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.

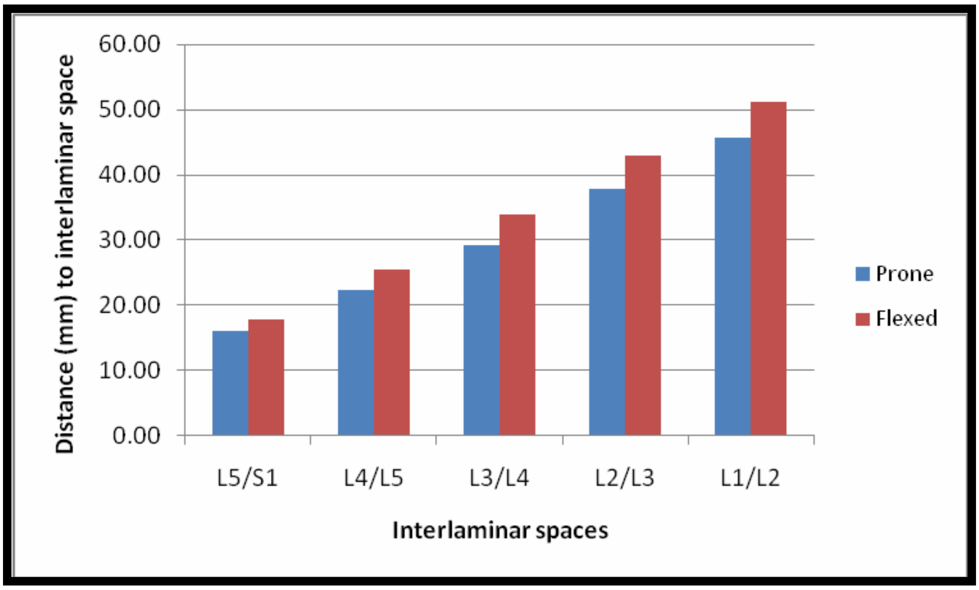

Figure 5.1: Distances from the apex of the sacrococcygeal membrane to the neonatal lumbar epidural spaces.

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.

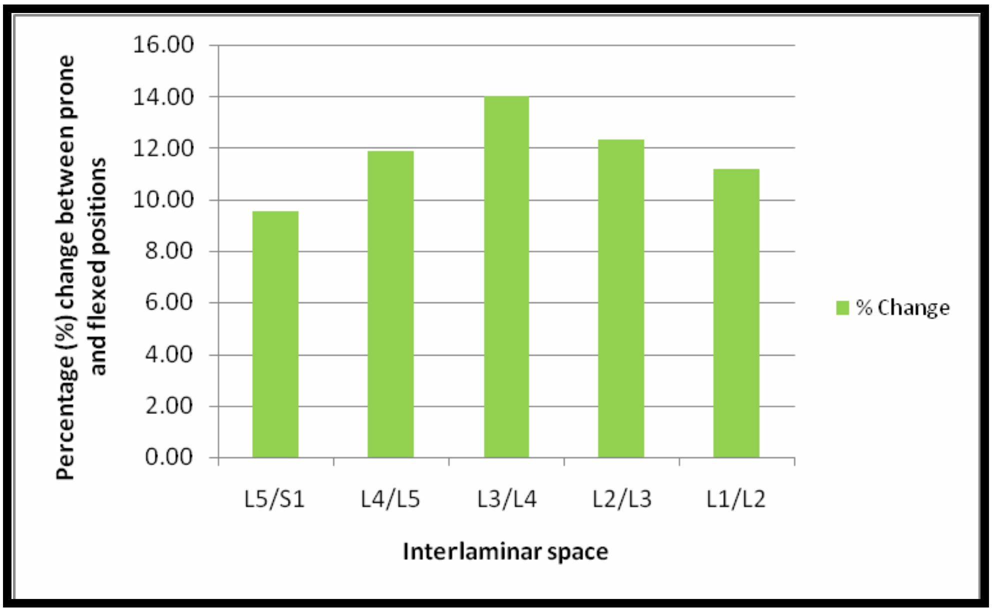

Figure 5.2: Percentage change of the distance from the apex of the sacrococcygeal membrane to the neonatal lumbar epidural spaces.

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.

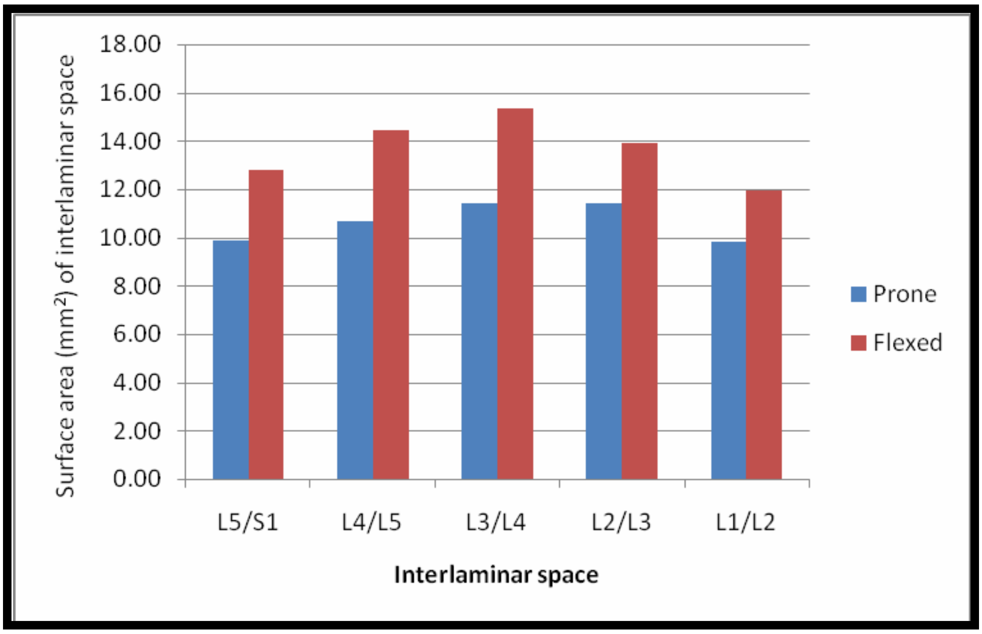

Figure 5.3: Surface area of neonatal lumbar interlaminar spaces.

