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Extraordinary features of the intraspinal extradural and intradural nerve root courses

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Abstract

OBJECTIVES: Very few studies have reported occasional intradural and extradural communications between adjacent nerve roots. These studies mostly focus on lumbosacral regions followed by cervical regions, and rarely in the thoracic region.
DESIGN: The aim of this work is to point out some extraordinary extradural and intradural features of the intraspinal nerve root courses and their possible participation in radiculopathy.
SUBJECTS AND METHODS: The anatomical study was performed in 43 cadavers. All intradural and extradural rami communicantes between nerve roots were examined histologically for the presence or absence of nervous tissue.
RESULTS: Findings of the normotype of plexus formation occurred in 30 cases (69.8%). Variations in its formation were observed in 13 cases (30.2%). Anatomical preparations revealed intradural rami communicantes in all cases of the lumbosacral plexus; 28 times (65.1%) in cases of cervical roots and in the thoracic region 4 times (9.3%). Extradural anatomical variations occurred in 26 cases (60.5%). In 9 cases (20.9%) current occurence of intraspinal extradural and intradural communicating branches in the spinal canal were observed. Multiple extradural rami communicantes were observed in 6 cases (13.95%), including the simultaneous occurrence of multiple intradural and extradural ones in 5 cases (11.6%).
CONCLUSIONS: This study allowed us to identify and describe current occurence of intraspinal extradural and intradural communicating branches in the spinal canal with their potential influence on the clinical picture. Anatomical preparations revealed a higher incidence of intraspinal intradural variations, particularly between sacral roots. The reliance of their incidence of the type of plexus was observed.

ORIGINAL ARTICLE

Abbreviations:

C	- cervical
T	- thoracal
L	- lumbal
S	- sacral
dx.	- dexter (Latin) – right
sin.	- sinister (Latin) – left

INTRODUCTION

The aim of this paper is to point out the extraordinary features of the intraspinal extradural and intradural nerve root courses and their interrelationships throughout the spinal canal as well as their possible impact on the clinical picture. Very few studies have reported occasional intradural and extradural communications between adjacent roots (Arslan, 2011; 2012). These studies mostly focus on lumbosacral regions followed by cervical regions, and rarely in the thoracic region. Additionally, such communications are primarily between the dorsal rootlets, while ventral root intercommunications have been rarely reported (Bardeen & Elting, 1901; Bedeschi & Bonola, 1956). To our knowledge, no study has reported interconnections between intradural and extradural nerve roots in the cervical, thoracic, and lumbosacral region in reference to a normal, prefixed, or postfixed type of brachial and lumbosacral plexuses. Most of the papers on the intraspinal variations of nerve roots dealt with extradural anatomical variations of lumbosacral nerve roots (Boden *et al.* 1990; Burke *et al.* 2013; Chin & Chew, 1997; Chotigavanich & Sawangnatra, 1992; Ethelberg & Riishede, 1952; Goffin & Plets, 1987; Haijiao *et al.* 2001; Hasue, 1993; Kadish & Simmons, 1984; Keegan, 1947; Keon-Cohen, 1968; Kikuchi *et al.* 1984; Kitab *et al.* 2009). The submitted paper comprehensively evaluates the topic of intraspinal intradural and extradural variations of nerve roots. Therefore, the present study was undertaken to determine if there is any relationship between the level and concentration of root interconnections and these variations in the formation of the plexuses. The anatomical data collected of 43 cadavers with nerve root variations represent the basis of the report. Such data may be helpful for understanding nerve root injuries and other intrathecal pathological processes.

