

ORIGINAL COMMUNICATION

Anatomical Relationship and Positions of the Lumbar and Sacral Segments of the Spinal Cord According to the Vertebral Bodies and the Spinal Roots

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Segments of the spinal cord generally do not correspond to the respective vertebral level and there are many anatomical variations in terms of the segment and the level of vertebra. The aim of this study is to investigate the variations and levels of lumbar and sacral spinal cord segments with reference to the axilla of the T11, T12, and L1 spinal nerve roots and adjacent vertebrae. Morphometric measurements were made on 16 formalin fixed adult cadaveric spinal cords. We observed termination of the spinal cord between the axilla of the L1 and L2 spinal nerve roots in 15 specimens (93.8%). In all cadavers the emergence of the T11, T12, and the L1 spinal nerve roots was at the level of the lower one-third of the same vertebral body. In 15 specimens (93.8%), the beginning of the lumbar spinal cord segment was found to be above the T11 spinal nerve root axilla and corresponded to the upper one-third of the T11 vertebral body. The beginning of the sacral spinal cord segment occurred above the L1 spinal nerve root axilla and corresponded to the upper one-third of the L1 vertebral body. The results of this study showed that when the conus medullaris is located at the L1–L2 level, the beginning of the lumbar spinal cord segment always corresponds to the body of T11 vertebra. This study provides detailed information about the correspondence of the spinal cord segments with reference to the axilla of the spinal nerve roots. *Clin. Anat.* 27:227–233, 2014. © 2013 Wiley Periodicals, Inc.

Key words: lumbar segment; root; sacral segment; spinal cord; topographical anatomy

INTRODUCTION

Although the location of the spinal cord segments corresponds well with that of the vertebral segments in the fetus, this correspondence is lost after birth because the spinal cord does not extend the full length of the vertebral column (Augustine, 2008). Eventually, the lower spinal cord segments do not colocalize with their corresponding numbered vertebrae (Thomson, 1894; Govender et al., 1989; Vettivel, 1991).

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Thomson published the first cadaveric report studying the location of the adult conus medullaris in 1894 (Thomson, 1894). Numerous studies were then undertaken to determine the level at which the spinal cord ends relative to the corresponding level of the vertebra (Needles, 1935; Lang and Geisel, 1983; Holsheimer et al., 1994; Macdonald et al., 1999). According to the results of these studies, the adult spinal cord may terminate anywhere between the last thoracic and the third lumbar vertebra although the first and second lumbar vertebrae are most common (Demiryurek et al., 2002; Soleiman et al., 2005).

In the literature, there is no consensus on where the lumbar and sacral spinal cord regions begin (McCotter, 1916; Barson, 1970; Vettivel, 1991; Soleiman et al., 2005). There is a lack of information regarding the relationship between the lower thoracic and upper lumbar spinal nerve roots and the termination of the spinal cord.

To our knowledge, there is no such study concerning the spinal cord topographical anatomy relevant to the axilla of the spinal nerve roots.

The purpose of this study is to analyze the variations of the levels of lumbar and sacral spinal cord

segments of the surgically exposed area with reference to the axilla of the T11, T12, and L1 spinal nerve roots and adjacent vertebrae in order to define more precise landmarks for the lower spinal cord. This information should provide more details for surgical orientation of this region.

MATERIALS AND METHODS

The topographical anatomy of the spinal cord was examined on 16 formalin-fixed adult cadaveric spinal cords; of these, 5 (31.3%) cadavers were female, and 11 (68.7%) were male. The age at death ranged from 49 to 82 (mean 62.6 ± 9.7) years old. Spinal cords with any sign of traumatic or non-traumatic spinal pathology, or which belonged to patients with any neurological symptoms related to the spinal cord, spinal nerves, or severe vertebral deformities, were excluded from the study. In the supine position, vertebrectomies extending from C2 to S2 were performed by using an autopsy saw (Stryker Instruments, Kalamazoo, MI). Following vertebrectomies, the S1 spinal nerve roots were identified in situ and marked