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.

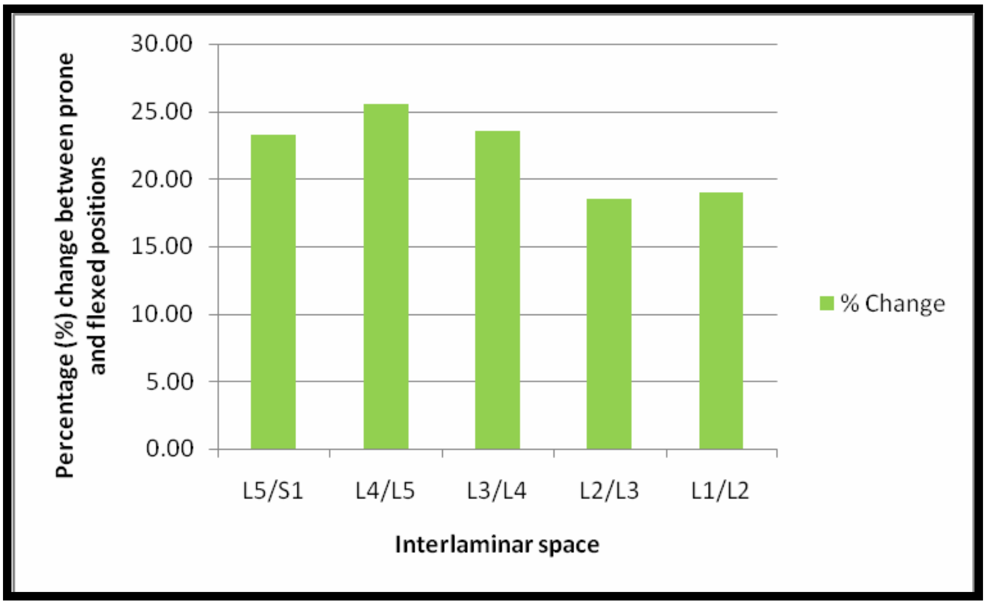

Figure 5.4: Percentage change of the surface area measurements of the neonatal lumbar interlaminar spaces.

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.

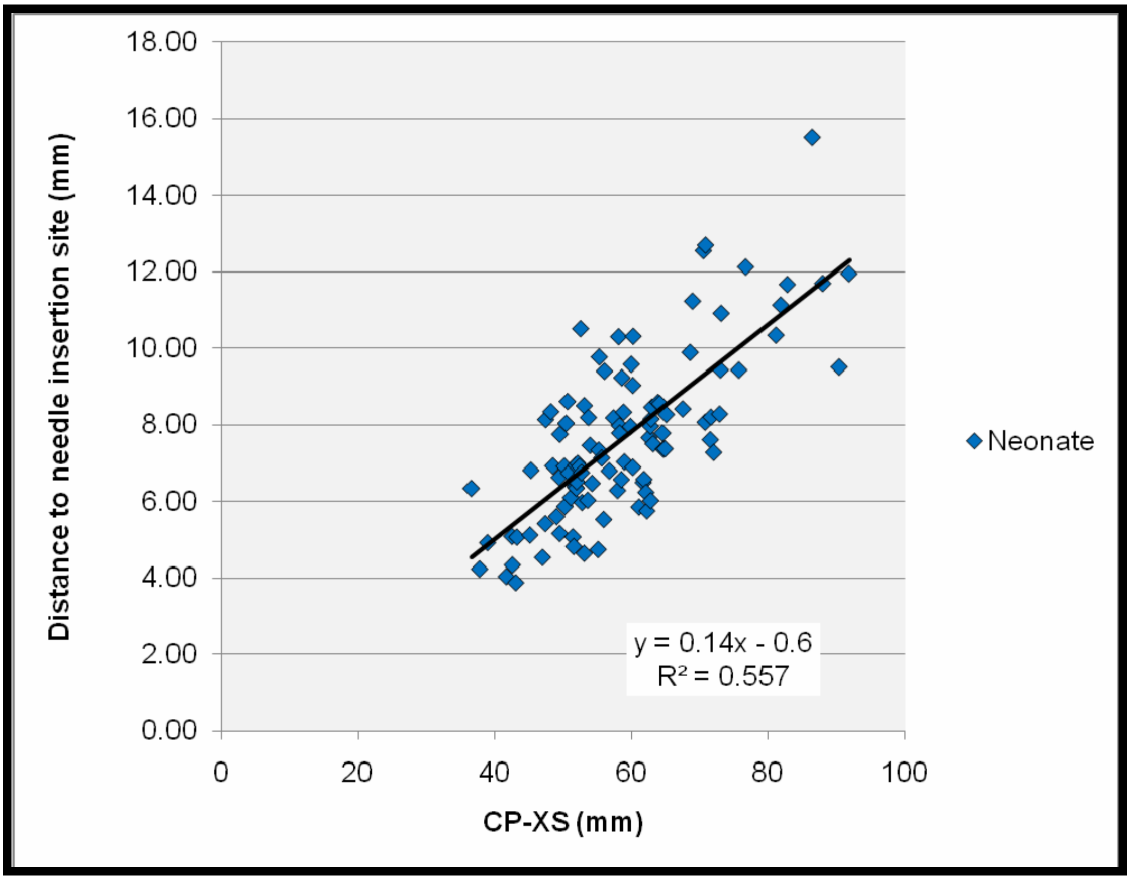

Figure 5.5: Linear regression formula for the distance of the point of needle insertion in neonates

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.

