrasound. They found that the conus medullaris between the levels of L2 and L4 in 78% of patients aged 30 to 39 postmenstrual weeks, while the spinal cord terminated between the levels of T12/L1 and L1/L2 in 84% of the sample, aged between 40 and 63 postmenstrual weeks.

When performing lumbar puncture or lumbar epidural, it is important to know the possible range for conus medullaris level so as to avoid complications. In neither of the two samples examined did the spinal cord extend caudad to the level of L3/L4, which is only two thirds of a vertebral body more caudal when compared to the study conducted by Demiryürek *et al.* (2002). Since the sample size in both studies were small this does not indicate that the spinal cord does not ever descend lower than the level of L3/L4, as Wolf *et al.* (1992) reported a spinal cord terminating at the level of L4 in a healthy three month old infant.

6.2.4 Conclusion for caudal and lumbar epidural blocks

Caudal and lumbar epidural blocks are the most widely used regional anaesthetic procedures 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 successful performance of these procedures requires a thorough knowledge of the anatomy of the lumbar vertebrae and sacrum, the spinal cord as well as the position of the dural sac, as many anaesthesiologists, not used to working with paediatric patients, may lack the knowledge of relative depths or position of key anatomical structures.

This study hopes to complement what is already known of the neonatal vertebral column and to shed some light on the changes that occur when the neonate is flexed during the conduction of either single-shot lumbar or caudal epidural blocks, or for the insertion of a continuous epidural catheter via the caudal or lumbar route.

6.3) Paediatric infraclavicular brachial plexus block

6.3.1 Anatomical considerations of the neonatal infraclavicular brachial plexus block

The infraclavicular brachial plexus block is a safe technique and provides adequate anaesthesia of the whole arm (De Jose Maia & Tielens, 2004). The safety of the technique is based on the needle being directed laterally from the midpoint of the clavicle and the pleura. The lung lies behind the medial one third of the clavicle and is therefore safe from accidental puncture, avoiding risk of pneumothorax (Borgeat *et al.*, 2001). Due to the close proximity of the brachial plexus to the subclavian and axillary blood vessels, the danger of penetrating the blood vessels is a very real complication, but not more prevalent than with some of the other upper extremity blocks (De Jose Maria & Tielens, 2004). The use of peripheral nerve stimulators and ultrasound guidance to locate the brachial plexus has simplified this technique (Marhofer *et al.*, 2004; Bloc *et al.*, 2006).

Failures are based on inexperience (Raj, 1997), a lack of anatomical knowledge when performing the block (van Schoor, 2004), technical difficulties, or changes in needle position before injection of the local anaesthetic solution (Raj, 1997).

Although it may require a certain level of experience to palpate the coracoid process in the very young, it is an important landmark used in most infraclavicular blocks (see *2.3.4: Techniques*). The coracoid process is in close relationship to the brachial plexus and is easily identified when using ultrasound guidance. The xiphisternal joint is another landmark that can be used, since the line connecting the coracoid process and xiphisternal joint transects the cords of the brachial plexus. This is an ideal location as local anaesthetic solution injected at the point where the line connecting the coracoid process and xiphisternal joint transects the brachial plexus, will effectively block the cords and branches of the brachial plexus above and below the formation of the musculocutaneous and axillary nerves.

With the arm adducted to the trunk, the cartilaginous coracoid process found within the angle formed between the lateral third of the clavicle and the delto-pectoral groove (see Figure 6.1), is palpated and marked on the skin. The xiphisternal joint is located and marked by placing your finger inferior to the sternum in the subcostal angle (see Figure 6.2). A line should be drawn and measured between these two landmarks (the CP–XS line).

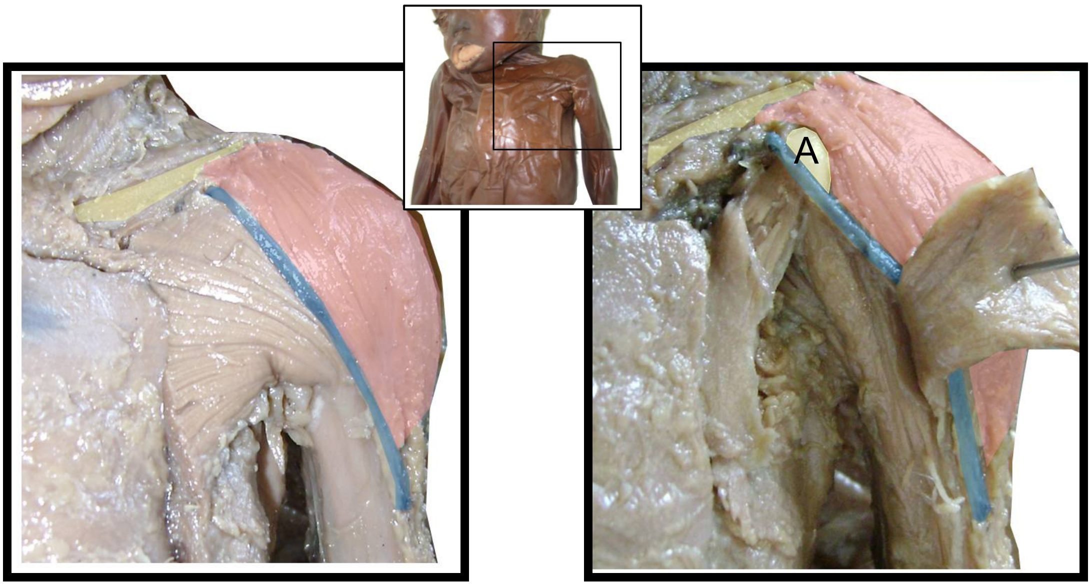


Figure 6.1: Dissection of the shoulder to expose the coracoid process.