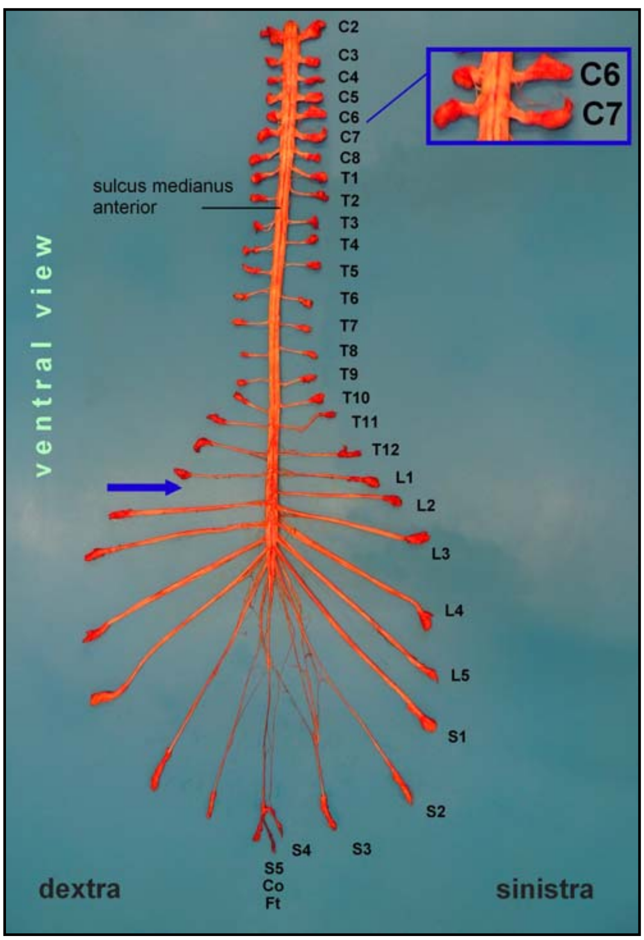

Fig. 1. Front view, intradural ramus communicans between the front roots C6 and C7. Complex formation of the roots of the lumbosacral plexus. Missing root L2 dx. Ramus communicans between the dorsal roots S3 dx. and S3 sin., ramus communicans between the dorsal roots S1 and S2 sin. and S1-S3 sin. Roots L4, L5.

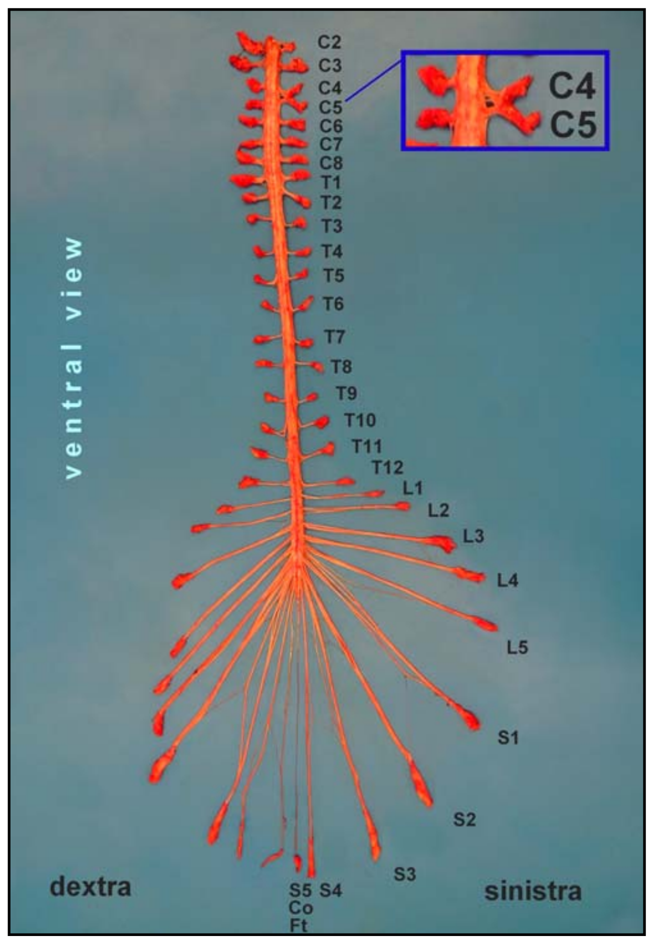

Fig. 2. Postfixed type, front view. Common sleeve of roots C4-C5 sin., asymmetry of roots. Roots L3, L4 were thinner, sacral roots S3, S4 clearer. The assimilation of segments in the region of sparing of sacral roots. Close and distal rami communicantes.