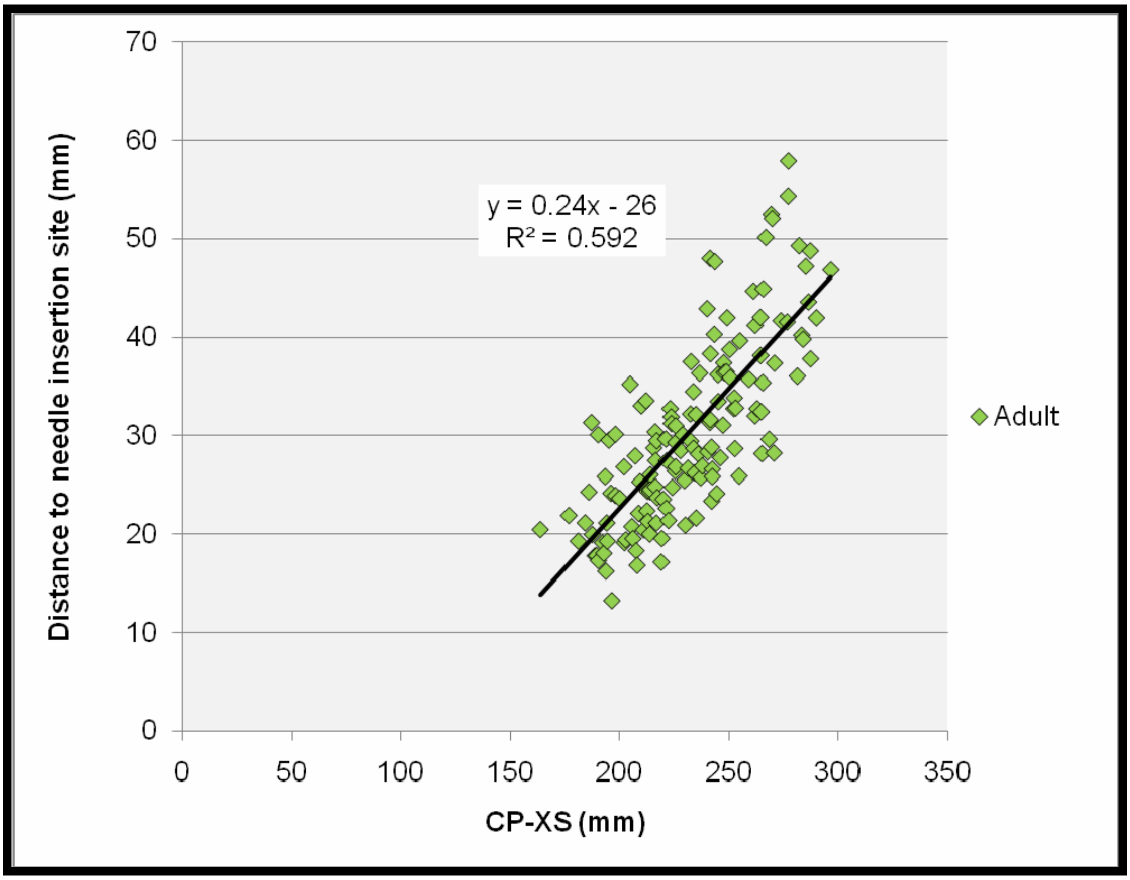

Figure 5.6: Linear regression formula for the distance of the point of needle insertion in adults.

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.

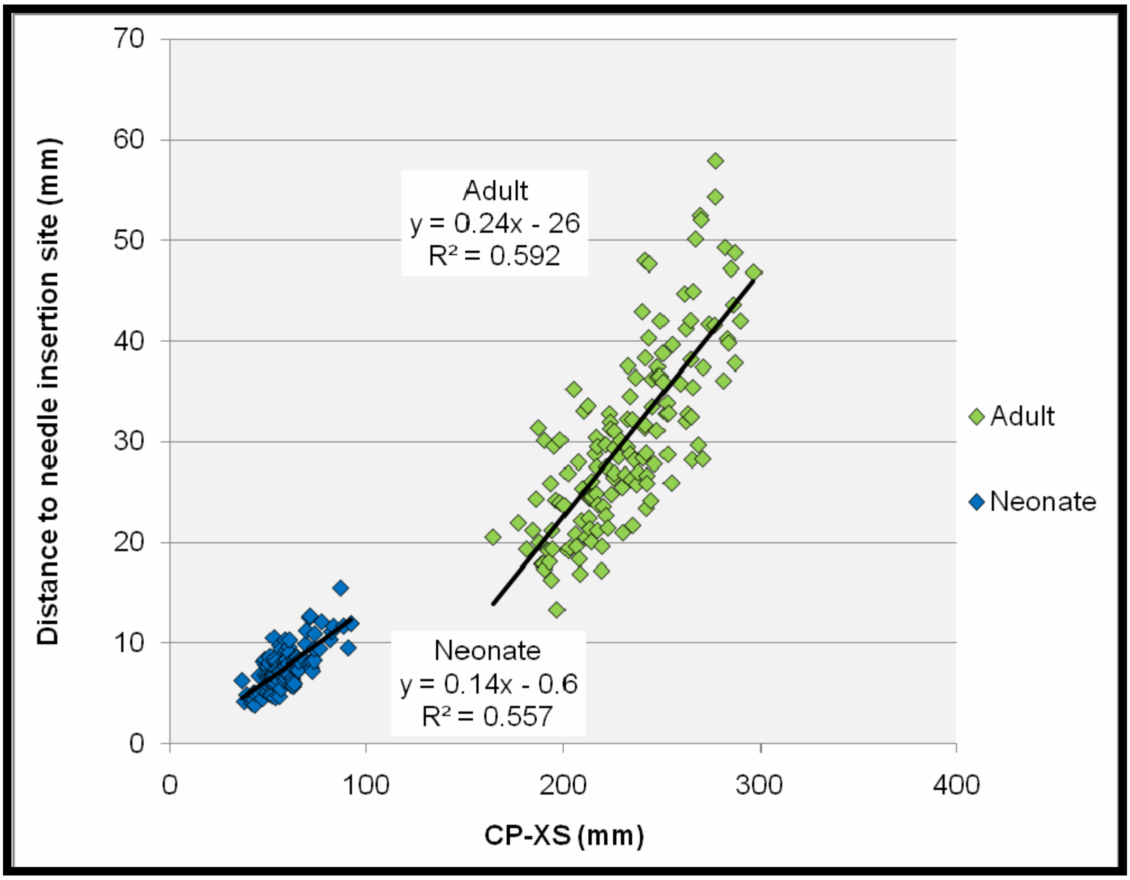

Figure 5.7: Linear regression formulae, for both the neonatal and adult samples.