The coracoid process (A) lying deep to the deltoid muscles (highlighted in red) and within the angle formed by the clavicle (highlighted in yellow) and the delto-pectoral groove, within which the cephalic vein (highlighted in blue) is running.

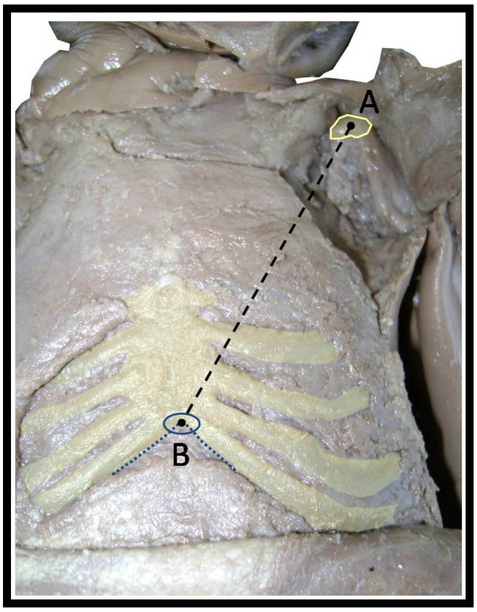


Figure 6.2: The coracoid process (A) and the xiphisternal joint (B) with the CP-XS line (dashed line) between them.

The results of this study, confirmed that in 95% of the sample (n=102 axillae), the lateral cord of the brachial plexus can be found between 4.93mm and 5.60mm from the coracoid process on the CP–XS line. The medial cord can be found between 9.53mm and 10.56mm from the coracoid process. Bloc and co-workers (2006) performed 500 infraclavicular blocks on adult patients in order to assess the ideal single motor response when employing 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. The ideal point for needle insertion is between the lateral and medial cords of the brachial plexus. In view of the convexity of the chest and infraclavicular area, a needle inserted perpendicular to the floor (or table) will enter the axillary sheath at a point lateral to the axillary artery in close proximity to the lateral cord. If the needle is inserted slightly deeper, it will be close to the posterior cord of the brachial plexus.

Injecting anaesthetic solution within the axillary sheath at this location should allow for the spread of the solution to block all the cords of the brachial plexus and subsequently all the terminal branches as well. This should also include the intercostobrachial nerve that joins the medial cutaneous nerve of the arm as it branches from the medial cord and negate the need for additional blocks when using a tourniquet.

The results of this study showed that in 95% of the sample, the ideal point of needle insertion is between 7.24mm and 8.08mm from the coracoid process on the CP–XS line. A Pearson's correlation test revealed a strong correlation between the point of needle insertion (mm) and the CP–XS line distance (R=0.7460) of the sample. Because of this strong correlation, a linear regression formula was developed for the neonatal sample with the distance to the point of needle insertion from the coracoid process (in mm) as the dependent variable and the distance between the CP and XS (in mm) as the independent variable (see Figure 5.5). The point of needle insertion can therefore be determined by using the following regression formula:

Point of needle insertion (mm)=0.14 x (CP–XS line distance (mm))–0.6

A moderate correlation with the length (R=0.6810) and weight (R=0.6171) of the sample was found. The following formulae can be used to determine the point of needle insertion if either the length or weight of the patient is known:

Point of needle insertion (mm)=18.24 (length (m))–0.21 and **Point of needle insertion (mm)=0.90 (weight (kg)) + 5.97**.

The needle should be inserted perpendicular to the floor (or table). This should avoid the possibility of piercing the parietal pleura, causing a pneumothorax. In the cadaver sample the distance from the medial cord of the brachial plexus (at the point where it is crossed by the imaginary CP–XS line) to the closest rib was also measured. This "safe" distance was found to be between 4.38mm and 5.28mm in 95% of the sample.

This study shows that in neonates, with the arm adducted, the needle insertion site lies approximately 7.5mm from the coracoid process on a line connecting the coracoid process and the xiphisternal joint. This effectively increases the chance of blocking the musculocutaneous and axillary nerves as well as the ulnar segment of the medial cord, which means that the intercostobrachial nerve is also blocked. The needle should be inserted perpendicular to the floor, avoiding the possibility of piercing the pleura. The needle will pierce the skin and subcutaneous tissue, the pectoralis major and minor muscles (covered anteriorly and posteriorly with clavipectoral fascia) and the axillary sheath, within which the brachial plexus and axillary artery lies. Because of the convexity of the chest, when the needle is inserted perpendicular to the floor, it will course past the lateral (or superior) aspect of the axillary artery towards the posterior cord of the brachial plexus.

Unfortunately it was impossible to determine the depth of the brachial plexus from the skin in the neonatal sample. A search of the literature also revealed very little regarding this fact, except that the distance in adults is between 20mm (Sims, 1977) and 45mm (Rodriguez *et al.,* 2004a). Determining this distance in neonates and the very young using ultrasound will be of great benefit to the anaesthesiologists.

This technique, in conjunction with the use of ultrasound and/or nerve stimulation, should allow for accurate placement of the needle tip with minimal risk of pneumothorax (although vascular puncture is possible in view of the close relationship of the brachial plexus to the axillary artery and vein). Locating the brachial plexus at this position also means that several structures need to be pierced. This facilitates anchoring of continuous catheters placed in this area when post-operative or long-term anaesthesia is required (Fisher *et al.,* 2006).

neonate and with growth, the distance between the coracoid process and the xiphisternal joint enlarges. This is clearly not proportional; otherwise there would not have been significant differences.

Regardless of the position of the cords of the brachial plexus within the axilla, there is a significant difference between the location of the ideal point of needle insertion (a point between the medial and lateral cord of the brachial plexus, on the CP-XS line). This study showed that one can determine the distance from the ideal point of needle insertion by using the linear regression formulae developed for each individual sample. The point of needle insertion is also a sufficient distance from the thoracic wall, and subsequently the pleura, to consider it safe from possibly causing a pneumothorax.