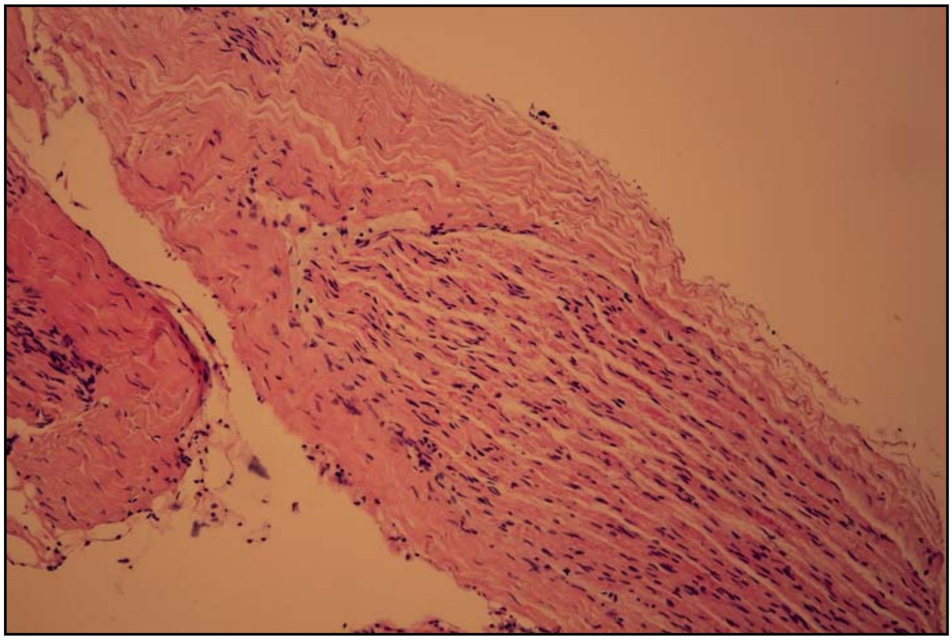

Fig. 3. Longitudinal section of the nerve with perineurium, no inflammation, fibrosis, H&E 200x.

SUBJECTS AND METHODS

The anatomical study was carried out in 43 fresh cadavers without congenital or detected abnormalities, tumour diseases, orthopaedic deformities and spinal operations within 24 hours from the death. The study included 32 men (74.4%) aged 30 to 75 years and 11 women (25.6%) aged 45 to 77 years. The subjects had died from a violent death, most often in car accidents, when the spine had not been damaged. The study was conducted with the approval of the ethics committee. In the prone position, we separated paravertebral muscles from processus spinosi and laminas on both sides from the cervico-cranial transition to the sacrum. Processus spinosi were removed using bone punches and Stryker´s saw. Laminas on both sides, as well as parts of articular projections, were removed with the Kerisson rounger. Such "roofing off" allowed the direct visualization of the spinal canal without damaging the spinal cord and nerve roots. A wide laminectomy from cervico-cranial transition to the sacrum revealed the whole spinal canal to examine each cervical, thoracic, lumbar, and sacral nerve root from its protrusion out of the spinal cord to its exit from the spinal canal through the foramen intervertebrale and hiatus sacralis. Subsequently, we made a longitudinal incision of the dura and we removed it entirely from the spine and nerve roots. The nerve roots were cut distally from the spinal ganglion to allow direct visualization of the spinal cord, conus medullaris, and spinal nerve roots. The exposed segments of the spinal cord and nerve roots were examined, monitored and reviewed, including a detailed examination of the intradural and extradural rami communicantes. All intradural and extradural rami communicantes between nerve roots were excised and then examined histologically to find out the presence or absence of nervous tissue. The type of the plexus was defined by subtracting from the root C2. Specification of the type of plexus was carried out on the basis of the formation of intradural and extradural roots. Normal anatomical levels of cervical intumescences (cervical enlargement) are C4-T1 segment (C4-T1 vertebra level) brachial plexus. Lumbosacral intumescences (lumbosacral enlargement) are L1-S3 segment (T9-T12 vertebra level) lumbosacral plexus. In the normotype from the top of the cervical intumescence, the C6 root was retracted. In the prefixed type, the C5 root and in the postfixed type C7 and C8 roots were retracted. From the top of lumbar intumescence in the normotype the L3 root, in the prefixed type the L2 root and in the postfixed type L4, L5 roots were retracted.

RESULTS

Findings with the normotype in 30 cases (69.8%) of intraspinal intradural and extradural formation of the brachial and lumbosacral plexus were dominant (Table 1, 2, 3). Variations of the formation were observed in 13 cases (30.2%). The prefixed type occurred in 9 cases (20.9%) (Figure 1), postfixed type in 4 cases (9.3%) (Figure 2). The formation of the isolated prefixed or postfixed type of brachial and lumbosacral plexus was not observed. The frequency of intradural and extradural rami communicantes between nerve roots showed variations among spinal levels. Rami communicantes are mostly concentrated in lumbosacral regions – in all cases, followed by cervical regions 28 times (65.1%) and rarely in the thoracic region 4 times (9.3%). Rami communicantes between the dorsal roots prevailed in all cases. All intradural rami communicantes were excised