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

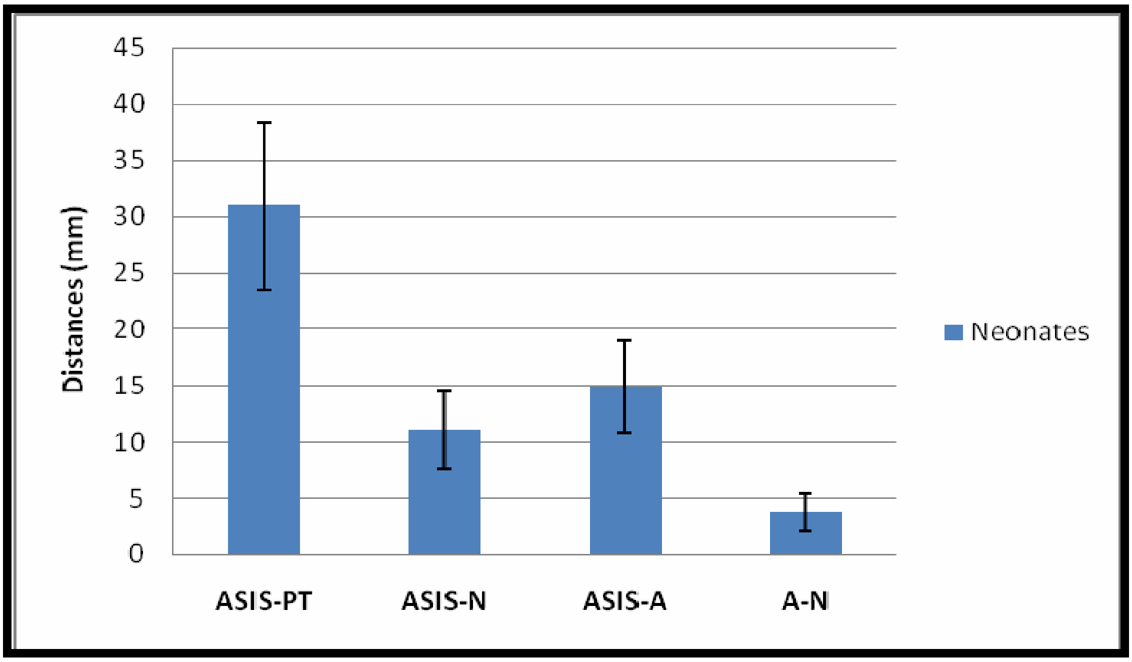

Figure 5.8: Measurements for total sample of neonatal cadavers.

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.

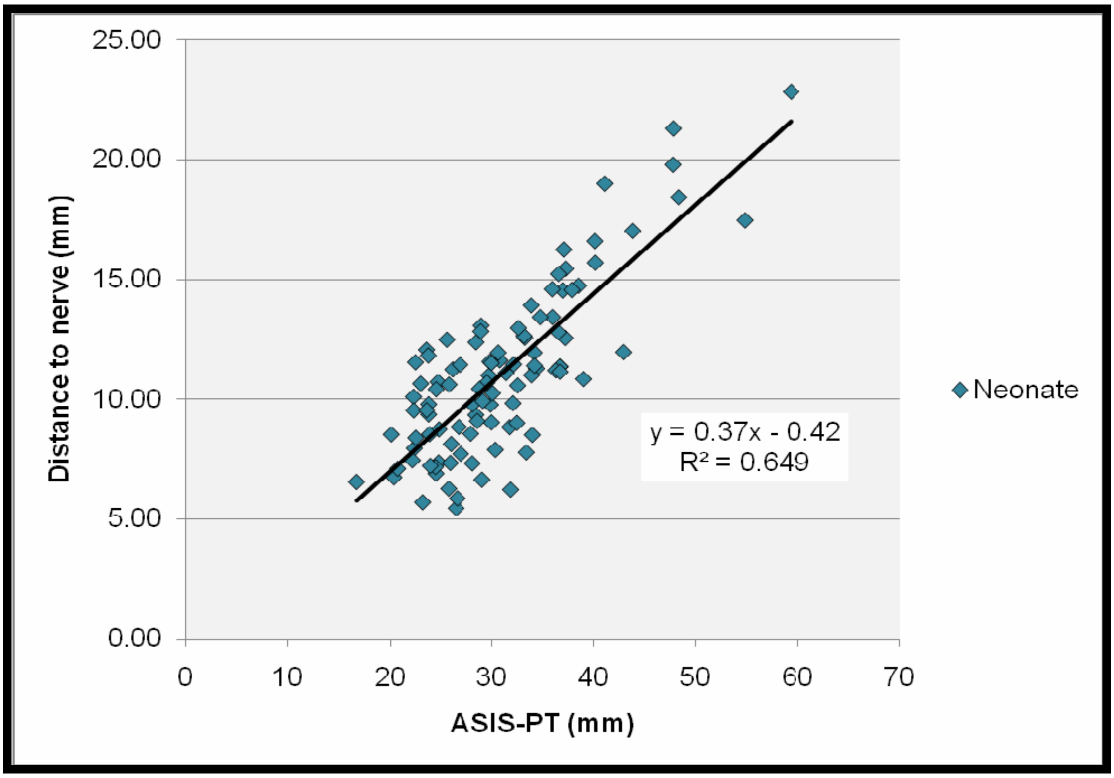

Figure 5.9: Linear regression formula for the distance of the neonatal femoral nerve from the ASIS.