6.3.3 Conclusion

Sound knowledge and understanding of anatomy is vitally important for successful nerve blocks. Extrapolation of anatomical findings from adult studies and simply downscaling these findings in order to apply them to infants and children is inappropriate. It has been demonstrated that there is a significant difference between the distance of the brachial plexus from the coracoid process between neonates and adults.

This suggests that caution should be taken when applying procedures originally described on adult patients to a paediatric population. A lack of knowledge regarding the differences in the distances from bony landmarks and the relative depth of the brachial plexus may result in various complications if performed by inexperienced anaesthesiologists.

Therefore, even with the aid of nerve stimulators or ultrasound guidance, the anatomy should be well understood before attempting brachial plexus blocks on neonatal patients.

6.4) Paediatric femoral nerve block

6.4.1 Anatomical considerations of the neonatal femoral nerve block.

It is believed that the femoral nerve block is the most commonly performed lower limb block in paediatric patients and it is of particular value to children with a fractured femoral shaft. It is also regarded as the most effective method of pain relief for femoral shaft fractures when general anaesthesia is contraindicated. In cases where there are femur fractures, a femoral nerve block should be performed as soon as possible to ensure the comfort of the patient during transport, physical and radiological examinations, wound dressing, and orthopaedic procedures (Dalens, 2003).

Despite technological advances such as ultrasound guidance and nerve stimulators which have greatly reduced failures and complications, blocking the femoral nerve quickly, effectively and safely requires a solid anatomical knowledge, especially when nerve stimulators and/or ultrasound are not readily available.

There is no mystery regarding the anatomy of the femoral nerve and its position within the femoral triangle in adults. There are still very few articles looking at the anatomy of the nerve in children, especially neonates. Classical anatomical literature describes the femoral artery entering the femoral triangle, posterior to the inguinal ligament, at the mid-inguinal point and in children the nerve can be found between 5mm and 10mm lateral to the artery (Katz, 1993; Dalens, 2003).

The dissection of one hundred neonatal femoral triangles showed that the femoral artery can be found between 47.00% and 49.64% (95% confidence level) along the inguinal ligament from the ASIS. This concurs with the literature with regard to the femoral pulse being at the mid-inguinal point. The femoral nerve was found between 33.38% and 36.30% (95% confidence level) along the inguinal ligament from the ASIS, or between 10.38mm and 11.73mm (average distance is 11.05mm±3.44mm) from the ASIS. The femoral nerve lies approximately 3.72mm±1.70mm (95% confidence level, range: 3.39mm–4.06mm) lateral to the femoral artery.

It is important to note that the femoral nerve lies closer to the femoral artery in a neonatal population than is stated in the literature; between 3.39mm and 4.06mm *versus* between 5mm and 10mm.

The measurements made on the sample of neonatal cadavers revealed a strong linear correlation between the ASIS to the femoral nerve distance (dependant variable) and the ASIS-PT distance (independent variable) (R=0.8058). The linear regression formula determined for the neonatal sample (see Figure 5.8) can be used to determine the position of the femoral nerve as it enters the femoral triangle posterior to the inguinal ligament. This distance can be obtained simply by multiplying the distance between the ASIS and PT (mm) of the patient with 0.37 and then subtracting 0.42. The coefficient of determination (R^2) for this linear regression formula is 0.6493. It should therefore be accurate for approximately 65% of all neonates. Alternatively, the pulse of the femoral artery can be palpated just inferior to the inguinal ligament. The femoral nerve can then be found (in 95% of neonates) between 3.4mm and 4.1mm lateral to the pulse femoral artery.

6.4.2 Anatomical considerations of the femoral nerve block– comparison between neonatal and adult data

Anatomical variations, particularly in developing children, as well as differences in the depth and position of peripheral nerves, make regional anaesthetic procedures performed on children more difficult. Fascial sheaths are thinner and identifying loss of resistance more difficult (Bosenberg, 1995).

The results of this study have shown clear differences between the position of the femoral nerve and artery, within the femoral triangle, when comparing adults and neonates. Firstly, dissections of 138 adult femoral triangles (70 left and 68 right sides) showed that the femoral artery can be found between 57.99% and 59.75% (95% confidence level) from the ASIS, along the inguinal ligament. This is more medial to the mid-inguinal point than is stated in the literature regarding the femoral pulse, which is regarded as being at the mid-inguinal point.

It is also important to clarify, that in this case, the mid-inguinal point is defined as the midpoint of the ASIS–PT line and not the midpoint of the inguinal region, which lies between the ASIS and pubic symphysis. The femoral nerve was found between 48.06% and 49.96% (95% confidence level) from the ASIS, along the inguinal ligament, which is approximately halfway between the ASIS and PT in the adult sample. The femoral artery can be found between 67.19mm and 70.78mm (average distance is 68.99mm±10.74mm) from the ASIS, or 57.99%-59.75% of the ASIS-PT line from the ASIS. The femoral nerve lies approximately 11.84mm±3.51mm (95% confidence level, range: 11.25mm–12.42mm) lateral to the femoral artery.

The measurements taken on the sample of adult cadavers also revealed a strong linear correlation between the distance of the femoral nerve from the ASIS (dependant variable) and the ASIS-PT distance (independent variable (R=0.7840). The linear regression formula developed for the adult sample (see Figure 5.9) can therefore be used to determine the position of the femoral nerve as it enters the femoral triangle, posterior to the inguinal ligament. This distance can be obtained simply by multiplying the distance between the ASIS and PT (mm) of the patient with 0.58 and then subtracting 10.25. The coefficient of determination (R^2) for this linear regression formula is 0.6147. It is thus accurate for approximately 61% of adults within this age range. Alternatively, the pulse of the femoral artery can be palpated just inferior to the inguinal ligament and the femoral nerve can then be found (in 95% of adults) between 11mm–13mm lateral to the femoral artery.