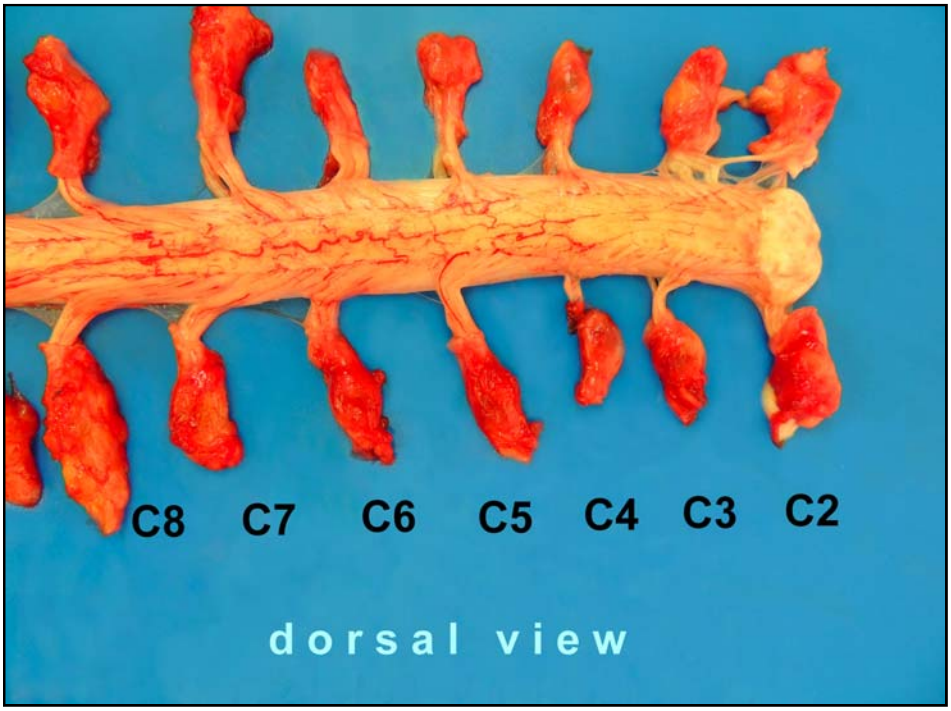

Fig. 4. Back view, ramus communicans between the dorsal roots C2-C3 sin.

and examined histologically and the presence of nervous tissue was found in all of them (Figure 3). They occurred more frequently in variations of formation of the plexus. In the prefixed type, we observed absence of ventral roots S3, S4, S5. In one case, the common spacing of the root L1 and L2 sin. was observed. The ventral root L4 was thicker or of the same thickness as the ventral roots L5, S1 and S2. The thickness of the anterior branch of the root L3 was equal to the anterior branch of the roots L5 and S1. Ramus communicans above 1-2 roots occurred in one case. In one case, we observed rami communicantes between the roots L2 and L3 bilaterally. In one case we observed cross-ramus communicans between dorsal roots S3 dx. – S3 sin. The asymmetry of roots was more pronounced in the lumbosacral plexus (31 cases, 72.09%), particularly at the level of spacing of roots L4-S3, maximum at the level of S1-S2. Their atypical spacing, multiple rami communicantes between dorsal sacral roots, at a short as well as at a longer distance from the spinal cord, or the absence of the ventral root occurred in 13 cases (30.2%), the absence of ventral and dorsal roots in three cases (7%), rami communicantes between the ventral and dorsal roots in 10 cases (23.3%). Rami communicantes only between ventral roots were present in 12 cases (27.9%) out of which there were three cases in the prefixed type. In eight cases (18.6%), they were present between sacral and lumbar roots. In the cervical region, rami communicantes between the dorsal roots prevailed (Figure 4). Extradural anatomical variations occurred in 26 cases (60.5%). They were more frequent on the left side in13 cases (30.2%), bilateral in 4 cases (9.3%). The asymmetry of roots was observed. It was more pronounced in the lumbosacral plexus, particularly at the level of spacing of the roots L4-S3, the atypical spacing, including four in the lumbosacral region, was observed. After an extradural course of different length, the nerve roots remained close to each other and in 4 cases (9.3%) left the spinal canal through one neuroforamen. Two incidents of two roots in the thoracic region in one neuroforamen and one incident of two roots in one neuroforamen in the cervical and lumbosacral regions. In two cases (4.65%), the absence of nerve roots (S3), and in one case the root (L2), on the right side was observed and in one case an aberrant root between roots of C2-C3. In 9 cases (20.9%), extradural rami communicantes between the nerve roots were observed (Figure 5). Two adjacent nerve roots were connected by a ramus communicans shortly after their emergence from the dura. In one case, we observed cross-dx sin extradural anastomosis in the lumbosacral area (Figure 6). Multiple extradural rami communicantes were observed in 6 cases (13.95%), including the simultaneous occurrence of multiple intradural and extradural ones in 5 cases (11.6%). In the cervical region in 3 cases (Figure 7, 8) and in 2 cases in the lumbosacral region.