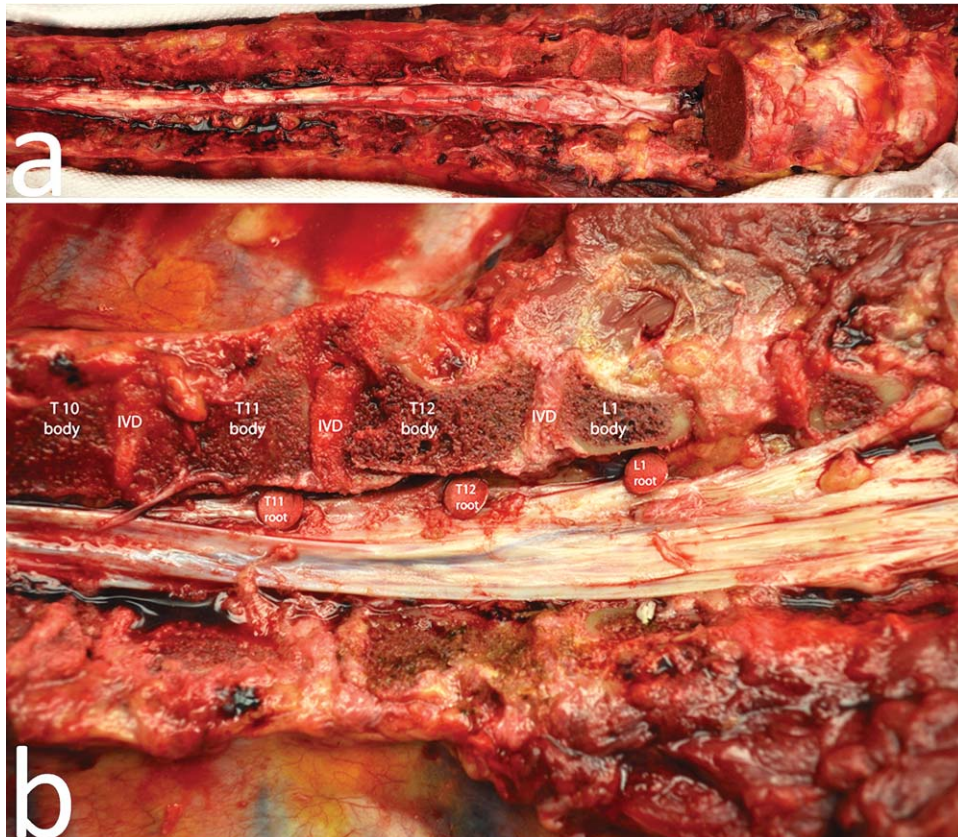


Fig. 1. Photomicrographs of the cadaveric dissections with low- (a) and high-magnification (b) demonstrate the topographic anatomy of the T11, T12, and L1 vertebrae in relation to the spinal nerve roots. After the vertebrectomies performed, T11, T12, and L1 spinal nerve roots were identified in situ (a), and marked with red spots for exact localization (b). Anterior views. IVD: Intervertebral disc.

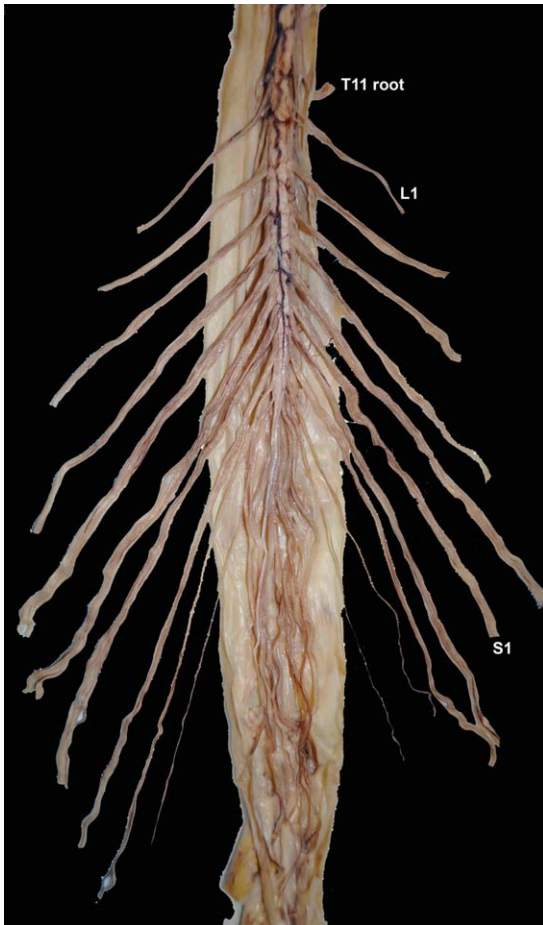


Fig. 2. Demonstration of the lumbar and sacral dorsal roots after opening the dura.