A paired *t*-test was performed on the data of the neonatal and adult samples in order to determine whether there are statistically significant differences between the two populations. Firstly, all the distances (in mm) that were measured were converted to a percentage of that specific cadaver's ASIS–PT distance. This allowed for comparisons to be made regarding the percentage along the inguinal ligament the femoral artery and nerve can be found. There was found to be a statistically significant difference between the positions of the femoral nerve (p=0.00001) and femoral artery (p=0.00001) within the femoral triangle, as well as the distance (as a percentage of the ASIS–PT distance) of the femoral nerve from the femoral artery (p=0.0027).

Because there is a statistically significant difference between the neonatal and adult data and the strong linear correlation between the distance of the femoral nerve and ASIS–PT distance in each sample population, two separate linear regression formulae were developed for determining the distance of the femoral nerve from the ASIS.

The content of both left and right femoral triangles was dissected on a single eleven year old female cadaver (height: 1.4m; weight: 26.7kg). The distance of the femoral artery was 59.98mm from the ASIS (69.87%) on the right and 58.84mm (64.31%) on the left. The femoral nerve was 41.56mm (48.41%) from the ASIS or 18.42mm from the femoral artery on the right and 47.23mm (51.62%) from the ASIS or 11.61mm lateral to the femoral artery on the left (see Figure 6.3).

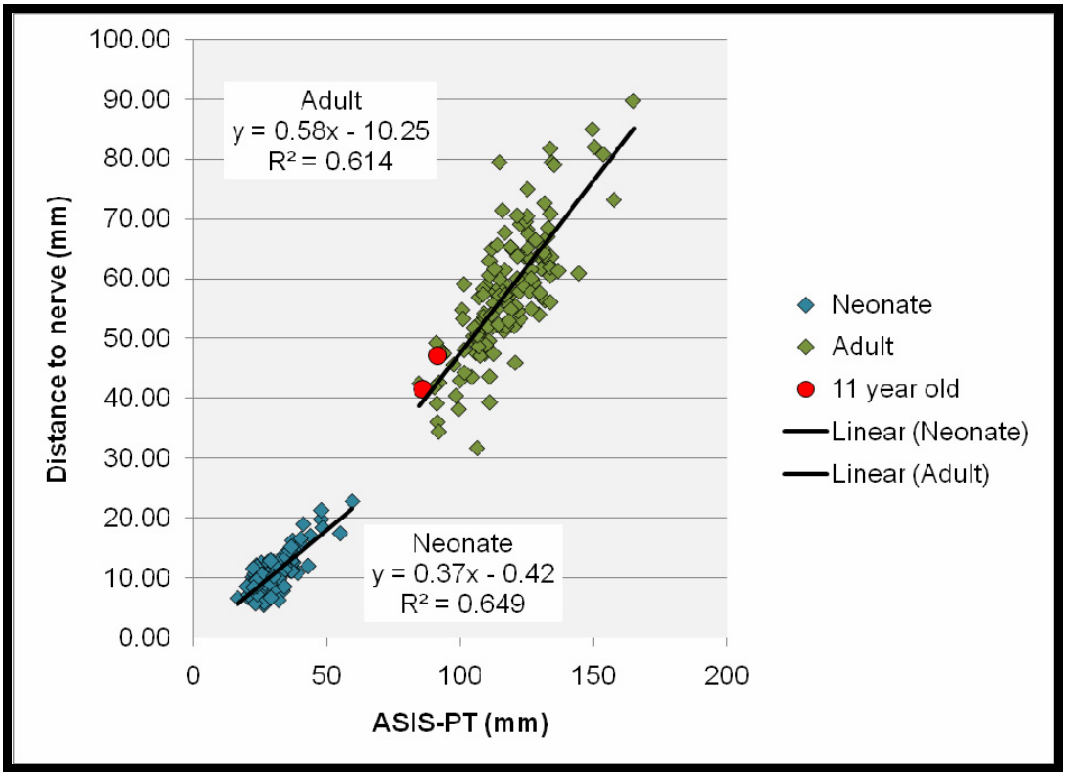


Figure 6.3: Linear regression formulae, for both the neonatal and adult samples

The distance of the femoral nerve from the ASIS is the dependent variable and the ASIS-PT distance is the independent variable. The measurements for the eleven year old cadaver are indicated as two red circles.

Although no inferences can be made from the following, it is interesting to note that when plotted on the two linear regression formulae developed for the neonatal and adult samples the eleven year old coincides better with the adult population. Since this cadaver almost reached the average age of puberty in females (approximately 12 years) (Jones, 1946), it would make sense that the positional anatomy of the structures within the femoral triangle would resemble that of an adult rather than a neonate or young infant.

6.4.3 Conclusion

There are significant differences between the anatomy of the femoral triangle of neonates and adults. Although the structure of the femoral artery and nerve remains essentially the same, the positions of these structures within the femoral triangle differ. This is of utmost importance, especially for anaesthesiologists who wish to perform regional nerve blocks on neonates and infants. This is especially true when attempting a femoral nerve block without the use of ultrasound to identify the nerve prior to needle insertion. Even with the use of a nerve stimulator, the position of the nerve must be known before inserting the needle in an attempt to stimulate the femoral nerve, as inadvertent puncture of the femoral artery, especially in a neonatal patient can have serious consequences. If possible, the use of surface mapping with transcutaneous electrical stimulation can be used to determine the point of needle insertion, if ultrasound guidance is not available. In both cases, stimulation of the femoral nerve will cause quadriceps muscle contraction (Bosenberg *et al.*, 2002).

