A new anatomic zone division within the cervical spinal canal

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Abstract

Background: Detailed anatomical information is important for identifying the origin and anatomic basis of symptoms in cervical spondylosis patients, but very little quantitative data have been reported. This study characterized the morphologic features of cervical spinal nerve rootlets and defined different zones at cervical spinal canal to provide an anatomic basis for studying cervical spondylosis. Methods: Ten cervical spines from C2 to T1 were obtained for the present study. We defined three zones from midline to lateral part (zone I, II and III) and two zones from cranial to caudal (zone P and zone IP) on the coronal plane within the cervical spinal canal. Quantitative anatomy of the zones at different cervical segments were measured including: 1) horizontal widths of zone I, II and III; 2) Length of the cervical spinal cord segment at the ventral rootlets (LV); 3) The pedicle height (PH, zone P) and the inter-pedicle height (IPH, zone IP); 4) The distance between the superior margin of pedicle and the exit of the uppermost ventral nerve rootlet (PN). Results: There was a trend that the horizontal widths of zone I gradually decrease from C4 to C8 but without significant differences (P=0.98). The value of zone II at C4 was significantly less than that at other levels (P=0.008). The value of zone III increases from C4 to C8, and the values at C7 and C8 were significantly higher than those at C4, C5 and C6 (P=0.032). PHs and IPHs were not significantly different between different levels (P1=0.365; P2=0.240). The values of LV at C4 and C8 were smaller than those of C5, C6 and C7 (P=0.001). The value of PN showed an increasing trend. At C4, the uppermost ventral rootlet was at about the same height as C3 pedicle, while C8 uppermost ventral rootlet was at the same level as the inferior part of C6 pedicle. Ventral intradural intersegmental connections were found in three intersegments (two specimens) out of 20 intersegments (15%). Conclusions: The current definition of anatomic zones may be useful for an accurate diagnosis of cervical spondylosis and a safe and effective anterior decompression surgery.

Background

Cervical spondylosis is often caused by degenerative disc disease which may lead to neck pain, radiculopathy, and myelopathy [1-3]. Theoretically, cervical radiculopathy is due to compression of the nerve roots, whereas cervical myelopathy is resulted from compression of the spinal cord. Radiculopathy and myelopathy patients often have distinct syndromes [4], and hence the pathogenesis diagnosis can be relative easily achieved. Comparatively, it is more challenging to correctly diagnose myeloradiculopathy, as patients may show complicate syndromes, including signs of nerve root dysfunction in the upper limbs and symptoms of long tract compression affecting the lower limbs.

The pathogenic mechanisms of myeloradiculopathy remain unclear, and it has been difficult to ascertain whether the dysfunctions are due to compression of the nerve root and/or the spinal cord [5]. In particular, patients with cervical radiculopathy may have various symptoms without clear nerve root location. Anatomic differences in brachial plexus may partially underlie the large variation of clinical symptoms of cervical radiculopathy patients [6]. Since adjacent dorsal rootlets may have intradural intersegmental connections, compression of one dorsal rootlet can lead to impairments at adjacent rootlets leading to more symptoms. A previous study showed an increased obliquity of nerve roots, especially in the lower cervical region, when these roots pass downward before reaching intervertebral foramina [8]. Accordingly, it has been difficult to ascertain whether the nerve roots are compressed above or at the corresponding disc level in imaging study.

Detailed anatomical information of the cervical spinal cord and nerve roots is important for identifying the origin and anatomic basis of symptoms in cervical spondylosis patients, which is essential to use surgical intervention to decompress the affected neural structures and avoid complications. By dissecting cervical spinal cord of adult cadavers, we characterized the morphologic features of cervical spinal nerve rootlets and defined different zones at cervical spinal canal. Current findings provide an anatomic basis for future study to differentiate subtypes of cervical spondylosis and examine the underlying mechanisms.

Methods

Cervical spines were harvested from 10 formalin-fixed adult cadavers (6 males, 4 females, aged 67 ± 12.1 years) without cervical metastasis or gross deformities as scoliosis or kyphosis. These cadavers were obtained from the Department of Human Anatomy, Capital Medical University, China. The research protocol for this study was approved by Institutional Review Board at LuHe Hospital, Capital Medical University.