bilaterally with silk sutures. Subsequently, the T11, T12, and L1 roots were identified and their relationship with the adjacent vertebrae was photographed at a distance of 50 cm using a Nikon D5000 high-resolution digital camera (Nikon Co., Tokyo, Japan) (Fig. 1). The spinal cord with its dura was then removed from the fresh cadavers and fixed in formalin for one week. After fixation, the dura was opened along the posterior midline and the bilateral spinal nerve roots were exposed. All of the lumbosacral spinal nerve roots, the first coccygeal nerve root, and their origins from the dura were identified. Subsequently, the dorsal nerve roots were dissected up to their distal root entry zones (Fig. 2). The topographical anatomy was studied according to the axilla of the T11, T12, and L1 nerve roots where they emerge from the dura. Emergence points of these nerve roots were taken as landmarks. Additionally, axilla of the T11, T12, L1 spinal nerve roots and their relationships with the T11, T12, and L1 vertebral bodies were also noted. Each lumbar and sacral spinal cord segment was determined according to dorsal rootlets. In each specimen, the beginning of the lumbar and sacral spinal cord segments and the termination of the spinal cord according to the axilla

of the T11, T12, and L1 spinal nerve roots and adjacent vertebral level were measured (Fig. 3). Each lumbar and sacral spinal cord segment was measured based on the distance between the two consecutive most rostral rootlets. Microsurgical examination and measurements of the dorsal lumbosacral rootlets were performed under a surgical microscope (Leica Wild M 695, Leica Microsystems Inc., Wetzlar, Germany) at magnifications ranging between $\times 3$ and $\times 40$. Measurements were taken with Fisherbrand Traceable Digital Calipers (Fisher Scientific, Pittsburgh, PA). The mean and standard deviations of the measured parameters were calculated using SPSS for Windows, version 11.5 (IBM Corporation, Armonk, NY).

RESULTS

Our findings regarding the termination of the spinal cord, the distances between the axilla of the T11 spinal nerve roots and the beginning of the lumbar sections, the distances between the axilla of the L1 spinal nerve roots and the beginning of the sacral spinal cord segments, the length of the lumbar spinal cord segments, the length of the sacral spinal cord segments, the gaps between the L1 and L2 dorsal root entry zones and the existence of the coccygeal nerve roots are presented in Table 1. The relationships between the axilla of the T11, T12, and L1 spinal nerve roots and spinal cord segments are given in Table 2.

Termination of the Spinal Cord

In 15 cadavers (93.8%), the termination of the spinal cord was found to be between the axilla of the L1 and L2 spinal nerve roots. Only one specimen (6.3%) showed a different level of spinal cord termination, which was between the axilla of the T12 and L1 spinal nerve roots. The average distance between the termination of the spinal cord and the last rootlet of the sacral spinal segments was 5.5 ± 0.7 mm. The average thickness of the filum terminale at the beginning point was 1.9 ± 0.3 mm.