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

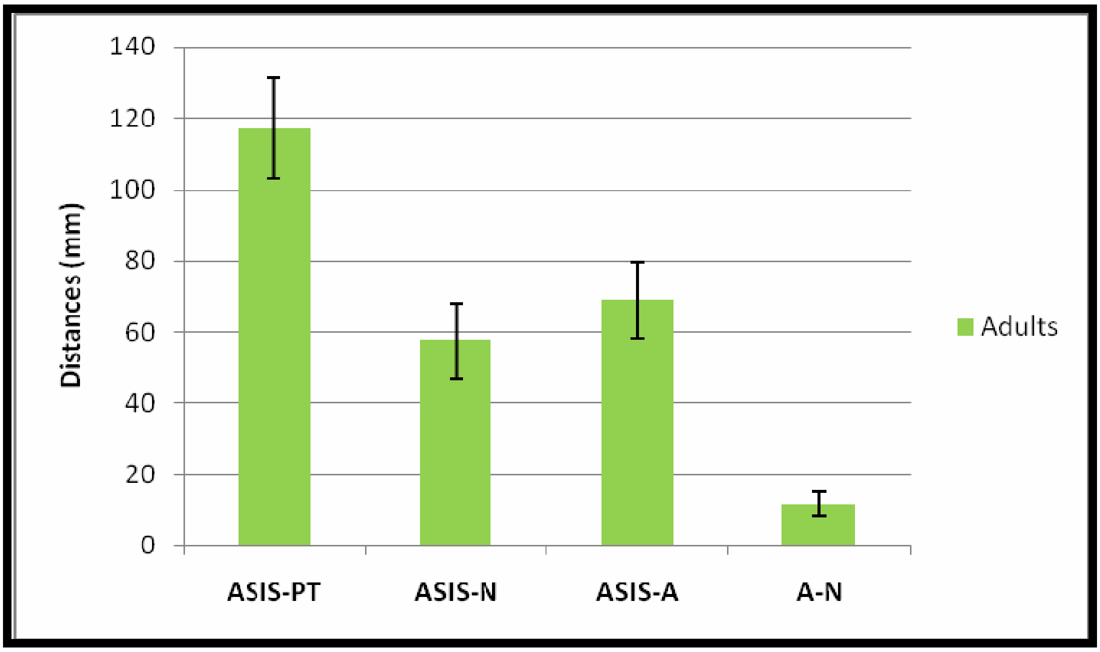

Figure 5.10: Measurements for total sample of adult cadavers.

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.

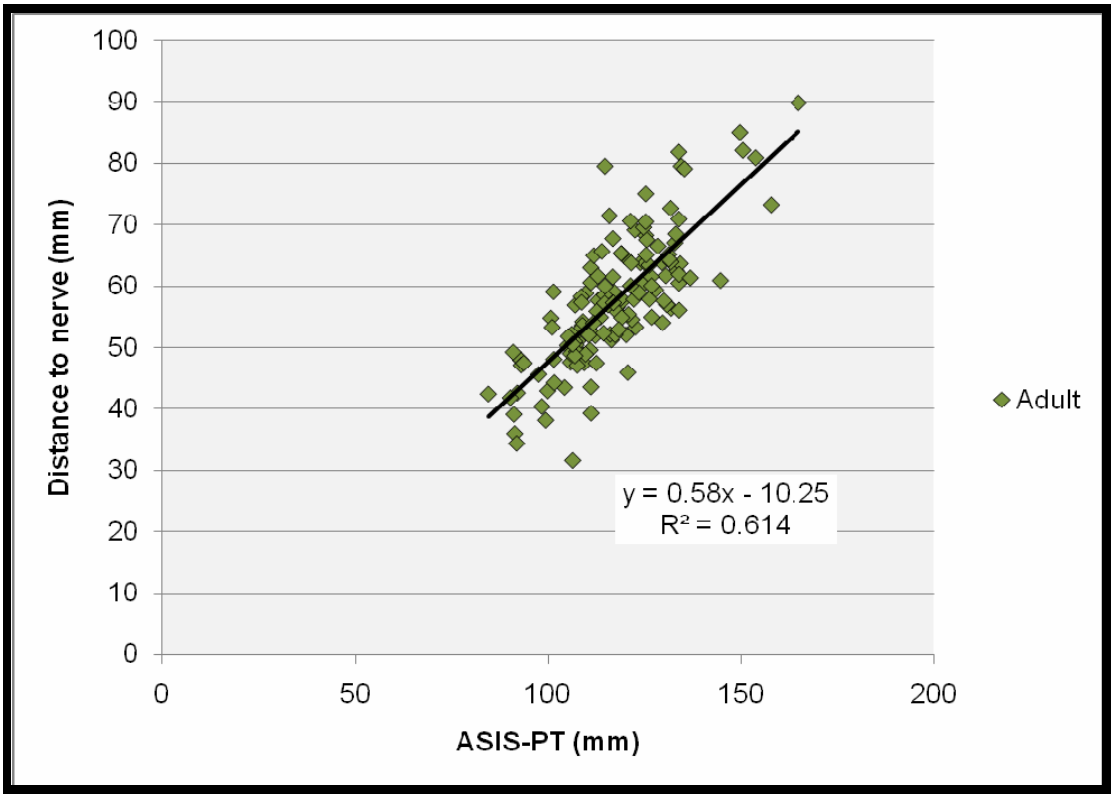

Figure 5.11: Linear regression formula for the distance of the adult femoral nerve from the ASIS.