Cadaveric dissections

The cervical spines were fixed in supine position. Soft tissues superficial to vertebrae were removed. The vertebral bodies and the anterior tubercle of transverse process from C3 to C7 were resected completely. The posterior longitudinal ligament from the anterior dura was then resected with caution. The dura and arachnoid membrane were excised carefully from C4 to C8 without damaging the spinal cord and ventral nerve rootlets. The anterior part of nerve root sleeves was also resected to provide a unobstructed observation of the ventral nerve rootlets (Figure 1).

Anatomic zones in the coronal plane

In the coronal plane, the anterior surface of spinal canal was divided into three zones from midline to lateral part: zone I (medial zone), zone II (paramedian zone), and zone III (lateral zone) (Figure 2). Zone I represents the area between bilateral origins of ventral nerve rootlet. Zone II contains the area between the origin of ventral nerve rootlets and lateral border of spinal cord. Zone III represents the area between lateral border of spinal cord and medial margin of the pedicle. Two

zones were defined from cranial to caudal: pedicle zone (zone P) and interpedicle zone (zone IP). Zone P defines the area between the upper and lower margins of the corresponding pedicle, which contains the major part of corresponding spinal cord segment and ventral nerve rootlets. Zone IP includes the area between the lower margin of the upper pedicle and the upper margin of the lower pedicle, which contains the caudal part of corresponding spinal cord segment and ventral nerve rootlets as well as the cranial part of inferior segmental spinal cord and the ventral nerve rootlets (Figure 2).

Parameters

The measurements of the anatomic structures from C4 to C8 include: 1) Horizontal widths of zone I, II and III (Figure 2); 2) Length of the cervical spinal cord segment at the ventral rootlets (LV, Figure 2); 3) The pedicle height (PH, zone P) and the interpedicle height (IPH, Figure 2, zone IP); 4) The distance between the superior margin of pedicle and the exit of the uppermost ventral nerve rootlet (PN, Figure 2). All measurements were performed bilaterally and the mean values were reported. The widths of zone I, II, and III were measured at three different levels (uppermost, middle, lowermost) and the mean values were used for comparison. The linear measurements were obtained using a digital caliper. All parameters were measured twice by two researchers.

Statistical analysis

The differences between parameters measured at different levels were compared by one-way analysis of variance (ANOVA) with LSD (least significant difference) post-hoc test. All statistical analyses were conducted with using SPSS 21.0. Data are presented as mean ± standard deviation (SD), and the statistical significance was viewed as $P<0.05$.

Results

Horizontal widths of zone I, II and III

There was a trend that the horizontal widths of zone I gradually decrease from C4 to C8 (Table 1). However, the horizontal widths of zone I were not significantly different between different levels ($F=2.157$, $P=0.98$). The value of zone II at C4 was significantly less than that at other levels ($F=4.228$, $P=0.008$). The value of zone III increases from C4 to C8, and the values at C7 and C8 were significantly higher than those at C4, C5 and C6 ($F=3.050$, $P=0.032$). The example of zone division and the contained neural structures were illustrated in Figure 3. After removing the vertebral body and intervertebral disc, compressions at zone I and zone II were identified in two samples (Figure 4).

Table 1. The horizontal widths of zone I, II and III from C4 to C8 (mm)

	C4	C5	C6	C7	C8
zone I	6.11±0.63	5.58±0.49	5.69±0.59	5.45±0.62	5.11±0.62
zone II	2.35±0.61**	3.34±0.56	3.56±0.68	3.73±0.61	3.51±0.69
zone III	4.22±0.57	4.49±0.68	4.98±0.68	5.01±0.82*	5.21±0.76*

Note: Zone I: There was no significant difference in horizontal width between different levels. Zone II: * * p<0.01 versus C 5,6,7,8. Zone III: * p<0.05 versus C 4, 5,6.

Longitudinal heights of zone P and zone IP

The pedicle height (PH) and the interpedicle height (IPH) were measured to represent the longitudinal heights of zone P and zone IP (Table 2). PHs and IPHs were not significantly different between different levels (F1=1.121, P1=0.365; F2=1.458, P2=0.240).

Table 2. The pedicle height (PH) and the interpedicle height (IPH) from C3 to C7 (mm)

	C3(C3/4)	C4(C4/5)	C5(C5/6)	C6(C6/7)	C7(C7/T1)
PH	7.9±0.88	8.52±1.1	8.18±1.26	8.53±1.29	9.12±1.16
IPH	8.15±1.09	8.29±0.94	7.85±1.88	7.23±0.46	7.17±0.77

Note: C3(C3/4) means PH of C3 and IPH of C3/4. PH, pedicle height; IPH, interpedicle height.