Relations Between the Axilla of the T11, T12, and L1 Spinal Nerve Roots, Vertebral Bodies and Spinal Cord Segments

In all of the specimens, the emergence of the T11, T12 and the L1 spinal nerve roots from the dura was at the level of lower one-third of the same vertebral body (Fig. 1). In the 15 cadavers (93.8%) in which spinal cords terminated between the axillas of the L1 and L2 spinal nerve roots, the L1 spinal cord segments always corresponded to the level of the axillas of the T11 spinal nerve roots. Of these 15 cadavers, the axillas of the T12 spinal nerve roots corresponded to the L3 segments of the spinal cords in 8 specimens (53.3%), to the L4 segments in 6 specimens (40%); and to the L5 segment in 1 specimen (6.7%) (Fig. 4). The axillas of the L1 spinal nerve roots corresponded to S1 segments of the spinal cords in five specimens

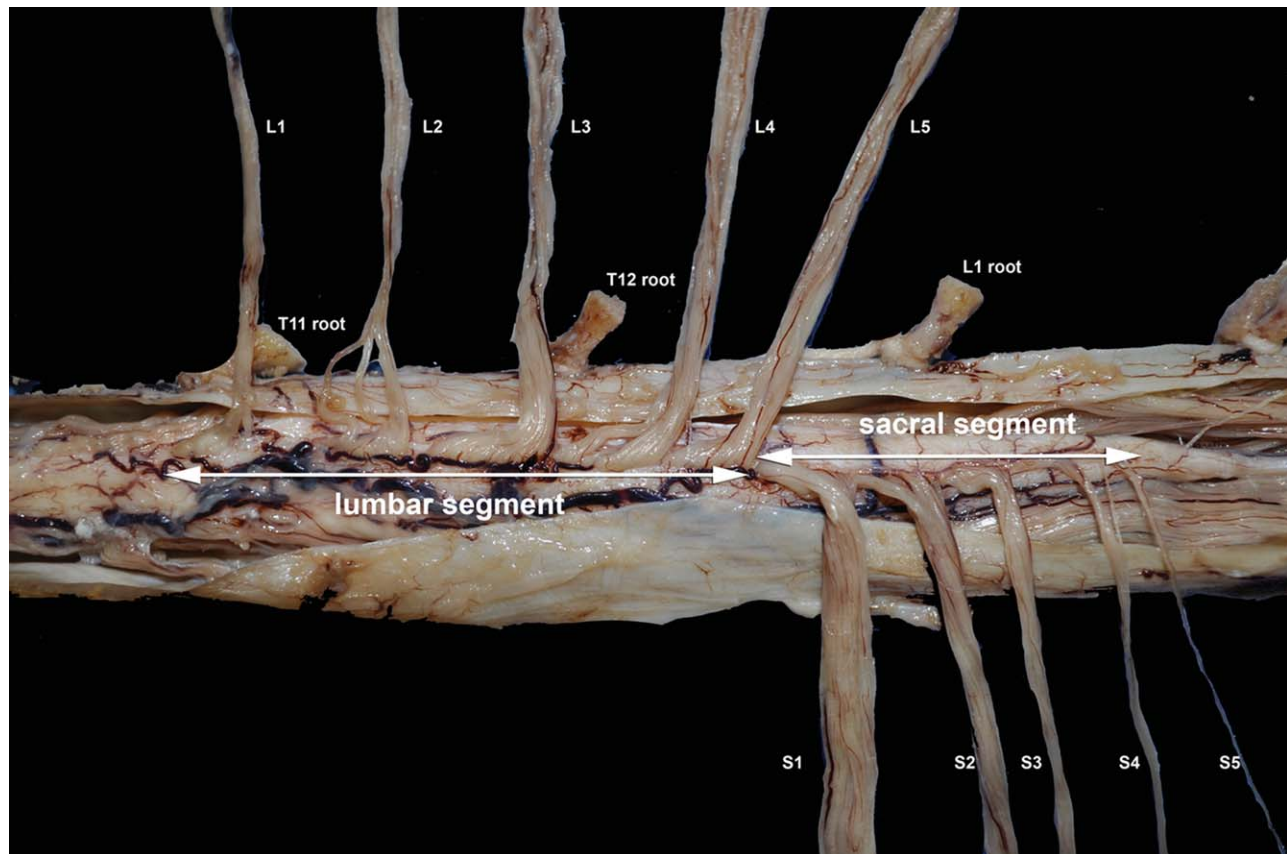


Fig. 3. The relationship between the lumbar and sacral spinal cord segments and axilla of the T11, T12, and L1 spinal nerve roots (topographic anatomy). The lengths of lumbar spinal cord segments and sacral spinal cord segments have been determined.