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

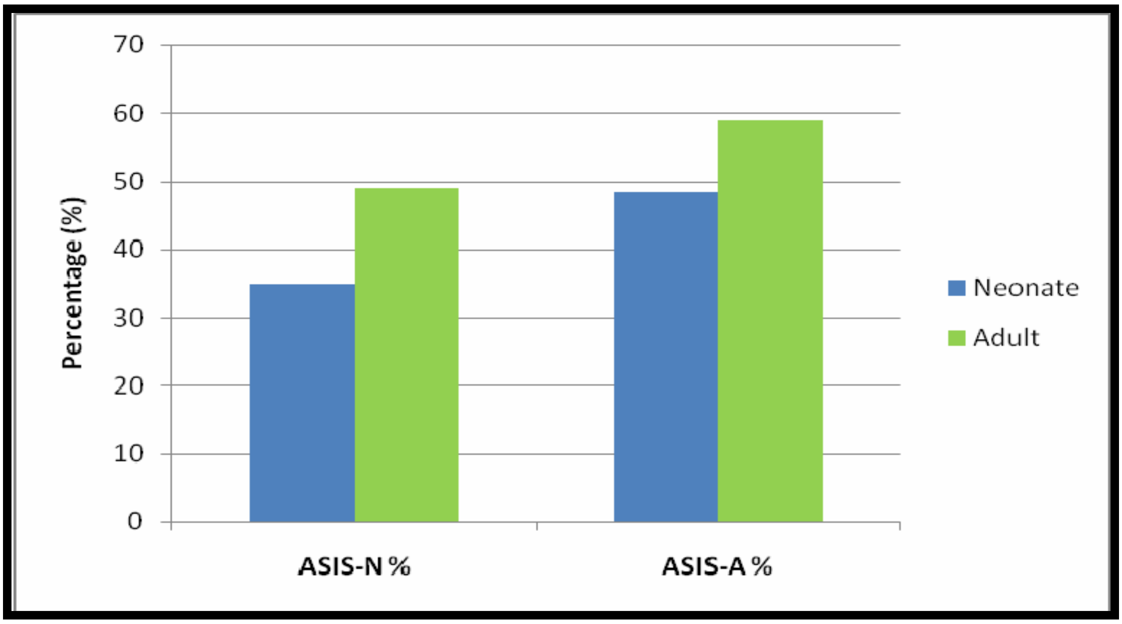

Figure 5.12: Comparison of distance of the femoral nerve (N) and femoral artery (A) from the ASIS.

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.

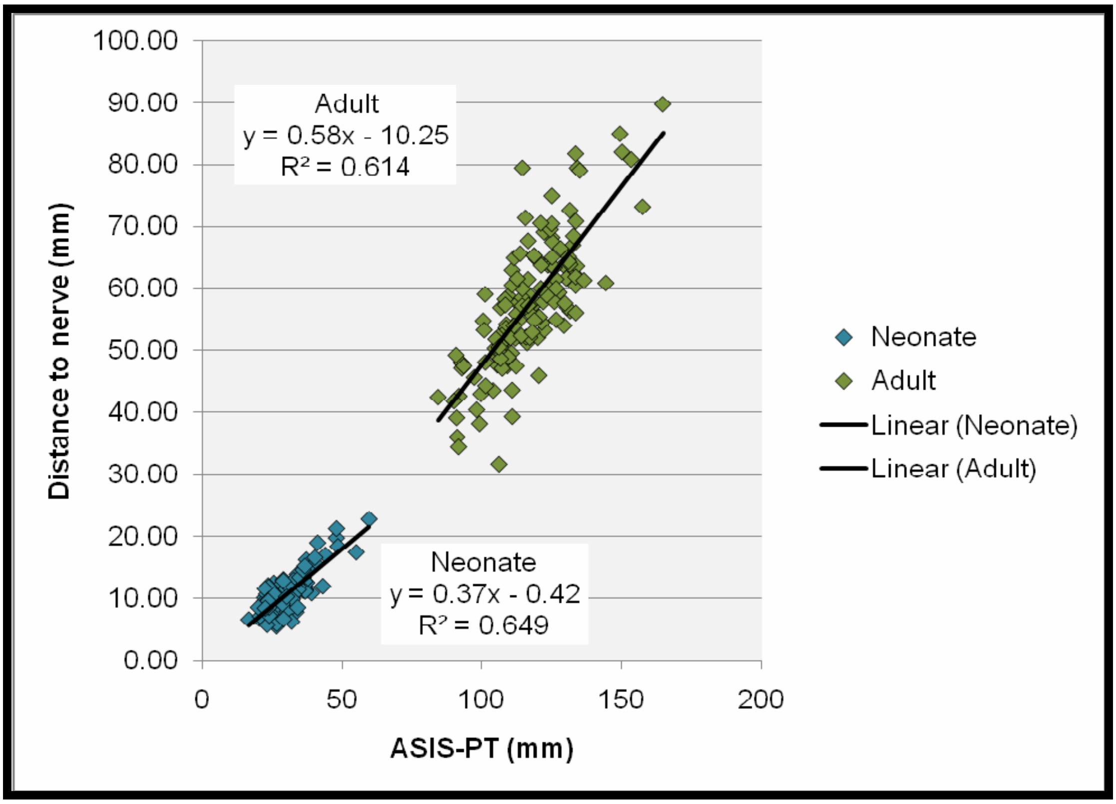

Figure 5.13: Linear regression formulae, for both the neonatal and adult sample.

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.

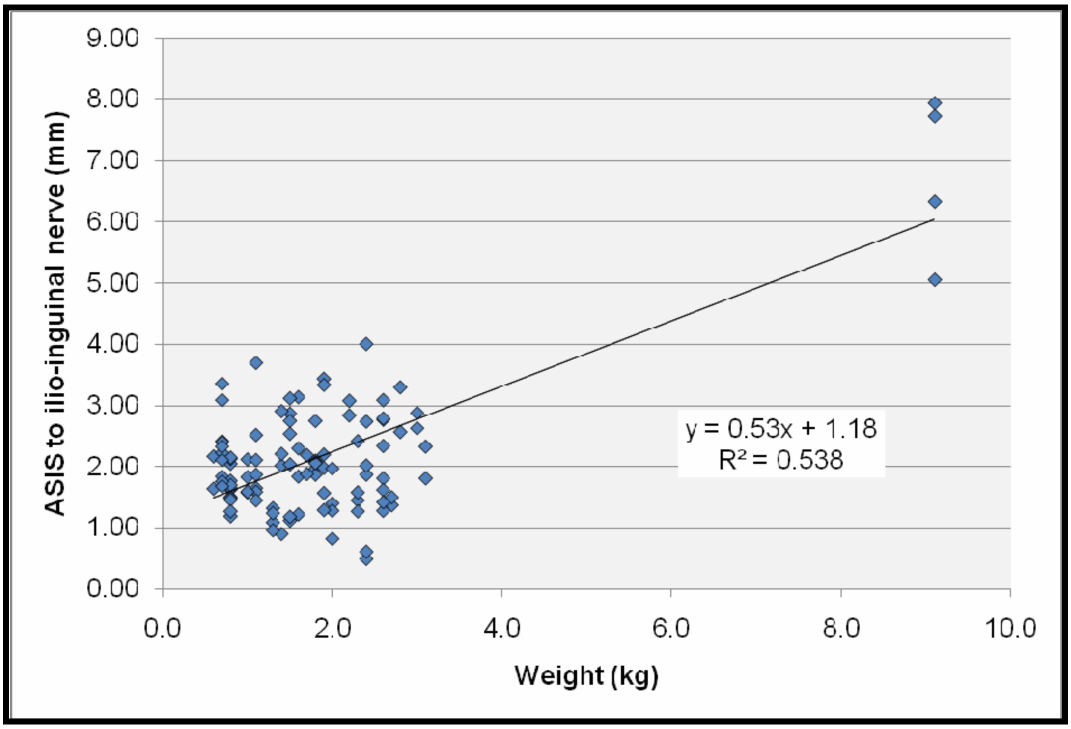

Figure 5.14: Linear regression formula for the distance of the ilio-inguinal nerve from the ASIS.