In the postfixed type, the roots L3, L4 were thinner, sacral roots S3, S4 clearer.

DISCUSSION

We have not met with the papers describing current occurence of intraspinal extradural and intradural communicating branches in the spinal canal, as well as their differences on individual levels. Our anatomical preparations allowed us to identify and describe a higher

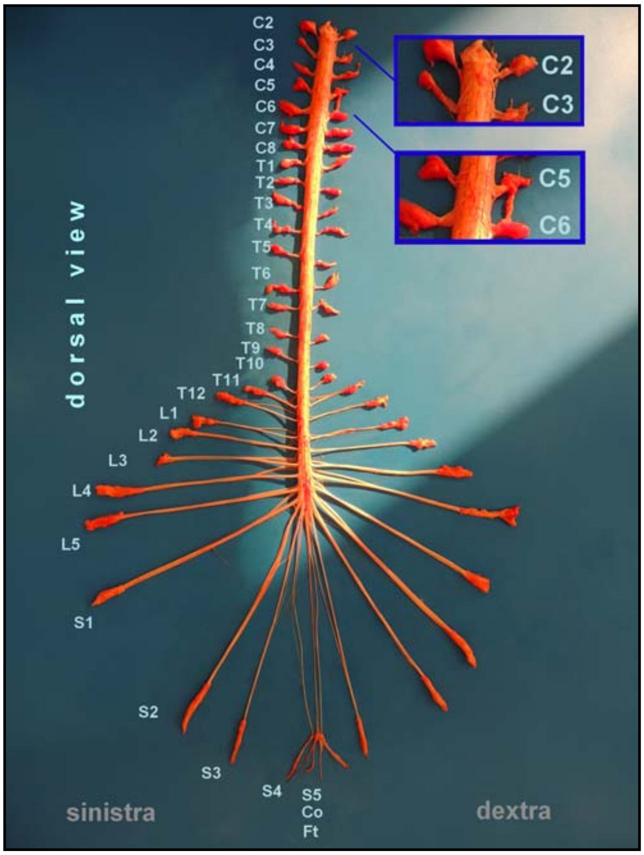

Fig. 5. Back view, extradural ramus communicans between the roots C5 and C6 dx. Intradural ramus communicans between the roots C2-C3 dx.

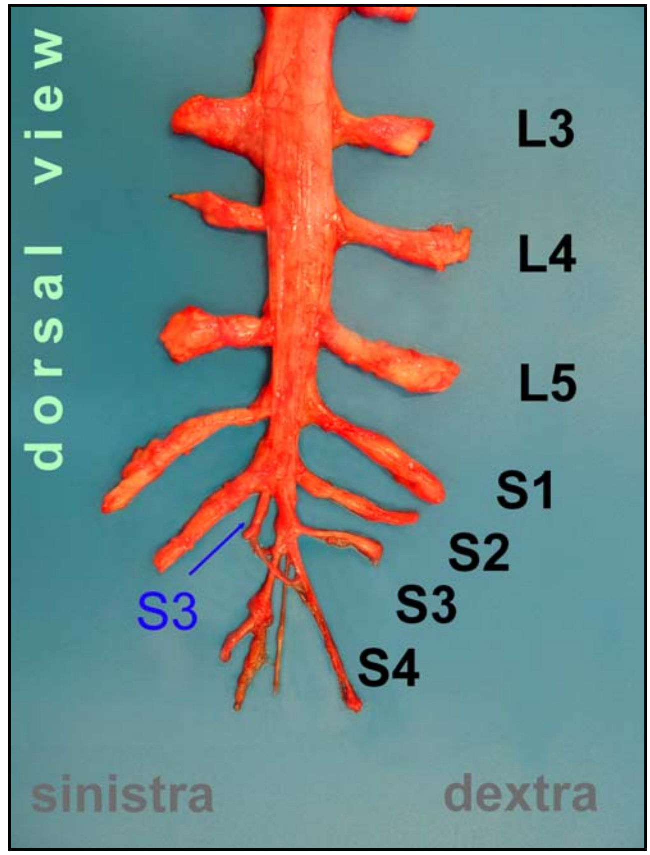

Fig. 6. Back view, asymmetry of the sacral roots, atypical spacing of the root S3 sin. Extradural ramus communicans between S3 sin. and S4 dx.