Longitudinal length of the cervical spinal cord segment at ventral rootlets

The mean value of LV from C4 to C8 was 10.92±1.95, 14.64±2.33, 13.27±1.33, 12.30±1.48, and 10.28±2.09 mm respectively. The values of LV at C4 and C8 were smaller than those of C5, C6 and C7 (F=6.177, P=0.001).

Anatomic relation between the segmental ventral rootlets and pedicle

The distance between the superior margin of pedicle and the uppermost ventral rootlet (PN) was measured to reflect the relative position of segmental ventral rootlets and pedicle. From C3 to C7 pedicle level, the value of PN was 0.33±0.87, 3.86±2.23, 4.11±2.36, 3.94±2.18, and 5.19±2.09 mm 7 (F=5.809, P=0.001). At C4, the uppermost ventral rootlet was at about the same height as C3 pedicle, while C8 uppermost ventral rootlet was at the same level as the inferior part of C6 pedicle, which explains why some patients with compression at C6/7 have symptoms of C8.

Ventral intradural intersegmental connections

Ventral intradural intersegmental connections were found in three intersegments (two specimens) out of 20 intersegments (15%). One specimen had bilateral connections while the other had unilateral connections (Figure 5). Both connections were found in C5/6 segment between C5 and C6 ventral rootlets.

Discussion

Cervical spondylosis encompasses different symptoms including both motor and sensory abnormalities as radiculopathy, myelopathy and myeloradiculopathy. However, the radiological findings in many patients do not match well with their symptoms [5]. A better understanding of the anatomic basis of cervical spondylosis may help to find the reasons for this mismatch. Veleanu et al. [9] initially divided the nerve groove into two portions: radicular portion and portion of the anterior ramus of the transverse process, but did not provide quantitative data. Ebraheim et al. [10] described the cervical nerve groove according to the different anatomic features along its length, and divided the nerve groove into three zones: medial (pedicle), middle (vertebral artery), and lateral. The medial zone was suggested to play an important role in the etiology of cervical spondylotic radiculopathy [8]. However, this zone division was focused on the cervical nerve groove, but did not include the spinal cord and ventral nerve rootlets within the spinal canal.

To better understand the etiology of cervical spondylosis which is important to accurate diagnosis for decompression site, we defined three zones from midline to lateral part and two zones from cranial to caudal on the coronal plane. The three zones from midline to lateral part were: zone I (medial zone), zone II (paramedian zone), and zone III (lateral zone). The coronal widths of zone I were not significantly different between C4-C8 levels. Since zone I contains only spinal cord and anterior spinal artery, localized compression in zone I may cause myelopathy without radiculopathy. Zone II contains cervical ventral nerve rootlet origin and lateral border of spinal cord. Compression in zone II may cause both myelopathy and radiculopathy. Ebraheim et al. [10] illustrated the importance of nerve root groove, but not preforaminal area, in the etiology of cervical spondylotic radiculopathy. Osteophytes of the posterolateral corner of the vertebral body, uncinated process, facet joints and lateral intervertebral disc herniation are often observed in zone III [11]. In the preforaminal area, compression in zone III can be missed by clinical examination, leading to misdiagnosis and inadequate decompression.

Cervical spondylotic amyotrophy (CSA) is characterized by weakness and wasting of upper limb muscles without sensory or lower limb involvement [12-14]. The underlying mechanisms of CSA may involve damages to the ventral nerve rootlets, and vascular insufficiency to the anterior horn cells. The definition of different zones is important for the diagnosis of CSA. Compression of zone I may cause anterior spinal artery impingement leading to dysfunction of anterior horn cells, which may partially explain why a moderate compression of the central canal sometimes led to CSA [13]. The compression at zone II will impair the ventral nerve rootlets and anterior horn of spinal cord, which may cause motion dysfunction without sensation loss (Figure 6). The compression at zone III defined in current study may only impair the ventral nerve rootlets. Since zone III at C6/7 contains ventral nerve rootlets of C7 and C8, compression in this region may cause CSA at both levels (Figure 3). Thus, the definition of zone division is particularly important to correct diagnosis of CSA and decompression of the ventral nerve rootlets. Early surgery is recommended to CSA patients who have failed conservative treatments. The zone definition established in current study may help the diagnosis of CSA for early surgical intervention.