The weight of the sample is the independent variable.

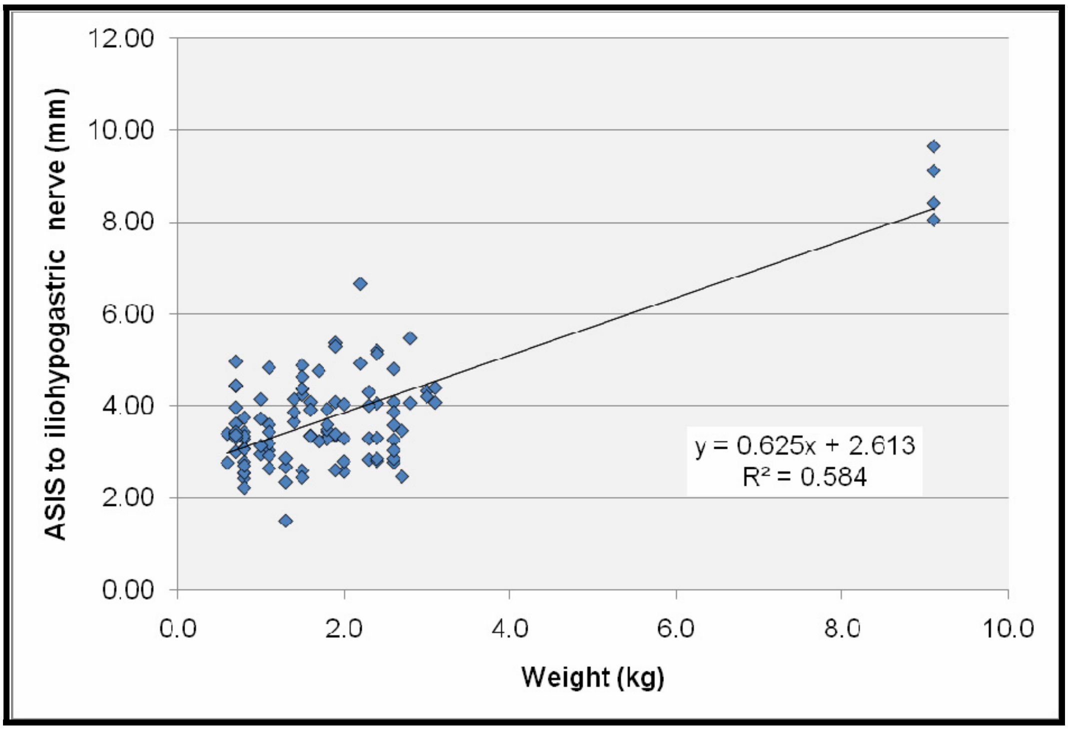

Figure 5.15: Linear regression formula for the distance of the iliohypogastric nerve from the ASIS.

The weight of the sample as the independent variable.

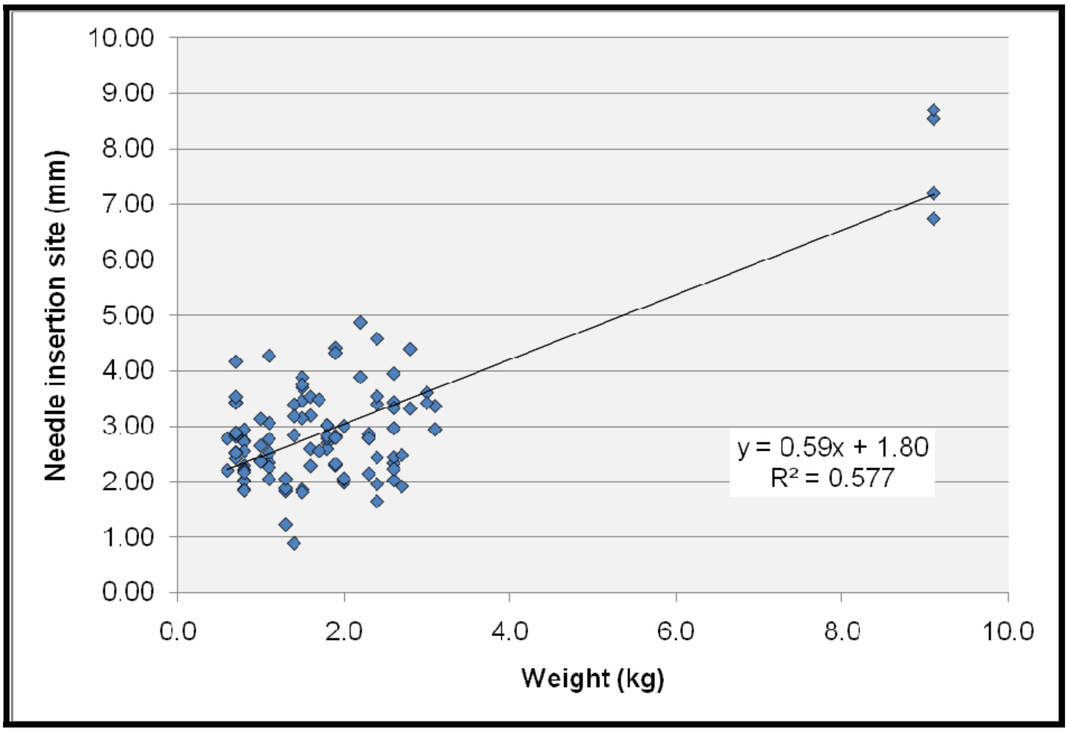

Figure 5.16: Linear regression formula for the distance of the point of needle insertion from the ASIS.