incidence of intraspinal intradural variations mainly between sacral roots. Variations were observed at sacral levels from 0% (Keon-Cohen, 1968) to 20-30% (Chin & Chew, 1987; Haijiao, 2001). We observed intradural rami communications in all cases of the lumbosacral plexus. Their number increased, especially among sacral roots. In the cervical region, they were less frequent – 28 times (65.1%). And in the thoracic region, they occurred rarely – 4 times (9.3%). Our results were evaluated in relation to the type of the plexus. Prefixation of the brachial plexus was reported in 28% and 5% were postfixed (Arslan *et al.* 2011). We found differences in 9 specimens (20.9%) that were prefixed and in 4 specimens (9.3%) that were postfixed. Our findings have indicated that the location of variations throughout the whole segment of the spinal cord is different as well as the form of variations. In some cases, they are few in number and they are located at a short distance from the spinal cord. In other cases, rami communicantes are multiple, they flow further away from the spinal cord. These data may help us understand nerve root injuries according to various pathologies, such as disc herniation, space-occupying lesions, and trauma. Interneural interconnections may cloud clinical interpretation (Arslan *et al.* 2012; Kyoshima *et al.* 1986; Marieb & Mallat, 2005; Grambalova *et al.* 2015). Some patients with hernias of intervertebral discs do not have a typical symptomatology characteristic of this type of the disease. In disc operations, sometimes, anatomical variations in nerve roots are found which resulted in monitoring these variations by examination of cervical, thoracic, lumbar, and sacral nerve roots at cadavers. The aetiology of these variations has to be elucidated. The most likely explanation of variations is that they result from defective migration of the nerve roots during the first four weeks of embryonic development (Marzo *et al.* 1987; Moriishi *et al.* 1989). Embryologic evidence can account for the frequent occurrence of intradural variations. The presence of an unbroken ridge of neural crest tissue travelling along the length of the spinal cord may provide the means for neighbouring dorsal roots to intercommunicate cavities the development (Arslan *et al.* 2011; Marzo *et al.* 1987; Moriishi *et al.* 1989). At the 4-mm stage in the embryo, the spinal ganglia develop processes, which are directed toward the spinal cord to become the dorsal roots. This period of dorsal root expansion and fusion with the spinal cord lasts up to the 10-mm stage and may depict the route by which connections between adjacent segments can be formed. Moreover, the dorsal roots are much slower to form than their ventral counterparts and do not begin to separate until approximately day 30 of development (Bardeen & Elting, 1901). This may be the reason for not identifying many more interconnections between