6.3.2 Anatomical considerations of the infraclavicular brachial plexus block–comparison between neonatal and adult data

Except for Fisher *et al.* (2006) who describes his technique on a single ten year old, all the infraclavicular techniques used for paediatric brachial plexus blocks were originally based on adult patients (see Table 5.16). The results clearly show a difference in the position of the brachial plexus within the axilla in neonates when compared to adults. Although examination of the neonatal brachial plexi dissected throughout this study did not reveal any marked differences in the macroscopic anatomy, it is in the positional anatomy where the differences lie.

Using a paired *t*-test, the data obtained from the adult sample were compared to the data obtained from the total sample of neonatal axillae (see *5.3.1: Anatomical considerations of the neonatal infraclavicular brachial plexus block*). Only the measurements that were converted to a percentage of the CP-XS line distance were compared between the two samples. This comparison showed that there is a statistically significant difference in the distance (as a percentage of the CP-XS line distance) of the coracoid process to the MBP, the distance between the LBP and MBP and the distance of the coracoid process to the ideal point of needle insertion. There were however no statistically significant difference between the distance of the coracoid process to the LBP. This would suggest that the lateral cord remains at a relatively fixed distance from the coracoid process throughout development. However, the medial cord of the brachial plexus moves closer to the coracoid process throughout development. The position of the medial cord changes from 17.07%±3.04% of the CP-XS line distance from the coracoid process in neonates to 13.87%±3.17% in adults. Consequently the distance between the medial and lateral cords decreases with age. Where this distance, as a percentage of the CP-XS line distance, is larger in neonates (8.18%±1.89%) than in adults (5.98%±1.12%), it would suggest that the brachial plexus takes up more space within the axillary space, relative to its actual size of it. Since the CP-XS line distance is used to determine these measurements as percentages, it could suggest that the thoracic region is more compact in a

6.5) Paediatric ilio-inguinal/iliohypogastric nerve block

6.5.1 Anatomical considerations of the neonatal ilio-inguinal/iliohypogastric nerve block

Sound knowledge and understanding of the anatomy is vitally important for successful nerve blocks, even when using ultrasound-guidance. Extrapolation of anatomical findings from adult studies and simply “downscaling” these findings in order to apply them to infants and children is inappropriate. This study demonstrates that the ilio-inguinal and iliohypogastric nerves in neonates and infants lie much closer to the ASIS than previously thought. This may explain the higher failure rate of ilio-inguinal/iliohypogastric nerve blocks reported in this age group.

Accurate placement of the needle in close proximity to the nerve is essential for a successful block (Montgomery *et al.*, 1973), and correct placement requires a familiarity with the regional anatomy and landmarks (Brown, 1985; Sethna and Berde, 1992). Difficulty arises when there is anatomical variation, as seen in the growing child and when landmarks are difficult to identify. Techniques based on measurements from a fixed anatomical point clearly have limitations when applied to all age groups.

For the ilio-inguinal/iliohypogastric nerve block, it has been estimated that complete failure could occur in about 10% of all procedures, while partial failure may be even more frequent in the order of 10 and 25% (Lim *et al.*, 2002). A failure rate as high as 20% to 30% has been reported for the classic ilio-inguinal/iliohypogastric nerve block technique (Eichenberger *et al.*, 2006).

The findings in this study may explain the high rate of failure of the block, particularly if the blocks are based on incorrect measurements or understanding of the anatomy in this age group.

The ilio-inguinal and iliohypogastric nerves were found to be much closer to the ASIS than was previously thought. The ilio-inguinal nerve on the right passes a mere 2.24mm (95% confidence range: 1.92mm to 2.56mm) from the ASIS. It runs between the transversus abdominis and internal oblique muscles to a point inferomedial to the ASIS, where it then pierces the internal oblique muscle, entering the inguinal canal. The left ilio-inguinal nerve is also very close to the ASIS, only 2.16mm (95% confidence range: 1.84mm to 2.48mm) from this bony point.

The same is true for both the right and left iliohypogastric nerves. The right iliohypogastric nerve can be found approximately 3.87mm (95% confidence range: 3.53mm to 4.22mm) from the ASIS (this is at a point on a line between the ipsilateral ASIS and the umbilicus). The nerve can also be found between the transversus abdominis and internal oblique muscles. It is only at a point after passing the line between the ASIS and umbilicus that the nerve pierces the internal oblique muscle, running between this muscle and the external oblique. It was observed in 52 neonatal cadavers that the iliohypogastric nerve would pierce the internal oblique muscle approximately at the semi-lunar line or the lateral border of the rectus sheath. The left iliohypogastric nerve can be found to be about 3.76mm (95% confidence range: 3.38mm to 4.13mm) from the ASIS.

These distances are substantially closer to the ASIS than was previously thought, especially when looking at the technique described by Von Bahr (1979), where the line between ASIS and the umbilicus is divided into quarters and the needle is inserted into the medial quarter and lateral three quarters. In the technique, success relies heavily on the fan-shaped manner in which the local anaesthetic solution is injected (from medial to lateral) and the anticipation that the solution will spread caudally between the transversus abdominis and internal oblique muscles.

The ideal point of needle insertion, according to the data obtained, is a point halfway between the ilio-inguinal and iliohypogastric nerves. On the right, this point is 3.04mm from the ASIS, on a line between the ASIS and the umbilicus, and 2.96mm from the ASIS on the left.