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).

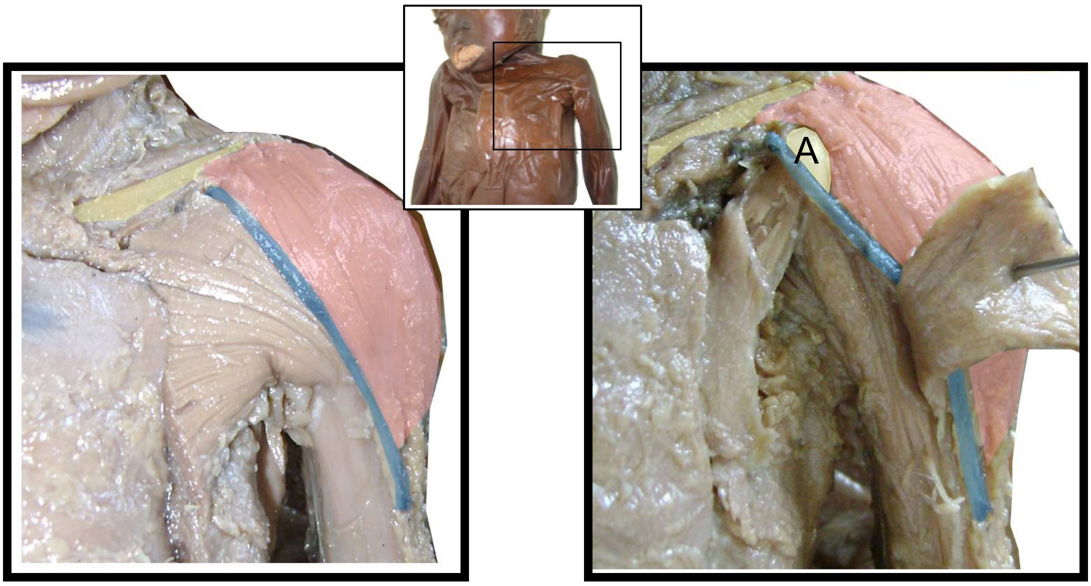

Figure 6.1: Dissection of the shoulder to expose the coracoid process.

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.

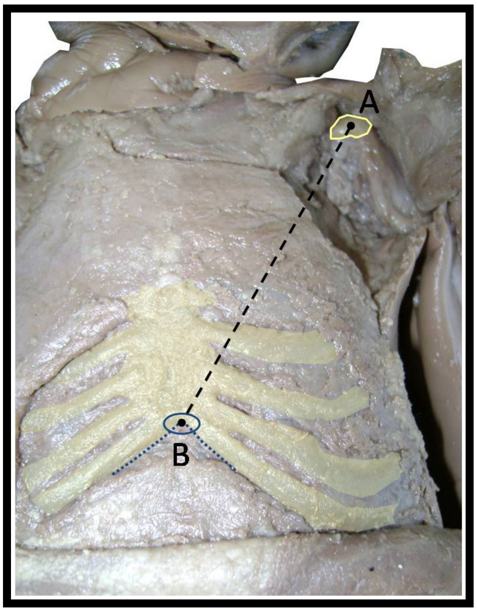

Figure 6.2: The coracoid process (A) and the xiphisternal joint (B) with the CP-XS line (dashed line) between them.

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).

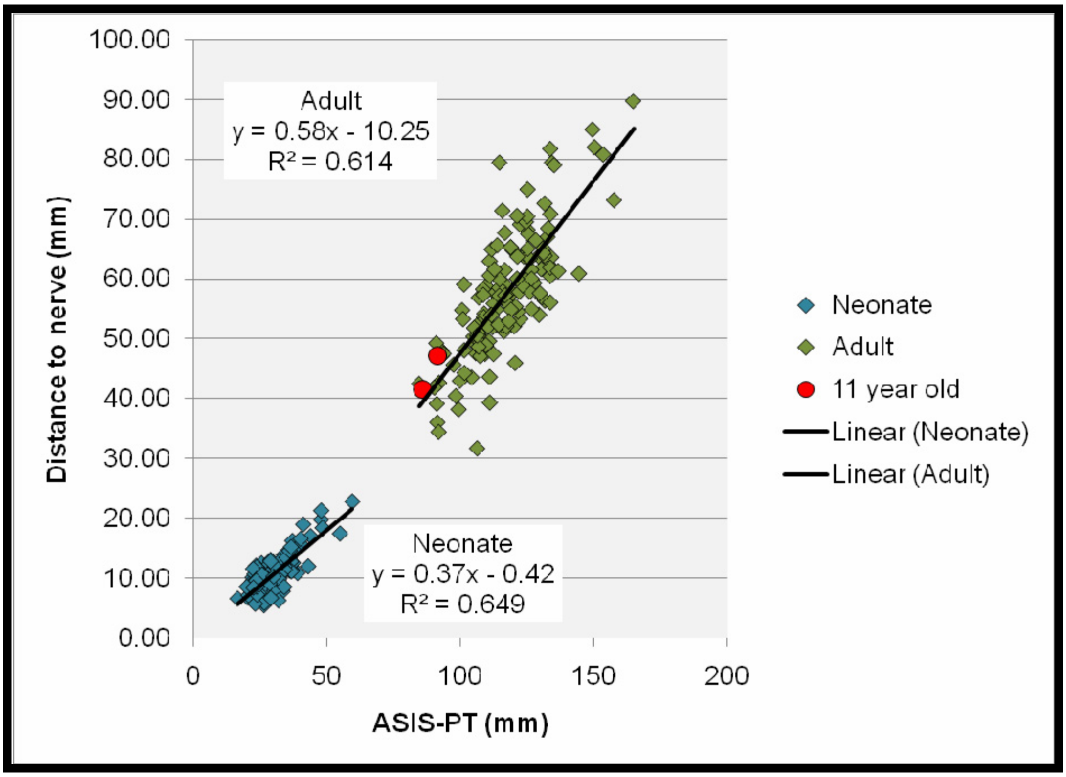

Figure 6.3: Linear regression formulae, for both the neonatal and adult samples

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.