To our knowledge, no study had examined the relative position of segmental ventral rootlet and pedicle. Here, we defined two zones in the coronal plane from cranial to caudal: pedicle zone (zone P) and interpedicle zone (zone IP). At C3 pedicle level, the segmental spinal cord and ventral nerve rootlets of C4 was at zone P. From C3 to C7, the position of segmental ventral rootlet and spinal cord become more rostral to the corresponding pedicle. For example, the segmental spinal cord and ventral nerve rootlets of C8 was near to the inferior part of C6 pedicle. This finding may help to explain why patients with disc herniation at C6/7 could have symptoms resulted from C8 nerve root compression. A previous study suggested that C8 nerve root does not have contact with C7–T1 disc, and hence the chance of a direct C8 nerve root compression by C7-T1 disc is very small [8]. However, current findings suggest that the chance of compression of C8 ventral nerve rootlets by C6/7 disc is rather large. Furthermore, compressions of zone I and zone II at C6/7 may also cause dysfunctions of C8 spinal cord and ventral nerve rootlets. While compression at zone III may lead to radiculopathy of both C7 and C8 ventral nerve rootlets.

Anatomical studies have been conducted to evaluate the width of the spinal segment [15-17]. Shinomiya et al. [17] investigated the width of the spinal segment from C5 to C8 using cadavers and reported that the width at C6 was the widest, while that at C8 was the narrowest. Kobayashi et al. [18] also confirmed that C8 was the narrowest and this characteristic continued to the entry of the root in the foramen. Karatas et al. [16] measured the widths from C2 to C8, and found that the longest longitudinal length was at the C5, while the shortest was at the C2. In current study, the longitudinal length of segmental ventral rootlets at C4 and C8 were shorter than those at C5, C6 and C7.

As shown in Tanaka's study [8], intradural intersegmental connections were rare in ventral rootlets (two connections out of 36 intersegments, 6%) and much thinner. Both connections were found between C4 and C5 ventral rootlets. In this current study, we found three connections (two specimens) out of 20 intersegments (15%) (Figure 5). One specimen had bilateral connections while the other had unilateral connections. Both connections were found in C5/6 segment between ventral rootlets of C5 and C6 and were relatively thinner compared with other bundles of the rootlets. This finding may also help to explain why symptoms are sometimes diffuse with blurred nerve root location in patients with cervical radiculopathy. There are some limitations of our study. The number of cadavers was small and the cadavers were formalin-fixed which may affect the accurate measurement.

Conclusion

A comprehensive understanding of neurologic anatomy in cervical spinal canal is important to accurate diagnosis of cervical spondylosis. The cervical spinal canal was divided into different zones in this study. The current definition of anatomic zones may be useful for diagnosis of cervical spondylosis and conducting safe and effective anterior decompression surgery. Further studies are needed to correlate the anatomic zones defined in current study with radiological findings and clinical symptoms in cervical spondylosis patients.

List Of Abbreviations

LV: length of the cervical spinal cord segment at the ventral rootlets; PH: pedicle height; IPH: inter-pedicle height; PN: distance between the superior margin of pedicle and the exit of the uppermost ventral nerve rootlet; P: pedicle zone; IP: inter-pedicle zone; ANOVA: one-way analysis of variance; LSD: least significant difference; SD: standard deviation

Declarations

1) Ethics approval and consent to participate

This study was approved by the Ethical committee of Beijing Luhe Hospital. Each participant gave written, informed consent to participate.

2) Consent for publication

Consent for publish potentially-identifying information of patients was obtained.

3) Availability of data and materials

The datasets used and/or analyzed during the current study are stored in our hospital and are available from the corresponding author on reasonable resquest.

4) Competing interests

The authors declare that they have no competing interests.

5) Funding

No funding was received.

6) Authors’ contributions

LYD did the measurement and wrote the paper. LL did the measurement and analyzed the data. KC did the dissection and measurement. YX did the dissection. CXM designed the study and revised the paper. GY (Yan Gao) performed the statistical analysis. GY (Yun Guan) revised the paper. All authors have read and approved the manuscript.