Willschke and co-workers (2005) performed ultrasound-guided ilio-inguinal/iliohypogastric nerve blocks on a hundred paediatric patients. They determined that the mean distance of the ilio-inguinal from the ASIS was 6.7mm±2.9mm. The mean weight of the population was approximately 13kg±8kg. This corresponds well with the data obtained from this study, where the mean distance of the ilio-inguinal nerve was found to be 2.20mm in a much smaller neonatal population with a mean weight of only 1.64kg±0.72kg. However, looking at the linear regression formula for the distance of the ilio-inguinal nerve and weight of the cadaver (see Figure 5.14), the distance of the ilio-inguinal nerve from the ASIS of two larger neonates, weighing 9.1kg, were between 5.06mm and 7.95mm, which falls within the range described by Willschke and co-workers (2005).

Therefore, the formula shown in Figure 5.14, i.e., distance of ilio-inguinal nerve (mm)=0.53(weight in kg) + 1.18, can be used to determine the position of the ilio-inguinal nerve. The same goes for determining the distance of the iliohypogastric nerve (see Figure 5.15): distance to the iliohypogastric nerve (mm)=0.625(weight in kg) + 2.613) and the point of needle insertion, which is at a point midway between the ilio-inguinal and iliohypogastric nerves (see Figure 5.16) distance of needle insertion point (mm)=0.59(weight in kg) + 1.8.

Willschke and co-workers (2005) also looked at the skin to ilio-inguinal nerve and ilio-inguinal nerve to peritoneum distance and found them to be 8.0mm±2.2mm and 3.3mm±1.3mm (shortest distance, 1 mm), respectively. This emphasises the risk of undetected peritoneal puncture when using the “fascial click” method. This may contribute to failed blocks and is a strong argument for the use of ultrasound guidance in young children.

Inadvertent femoral nerve block is also a recognised complication of ilio-inguinal/iliohypogastric nerve blocks (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 has shown that the fascial plane between the transversus abdominis muscle and the transversalis fascia was in continuity with the space around the femoral nerve posteriorly. Injection of methylene blue into this plane resulted in pooling of dye around the femoral nerve (Rosario *et al.*, 1997). This may partly explain the relatively high incidence of femoral nerve palsy, particularly if a relatively large volume of local anaesthetic is used. Incorrect placement of the needle below or closer to the inguinal ligament as a result of inappropriate measurements is more likely to involve the femoral nerve, even if small volumes of local anaesthetic are used.

Ultrasound-guidance is strongly recommended when performing the ilio-inguinal/iliohypogastric nerve block. It offers the advantage of direct visualisation of the nerves and adjacent anatomical structures. The real-time imaging of the local anaesthetic spread around the nerves allows for the maintenance of the quality of the block, while significantly reducing the amounts of local anaesthetic required compared with the recommended dose for the conventional methods.

6.5.2 Conclusion

The findings of this study suggest that the needle should be placed much closer to the ASIS than previously described in the literature. The local anaesthetic injection should be made approximately 3mm from the ASIS on a line drawn between the ASIS and the umbilicus in neonates. The linear regression formula could also be used as the distance of the insertion point indicates a strong correlation with the weight of the patient. Where ultrasound is unavailable, a short bevel needle is considered essential to identify the "give" or "pop" as the needle penetrates the external oblique aponeurosis. This give may be very subtle particularly in small infants.

Armed with this knowledge it is suggested that smaller volumes of local anaesthetic placed closer to the ASIS would improve the success rate of ilio-inguinal/iliohypogastric nerve blocks in this age group and, in the process, improve patient safety (van Schoor *et al.,* 2005).

6.6) Conclusion of the thesis

The overall aim of this study was to show the positional differences found between neonates and adults. The data obtained shows significant differences between the positions of anatomical structures commonly used for regional anaesthesia in neonates and adults. The disproportionate growth from the neonatal period through to adulthood means that one cannot rely on data obtained from adult samples when performing regional blocks on a neonate or even a young infant. The difference has been proven to be too great and the patient is put at risk.

Another observation that was made during the conduction of this study is the important role that ultrasound guidance plays in regional anaesthesia. Anatomical studies such as this one are vital for anyone interested in performing regional nerve blocks on young children. It is even more important, since paediatric anatomy texts are rare and anaesthesiologists obtain their anatomical knowledge mostly from adult human anatomy textbooks and literature. Not only can these studies identify differences in the position or relationships of neonatal anatomical structures when compared their adult counterparts, but possible anatomically related complications can be identified. Measurements from easily identifiable bony landmarks can lead to quantitative data regarding distances of one structure to another. The latter can then be used to determine statistical formulae (like the linear regression formulae that have been developed in this study. These can then be used to obtain a sense of where a structure should be on a given patient, based on independent variables such as the height or weight.

Although this data is invaluable for all paediatric anaesthesiologists, ultrasound-guided regional anaesthesia is the ultimate source of dynamic and real-time anatomical information required when performing regional blocks safely and successfully. Even the use of nerve stimulators or surface nerve mapping, which has been proven to be valuable tool, cannot compare to actual visualising the desired nerve as well as the needle tip as it traverses through muscular and other soft tissue structures. The main disadvantage, as with most advanced technological equipment, is cost as well as proficiency of the user.

In conclusion, it is therefore recommended that neonates, infants, toddlers and even small children should not be viewed as proportionately small adults. Even though the anatomical structures are mostly the same as in adults, their position and relationships to other structures differ to a greater or lesser degree.