TABLE 1. General Measurements of the Specimens

Specimen no.	Termination of the spinal cord	BLS-T11a ^a	BSS-L1a ^b	Length of the lumbar segments (mm)	Length of the sacral segments (mm)	Gap between L1 and L2 DREZ (mm)	Existence of the coccygeal nerve root
1	L1-2	8.1	15.4	52	25.7	3	R-1
2	L1-2	10.9	19	45.6	26.1	3.1	Absent
3	L1-2	15.6	19.3	50.3	25.2	2.9	Absent
4	L1-2	10.5	10	56	27	3.1	Absent
5	L1-2	11	20	45.7	26.2	3.2	Absent
6	L1-2	6	5	55	19	3.3	R-1, L-1
7	L1-2	7	15	47.2	31	3	R-1, L-1
8	L1-2	7.9	15.2	50	25.5	2.9	R-1, L-1
9	L1-2	10	4	58.5	27.5	2.8	R-1, L-1
10	L1-2	12.2	27.8	59	31	3.1	L-1
11	L1-2	15.8	19.5	50.5	24.2	2.9	Absent
12	L1-2	4.6	4.5	61.8	32.9	3.4	Absent
13	L1-2	5.8	4.4	60.8	31.8	3.2	Absent
14	L1-2	9.8	3.9	58.3	27.2	3.1	R-1, L-1
15	L1-2	8	16	47.4	33	3.2	R-1, L-1
16	T12-L1	10.3 (Rostral to T10)	10.9 (Rostral to T12)	47.3	24.9	3.7	R-1, L-1

DREZ: Dorsal root entry zone

^aBLS-T11a: distance between the beginning of the lumbar spinal cord segment and the axilla of the T11 spinal nerve root (Rostral to T11, mm).

^bBSS-L1a: distance between the beginning of the sacral spinal cord segment and the axilla of the L1 spinal nerve root (Rostral to L1, mm)

TABLE 2. Relationship Between the Axilla of the T11, T12, and L1 Spinal Nerve Roots, and Spinal Cord Segments

Specimen no.	Segment corresponding to T11 root	Segment corresponding to T12 root	Segment corresponding to L1 root
1	L1	L3	S2
2	L1	L4	S3
3	L1	L4	S3
4	L1	L3	S2
5	L1	L4	S3
6	L1	L3	S1
7	L1	L4	S2
8	L1	L3	S2
9	L1	L3	S1
10	L1	L5	S5
11	L1	L4	S4
12	L1	L3	S1
13	L1	L3	S1
14	L1	L3	S1
15	L1	L4	S2
16	L3 (L1 seg = T10 root-axilla)	S2	Filum terminale

(33.3%); to S2 segments of the spinal cords in five specimens (33.3%); to S3 segments of the spinal cords in three specimens (20%); to the S4 segment of the spinal cord in one specimen (6.7%); and to the S5 segment of the spinal cord in one specimen (6.7%).

In the single specimen (6.3%), in which the spinal cord terminated between the axilla of the T12 and L1 spinal nerve roots, the axillas of the T11, T12, and the L1 spinal nerve roots corresponded to the L3, S2 segments of the spinal cord and the filum terminale, respectively (Table 2).

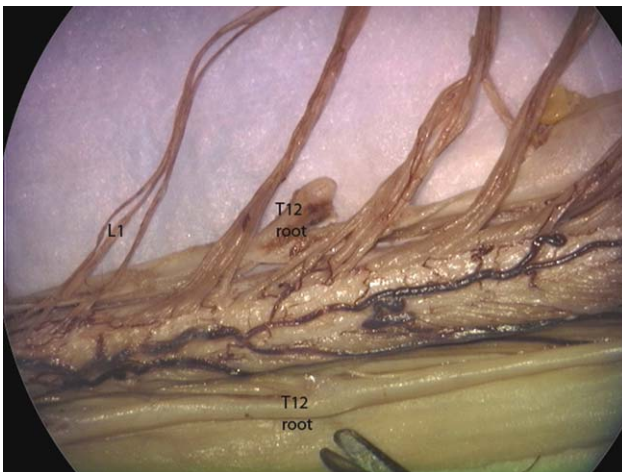


Fig. 4. Photomicrograph demonstrating the relationship between the axilla of the T12 spinal nerve roots and the spinal cord segments.