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Figures

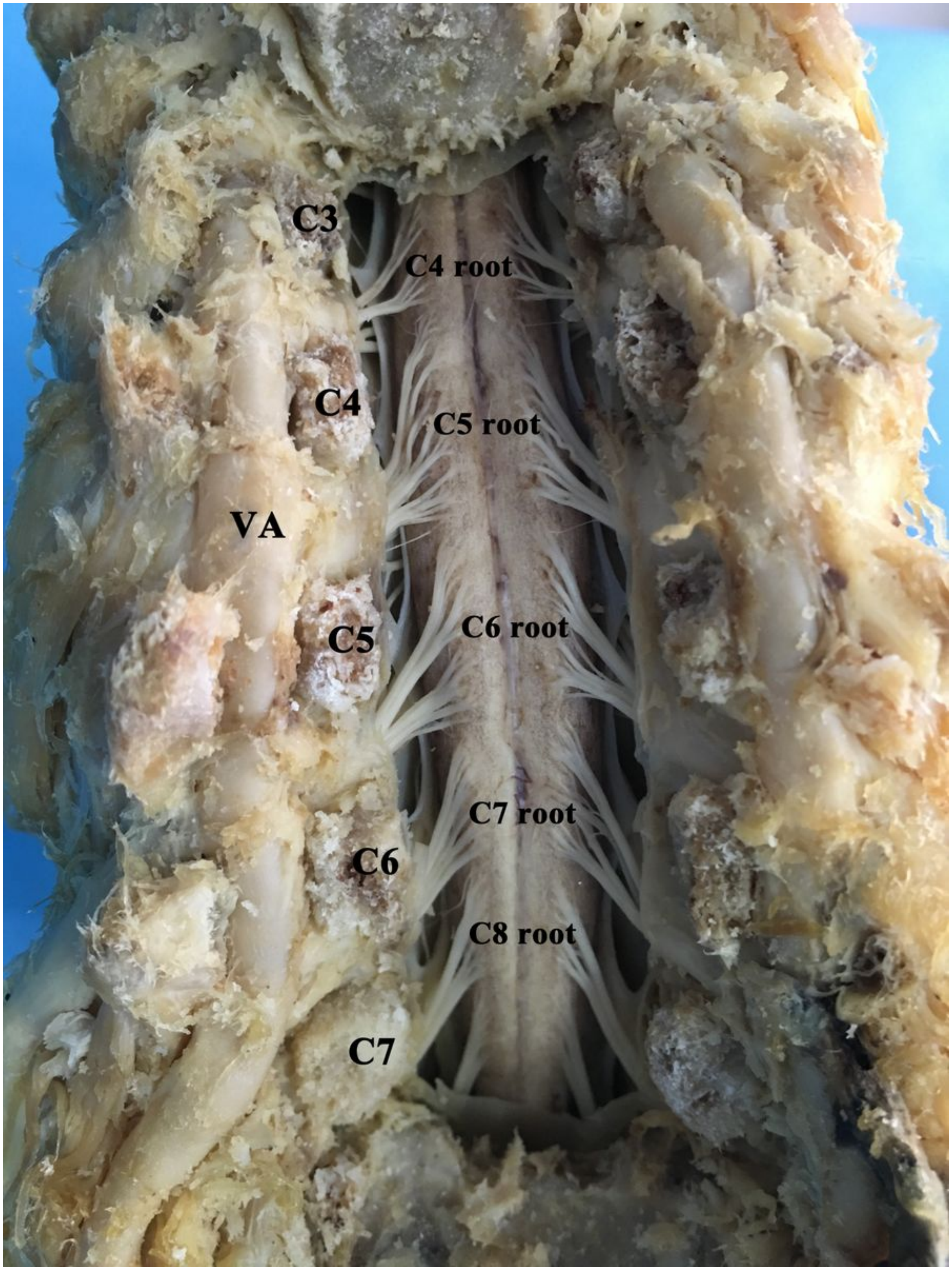

Figure 1

An example image of a cadaveric specimen showing the spinal cord and ventral nerve rootlets from C4 to C8. VA: vertebral artery.