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Appendices

Appendix A: Materials required when performing a local anaesthesia or regional block in children (Dalens, 1999)

Block Procedure	Recommended Device	Alternate Device
Intradermal wheals	Intradermal needles (25 G, 25 mm long)	-
Local infiltration and field blocks	Standard IM needles (21-23 G, 25-50 mm long)	-
Compartment blocks (fascia iliaca, penile, rectus sheath, peribulbar blocks)	21-23 G short (25-50 mm) and short bevel	Epidural needles (especially Tuohy needles for intercostal block) Neonatal spinal needle
Peripheral mixed nerve blocks and plexus blocks	Insulated 21-23 G short bevel needles of appropriate length (depending on block procedure and patient's size) Nerve stimulator (0.5-1 mA)	Unsheathed needles with the same characteristics connected to a nerve stimulator (0.5-1 mA)
Spinal anaesthesia	Spinal needle (24-25 G; 30, 50 or 100 mm long, Quincke bevel, stylet)	Neonatal lumbar tap needle (22 G, 30-50 mm long) Whitacre spinal needle
Caudal anaesthesia	Short (25-30 mm) and short bevel needle with stylet	Neonatal epidural needle (intraoperative catheter insertion) Occasionally: spinal needle IV short catheter: not recommended
Epidural anaesthesia	Tuohy needle (22 G and 30 mm long, 20 G and 50 mm long, 19-18 G and 80-90 mm long); LOR syringe and medium; Epidural catheter	Crawford, Whitacre, or Sprotte epidural needles appropriately sized; LOR* syringe and medium Epidural catheter

*LOR = Loss of Resistance

Appendix B: Questionnaire used during the survey of regional anaesthetic procedures.

The questionnaire was developed after an extensive literature review and also by means of feedback obtained from anaesthesiologists who completed a pilot questionnaire while attending a regional anaesthesia workshop at the Department of Anatomy, University of Pretoria (see Table B1). This pilot study provided useful information on shaping the questionnaire. Every data-item on the questionnaire was given a numerical value for all eight questions. The data for every procedure was then entered into the Excel® statistical program.

Table B1: Example of questionnaire given to anaesthesiologists.

Questions

1. I **perform this procedure** in my practice.
2. **How many times** did you perform this procedure in the **past year?**
3. The performance of this procedure is **important in my practice situation**.
4. I feel **comfortable to perform** this procedure.
5. I find **difficulty to perform** this procedure due to the following **reason/s**: (order in level of importance)
6. I met the following **complication/s** and have the following **difficulties** when performing the procedure (number in order of frequency)
7. The improvement of **critical anatomy knowledge necessary** to perform this procedure will **reduce difficulties and complications**.
8. Improvement of **anatomy knowledge** necessary for the procedure will **increase my confidence** in performing the procedure.

	1	2	3	4	5	6		7	8
Paediatric caudal epidural block	Yes	More than 20	Essential	Very comfortable	Knowledge of the procedure itself	Difficulty palpating landmarks for needle insertion	Injection into sacral bone marrow	Strongly agree	Strongly agree
		10-20	Desirable but not essential	Fairly comfortable	Equipment necessary for the procedure	Difficulty piercing the SC ligament	Vascular puncture	Agree	Agree
	No	5-10	Useful	Uncomfortable	Practical skills to perform the procedure	Dural puncture	Subarach-noid injection	Disagree	Disagree
		Less than 5	Not necessary	Very uncomfortable	Regional anatomy knowledge	Misplacement into soft tissue or rectum (pelvic viscera)		Strongly disagree	Strongly disagree

After an extensive search of the literature, a total of 17 paediatric regional anaesthetic procedures were selected for the survey (see Table B2).

Table B2: List of 17 paediatric regional anaesthetic procedures included in the questionnaire.

Paediatric regional anaesthetic procedures	
Neuraxial/central blocks	
1.	Caudal epidural block
2.	Spinal anaesthesia
3.	Lumbar epidural block
4.	Thoracic epidural block
Peripheral nerve blocks	
1.	Infraclavicular brachial plexus block
2.	Supraclavicular brachial plexus block
3.	Femoral nerve block
4.	Lateral femoral cutaneous nerve block
5.	“3-in-1” block
6.	Fascia iliaca block
7.	Psoas compartment block
8.	Sciatic nerve block: Anterior approach
9.	Sciatic nerve block: Posterior approach
10.	Sciatic nerve block: Lateral approach
11.	Ilio-inguinal/iliohypogastric nerve block
12.	Penile block
13.	Intercostal block

Appendix C: Results of survey into paediatric regional anaesthesia in South Africa.

Procedures were scored to best represent the selection criteria of the study, portraying a block that is performed, has anatomically related difficulties and complications associated with it, and where improvement of anatomical knowledge will make a difference in reducing difficulties and complications and increase confidence of performance. The five “problem” procedures are shown in Table C1.

Table C1: Procedures that scored the highest points, according to the scoring option.

Procedure	Score	Incidence of Performance
Femoral nerve block	9/12	22.5%
Brachial plexus block	9/12	22.5%
Caudal epidural block	8/12	63.75%
Ilio-inguinal/ iliohypogastric nerve block	8/12	26.25%
Lumbar epidural block	8/12	20%

The results from the questionnaires were analysed and the importance, comfort levels and possible difficulties that an anaesthesiologist may experience when performing one of the five “problem” procedures is summarised in Table C.2.

Table C2: Importance rating, comfort levels and possible difficulties associated with the most frequently performed procedures.

Procedure	% that believe block to be important	% that feel comfortable performing the block	% that has difficulties with…			
			knowledge of procedure	necessary equipment	practical skill	clinical anatomy knowledge
Caudal epidural block	80.4%	90.2%	9.8%	21.6%	15.7%	15.7%
Lumbar epidural block	43.8%	75%	0%	37.6%	18.8%	18.8%
Brachial plexus block	44.4%	72.3%	27.8	22.3%	50%	33.3%
Femoral nerve block	72.2%	77.8%	22.3%	22.3%	27.8%	22.3%
Ilio-inguinal/ iliohypogastric nerve block	66.7%	80.9%	19.1%	9.5%	14.3%	19.1%

The specific anatomically related complications associated with each of the five “problem” procedures, as well as the frequency of occurrence is summarised in Table C3.

Table C3: Complications experienced during the performance of the five "problem" procedures.