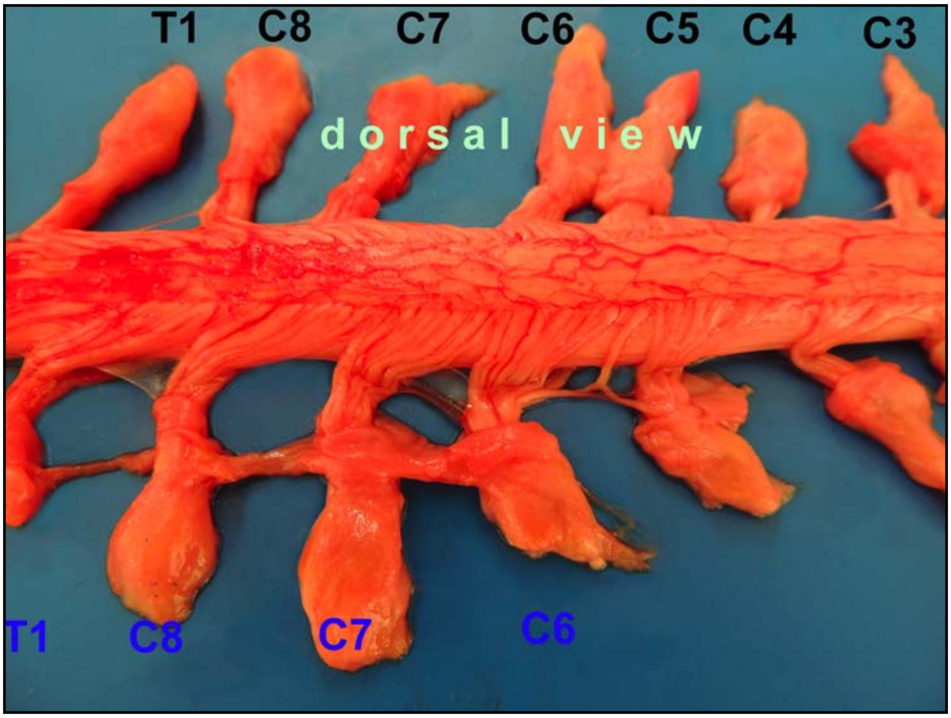

Fig. 7. Intradural ramus communicans between the roots C5-C6 dx. Extradural rami communicantes between the roots C6-C7-C8 dx.

the ventral roots. Most papers refer to extradural anomalies of lumbosacral nerve roots (Burke *et al.* 2013; Chin & Chew, 1997; Chotigavanich & Sawangnatra, 1992; Ethelberg & Riishede, 1952; Hasue, 1993; Kadish & Simmons, 1984; Kikuchi *et al.* 1984; Kitab *et al.* 2009), what resulted in analysing and comparing mainly this part of our observations. We observed extradural variations in 26 cases (60.5%), 10 cases (23.3%) of the lumbosacral plexus. Symptoms of radiculopathy may manifest extradural variations of lumbosacral nerve roots even in cases of the absence of pressure on nerve roots (Boden *et al.* 1990; Burke *et al.* 2013; Ethelberg & Riishede, 1952; Neidre & MacNab, 1983). Some papers are based on surgical findings (O'Rahilly *et al.* 1990); others are based on anatomical studies (Ethelberg & Riishede, 1952; Hasue, 1993). Their incidence

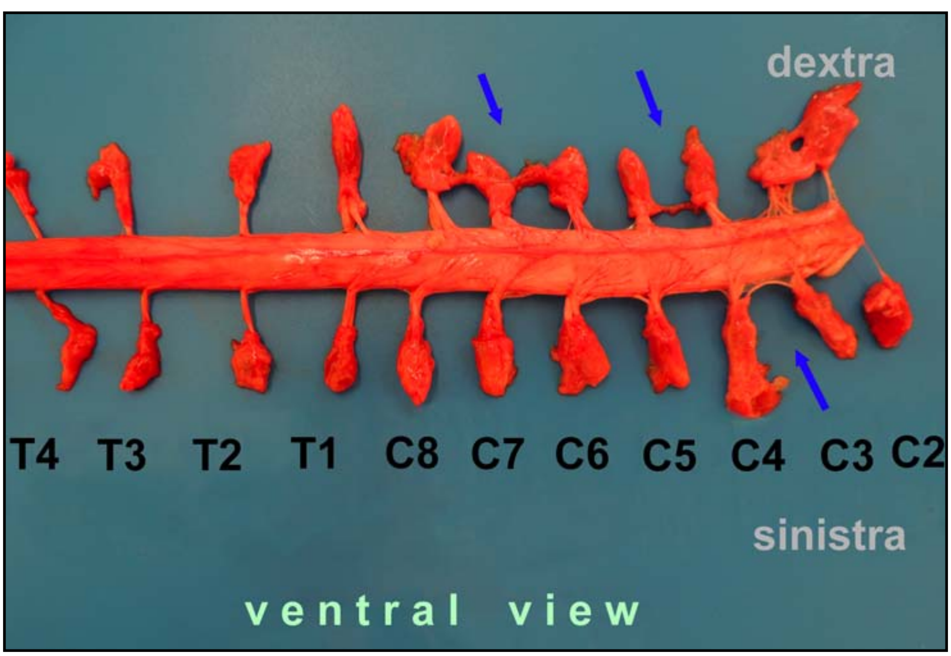

Fig. 8. Front view, intradural ramus communicans between C3-C4 sin. Extradural rami communicantes between the roots C4-C5 dx. and C6-C7-C8 dx.