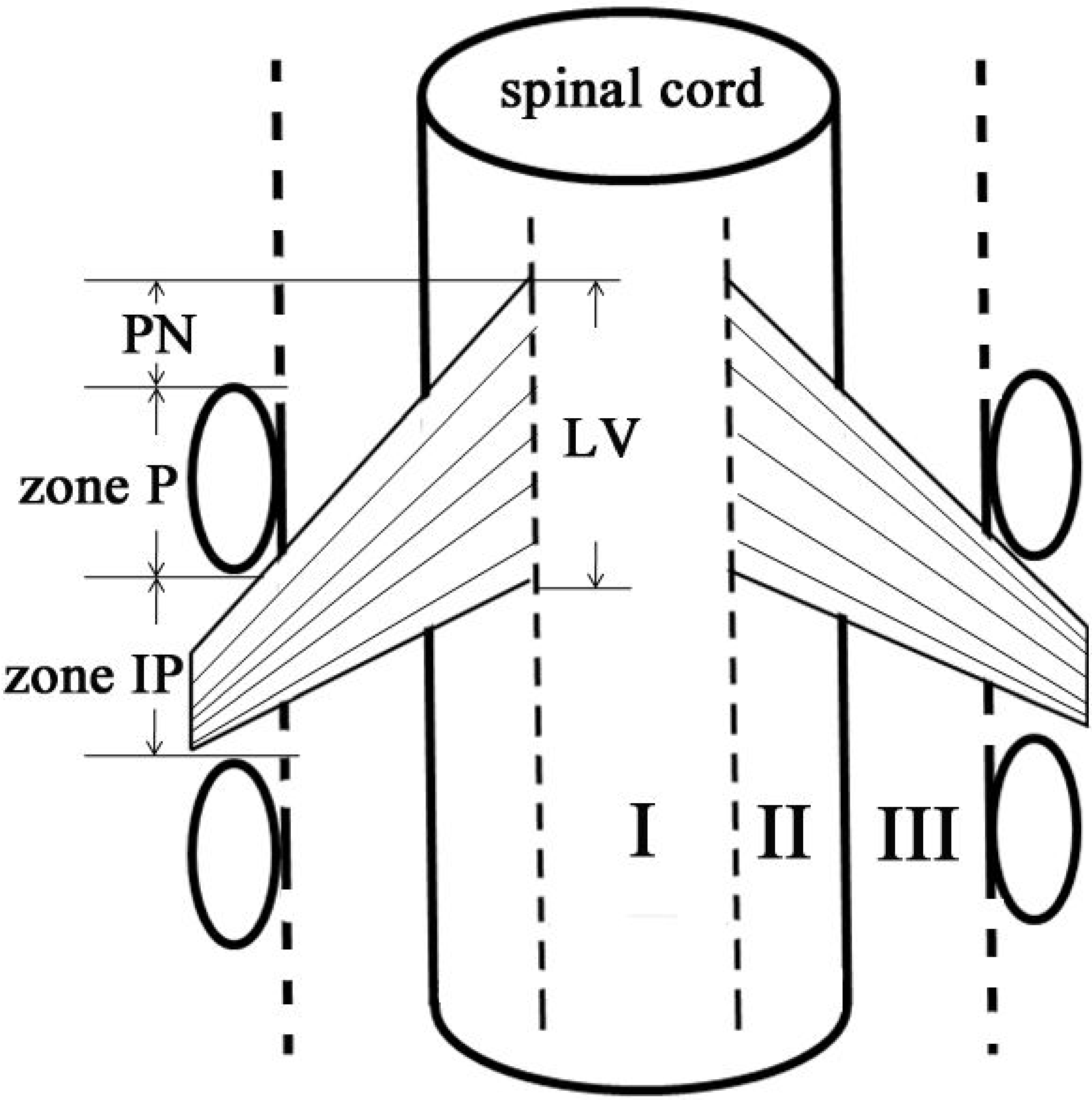

Figure 2

Zone division of the cervical spinal canal. Zone I represents the area between bilateral origins of ventral nerve rootlet. Zone II contains the area between the origin of ventral nerve rootlets and lateral border of spinal cord. Zone III represents the area between lateral border of spinal cord and medial margin of the pedicle. Zone P defines the area between the upper and lower margins of the corresponding pedicle. Zone IP includes the area between the lower margin of the upper pedicle and the upper margin of the lower pedicle. LV, length of the segmental ventral rootlets. PN, the distance between the superior margin of pedicle and the exit of the uppermost ventral nerve rootlet.

Figure 3

Example of zone division at cervical segments. a, At C4/5 level, all C6 nerve rootlets were located at zone IP, and zone III contains only C5 nerve rootlets. b, At C6/7 level of the same specimen, part of C8 nerve rootlets reaches zone P, zone III contains both C7 and C8 nerve rootlets.