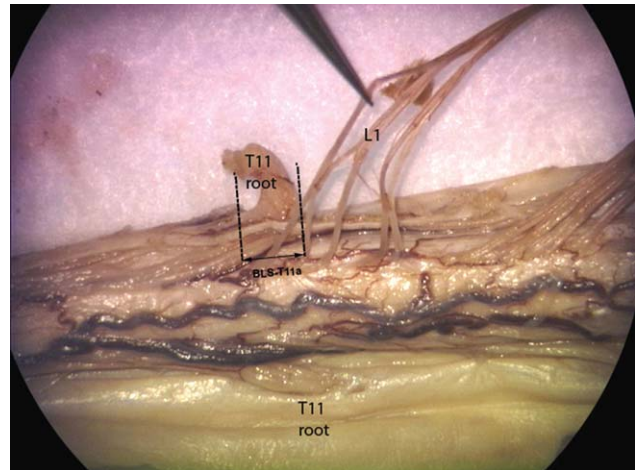


Fig. 5. Photomicrograph demonstrating the distance between the beginning of the lumbar spinal cord segment and the axilla of the T11 spinal nerve root. BLS-T11a: distance between the beginning of the lumbar spinal cord segment and the axilla of the T11 spinal nerve root.

Beginning and Ending of the Lumbar Spinal Cord Segments

In 15 cadavers (93.8%), the beginning of the lumbar spinal cord segments was above T11 spinal nerve root axillas, and corresponded to the upper one-third of the T11 vertebral body. The average value of the distances between the beginning of the lumbar spinal cord segments and the axillas of the T11 roots was 9.6 ± 3.3 mm (Fig. 5). In one specimen (6.3%), the beginning of the lumbar spinal cord segment was 10.3 mm above the T10 spinal nerve root axilla. For 15 of the cadavers (93.8%), the ending of the lumbar spinal cord segments were above L1 spinal nerve root axillas, and corresponded to the upper one-third of the L1 vertebral bodies. The average distance between the ending of the lumbar spinal cord segments and the axillas of the L1 roots was 13.3 ± 7.5 mm. In one specimen (6.3%), the ending of the lumbar spinal cord segment was 10.9 mm above the T12 spinal nerve root axilla.

Beginning and Ending of Sacral Spinal Cord Segments

In 15 of the 16 cadavers (93.8%), the beginning of the sacral spinal cord segments was above the axillas of the L1 spinal nerve roots, and corresponded to the upper one-third of the L1 vertebral body. The average value of the distances between the beginning of the sacral spinal cord segments and the axillas of the L1 roots was 13.3 ± 7.5 mm. In one specimen (6.3%), the beginning of the sacral spinal cord segment was 10.9 mm above the axilla of the T12 spinal nerve root. In 15 cadavers (93.8%) the ending of the sacral

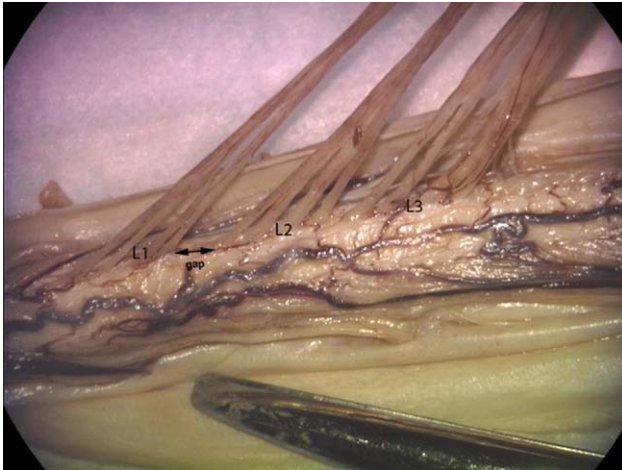


Fig. 6. Photomicrograph demonstrating the gap between the L1 and L2 dorsal root entry zones.

spinal cord segments was below the axillas of the L1 spinal nerve roots. The average distance between the ending of the sacral spinal cord segments and the axillas of the L1 spinal nerve roots was 15.5 ± 7.5 mm, corresponding to the L1–2 intervertebral disc spaces. In one specimen (6.3%), the ending of the sacral spinal cord segment was 12.2 mm below the axilla of the T12 spinal nerve root.