ranges from 1.3% found dutiny the operation (Burke *et al.* 2013) to 2–6.7% detected by imaging methods before surgery (Ethelberg & Riishede, 1952; Hasue, 1993; Kikuchi *et al.* 1984; Petraco *et al.* 1996), and from 8.5% to 30% during the study of cadavers (Burke *et al.* 2013; Neidre & MacNab, 1983). They occur most frequently unilaterally at the level of L5-S1 (Ethelberg & Riishede, 1952; Haijiao *et al.* 2001; Postacchini *et al.* 1982; Rask, 1977; Scarf *et al.* 1981), and can be the cause of failure in operations of discs (Haijiao *et al.* 2001). This explains the importance of recognizing variations of the nerve roots of different types, which may increase the number of successful operations (Goffin & Plets, 1987; Solmaz *et al.* 2015). Variations of nerve roots can cause symptoms at more than one level because of the pressure, e.g. by the herniated disc. The pressure placed on an abnormally situated nerve root may give incorrect information about the level of hernia of the disc. Variations are particularly sensitive to the retraction of nerve roots. Dissectomy is, therefore, more complicated. The nerve roots cannot be mobilized safely and the possibility of their damaging increases (Chin & Chew, 1997; Chotigavanich & Sawangnatra, 1992; Postacchini *et al.* 1982). Variations of roots occupy more space in the spinal canal, and so even a small bulging of an intervertebral disc may be the cause of symptoms. Variations themselves can cause pain. The spinal cord is mobile during normal flexion and extension. Therefore, larger traction forces may be produced with variations in nerve roots, as well as with normal movements of the spinal column (Stambough *et al.* 1988). Intradural and extradural nerve roots can be damaged by stretching (Marieb & Mallat, 2005; Transfeld & Simons, 1982). Stretch-induced nerve root injury may be related to changes in the length of the spinal canal and in the length of the nerve root. The perineurium and endoneurium have considerable mechanical strength and serve to protect neural tissues against mechanical forces. However, the intrathecal nerve roots do not have such a protective sheath (Marieb & Mallat, 2005; Tubbs *et al.* 2009). Excessive flexion of the torso during variations surgical procedures may be one of the risk factors for injury of the tethered roots in the presence of intrathecal pathologies (Arslan *et al.* 2012; Khoshab & Sloboda 2015). Therefore, the intradural nerve roots are vulnerable to mechanical stretch, including operative manoeuvres and trauma. Interneural interconnections may cause symptoms at more than one level and may give incorrect indication of the disc herniation level, and therefore, the results of decompression may be poor (Marieb & Mallat, 2005). The anatomical studies have revealed extradural variations of a lumbosacral root in 8.5% of cases (Yimaz *et al.* 2014; Zagnoni, 1949), 14% incidence (Hasue, 1993) and 30% incidence (Neidre & MacNab, 1983). In our study, it was in 10 cases (23.3%). The atypical spacing of two nerve roots is most frequently observed in the lumbosacral region (Ethelberg & Riishede, 1952; Scarff *et al.* 1981). The occurrence of such disorders was observed in 30% of cadavers (Haijiao *et al.* 2001; Hasue, 1993; Keegan, 1947; Neidre & MacNab, 1983; O'Rahilly *et al.* 1990; Postacchini, 1982). In our study, they occurred in 4 cases (9.3%). In two cases, it was the level of L5-S1, which is lower in comparison to other reports (Burke *et al.* 2013; Haijiao *et al.* 2001; Hasue, 1993; Kadish & Simmons, 1984; Kitab *et al.* 2009; O'Rahilly *et al.* 1990). In two cases, there was the extradural absence of a nerve root at the S3 level on the right side. Extradural rami communicantes between lumbosacral nerve roots were described in some studies (Chin & Chew, 1997; Ethelberg & Riishede, 1952; Haijiao *et al.* 2001; Hasue, 1993). They revealed the extradural rami communicantes ranging from 1% to 25% of cases. In our study, it was in 2 cases (4.6%). Comparing our anatomical findings with previous results of other authors (Boden *et al.* 1990; Goffin & Plets, 1987; Haijiao *et al.* 2001; Keegan, 1947), it appears that a percentage rate was lower, and the types of extradural variations were partially different. We did not frequently observe atypical spacing of nerve roots, as commonly observed in other studies (Burke *et al.* 2013; Goffin & Plets, 1987; Hasue, 1993).

CONCLUSION

Anatomical preparations revealed a higher incidence of intraspinal intradural variations mainly between sacral, and extradural mainly between cervical roots. Reliance of their incidence of the type of plexus was observed. Preoperative diagnosis of variations nerve roots is difficult. The lack of preoperative vigilance can lead to iatrogenic damage to the nerve roots. We believe that data obtained from anatomical dissection will be helpful to many surgeons. Our study is affected by some factors such as strong regional focus, and a small number of cadavers. This limitation affects the interpretation of our data quality, and the ability to generalise our findings.

DECLARATIONS OF INTEREST

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