Figure 4

a, The upper black circle shows the compression region in zone I, and the lower black circle shows the compression in zone II. b, Intact cervical spinal cord without any compression.

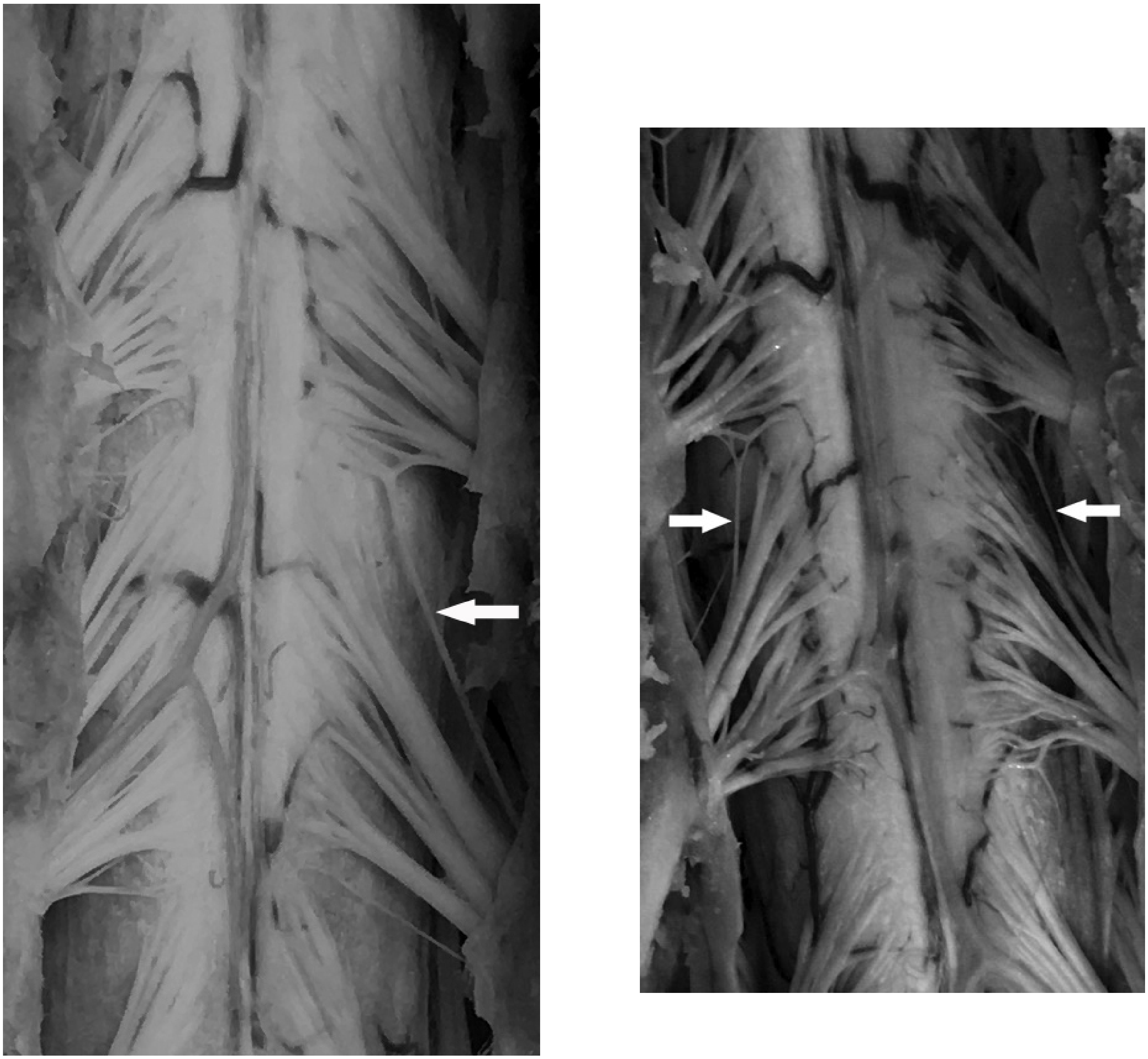

Figure 5

a, Unilateral intradural intersegmental connection between C5 and C6. b, Bilateral intradural intersegmental connections between C5 and C6.