Caudal epidural block		Lumbar epidural block		Brachial plexus block		Femoral nerve block		Ilio-inguinal/ iliohypogastric nerve block	
Complication	**%**	**Complication**	**%**	**Complication**	**%**	**Complication**	**%**	**Complication**	**%**
Difficulty palpating landmarks for needle insertion	47.1%	Difficulty locating needle insertion site	12.5%	Difficulty palpating landmarks for needle insertion	39.0%	Difficulty locating needle insertion site	39.0%	Difficulty in visualising position of the nerves	33.4%
Injection into sacral bone marrow	29.4%	Dural puncture	37.5%	Vascular puncture	44.4%	Vascular puncture	44.4%	Nerve trauma	23.8%
Difficulty piercing the SC ligament	33.3%	Lesions to IV discs and ligaments	6.3	Nerve trauma	11.2%	Nerve trauma	10.2%	Blocking of femoral nerve	14.1%
Vascular puncture	25.5%	Trauma of the spinal cord and nerve roots	12.5%	Pneumothorax	5.6%			Partial or incomplete block	61.9%
Dural puncture	17.7%	Vascular puncture	6.3%						
Sub - arachnoid injection	11.8%	Misplacement of epidural catheter	18.8%						
Misplacement into soft tissue or rectum (pelvic viscera)	23.5%								

* SC = Sacrococcygeal

* IV = Intervertebral

Participating anaesthesiologists were also asked to score whether they (1) Strongly agreed, (2) Agreed, (3) Disagreed or (4) Strongly disagreed with the statements: *Increased clinical anatomy knowledge will decrease complications* (see Figure C1) and *Increased clinical anatomy knowledge will increase confidence* (see Figure C2).

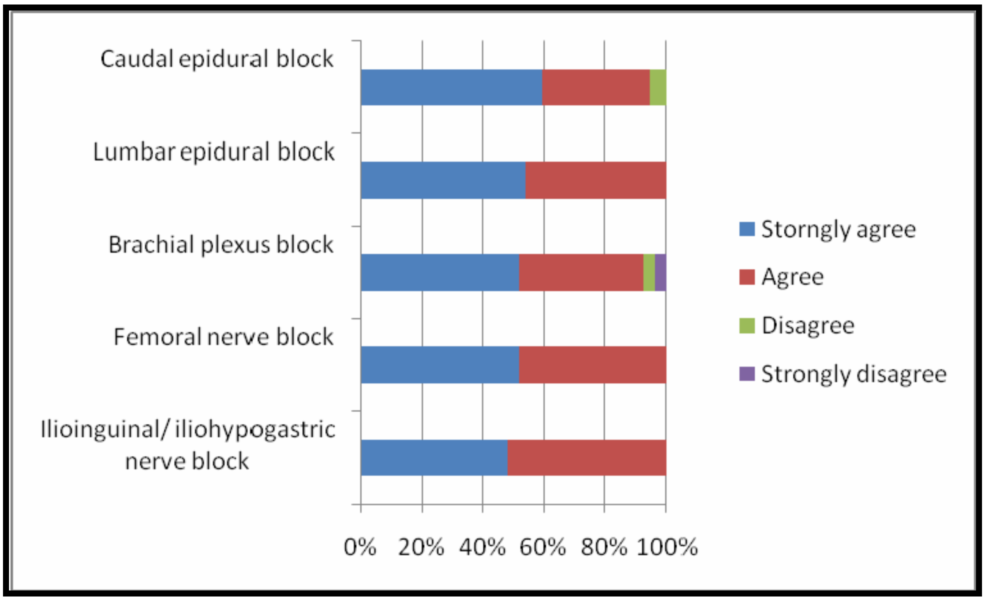

Figure C1: Importance of clinical anatomy knowledge in decreasing complications.

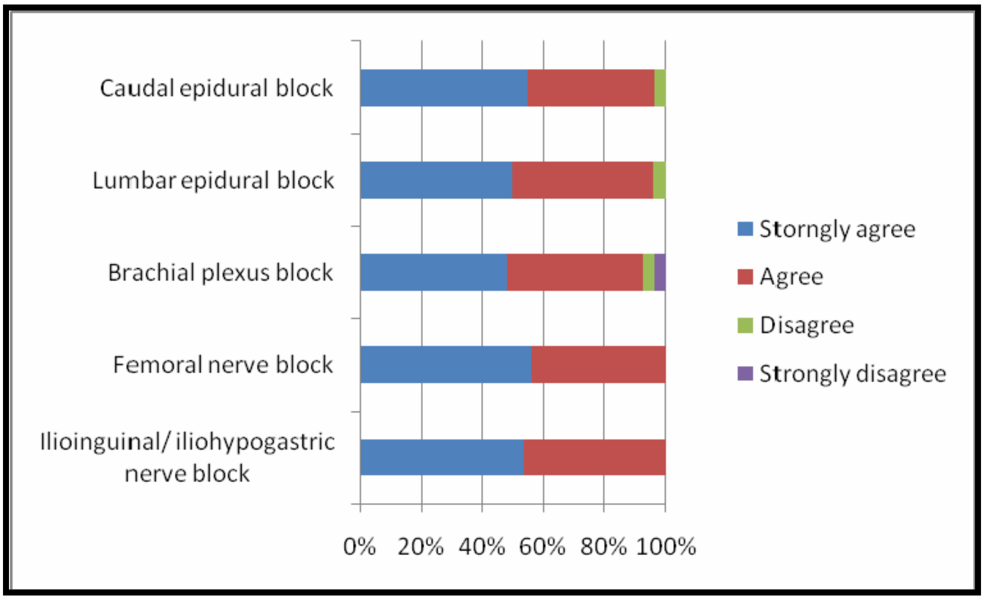

Figure C2: Importance of clinical anatomy knowledge in increasing comfort levels.