Length of Lumbar and Sacral Spinal Cord Segments

The average value of the length of the lumbar spinal cord segments was 52.8 ± 5.6 mm and the average length of the sacral spinal cord segments was 27.7 ± 3.1 mm. The average gap distance between L1 and L2 root entry zones was 3.1 ± 0.2 mm (Fig. 6).

Existence of the Coccygeal Nerve Root

In seven cadavers (43.8%), Co1 nerve roots were observed bilaterally. In another seven cadavers (43.8%), there were no Co1 roots observed. Additionally, in two of the specimens (12.5%), unilateral Co1 roots were observed; one specimen displayed a Co1 root on the left side, while the other possessed a Co1 root on the right side of the spinal cord.

DISCUSSION

The segments of the spinal cord do not correspond to their respective vertebra level (Icten et al., 1995; Demiryurek et al., 2002) and there is considerable variation in this relationship (Gatonga et al., 2010). Multiple studies have demonstrated that the spinal cord almost always terminates within the lower third of the L1, or upper third of the L2 vertebrae (Boonpirak and Apinhasmit, 1994; Saifuddin et al., 1998). Description of more constant landmarks such as the

axilla of the lower thoracic and upper lumbar spinal nerve roots is needed. Additionally, the relationship between the spinal nerve roots and their corresponding spinal cord segments should provide a conception about the likelihood clinical presentation of the lesions in this region. These measurements will help surgeon to acquaint with the lumbar and sacral spinal cord segments without opening the dura with the guidance of the emergence of the last two thoracic and the first lumbar spinal nerve roots.

In the present study, the spinal cords terminated between the lower third of the L1 and upper third of the L2 vertebral bodies. These observations are entirely in agreement with the previously reported cadaveric studies. Our study describing the position of the spinal cord segments relative to the spinal nerve roots provides supplementary information to previous studies. Our observations revealed that, when the spinal cord terminates between L1 and L2 spinal nerve roots, which occurred in 15 of our 16 specimens (93.8%), lumbar spinal cord segments always start rostral to the axilla of the T11 spinal nerve root, corresponding to the upper one-third of the T11 vertebra in the transverse plane. Although beginning of the lumbar spinal cord has been described anywhere between the T9 and T10 vertebrae in conventional textbooks (Hollinshead, 1982; Newell, 2008), no previous study has demonstrated the exact beginning of the lumbar spinal cord. Our study demonstrated that, in 15 of 16 specimens (93.8%), the beginning of the lumbar spinal cord segment was at the level of T11 vertebra. If the conus medullaris terminates one level above of L1 or below of L2, the beginning of the lumbar spinal cord segment is consisted with this displacement. In one specimen (6.3%), the termination of the conus medullaris was observed between the T12 and L1 spinal nerve roots; thus, the beginning of the lumbar spinal cord segment corresponded to 10.3 mm above the axilla of the T10 spinal nerve root. The axilla of the T12 spinal nerve root usually corresponded to the L3 and L4 segments of the spinal cord and the axilla of the L1 spinal nerve root usually corresponded to the S1 and S2 segments of the spinal cord.

The gap distance between the dorsal root entry zones of the spinal nerve roots is constant up to L2 spinal nerve root. In our study, the average gap distance between L1 and L2 root entry zones was 3.1 ± 0.2 mm. After this level the gap disappears, and the subsequent root entry zones of the nerve roots emerge tightly. This observation can also be beneficial to determine the level intraoperatively.

CONCLUSION

If the conus medullaris is located at the L1–L2 level, the beginning of the lumbar spinal cord segment always corresponds to the body of T11 vertebra. This study also provides detailed information about the correspondence of the spinal cord segments with reference to the axillas of the spinal nerve roots, which will guide the surgeon in navigating the surgically exposed area.

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