

Clinical Study

Observed patterns of cervical radiculopathy: how often do they differ from a standard, “Netter diagram” distribution?

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Received 6 February 2018; revised 7 August 2018; accepted 7 August 2018

Abstract

BACKGROUND CONTEXT: Traditionally, cervical radiculopathy is thought to present with symptoms and signs in a standard, textbook, reproducible pattern as seen in a “Netter diagram.” To date, no study has directly examined cervical radicular patterns attributable to single level pathology in patients undergoing ACDF.

PURPOSE: The purpose of this study is to examine cervical radiculopathy patterns in a surgical population and determine how often patients present with the standard textbook (ie, Netter diagram) versus nonstandard patterns.

STUDY DESIGN/SETTING: A retrospective study.

PATIENT SAMPLE: Patients who had single-level radiculopathy with at least 75% improvement of preoperative symptoms following ACDF were included.

OUTCOME MEASURES: Epidemiologic variables were collected including age, sex, weight, body mass index, laterality of symptoms, duration of symptoms prior to operative intervention, and the presence of diabetes mellitus. The observed pattern of radiculopathy at presentation, including associated neck, shoulder, upper arm, forearm, and hand pain and/or numbness, was determined from chart review and patient-derived pain diagrams.

METHODS: We identified all patients with single level cervical radiculopathy operated on between March 2011 and March 2016 by six surgeons. The observed pattern of radiculopathy was compared to a standard textbook pattern of radiculopathy that strictly adheres to a dermatomal map Fisher exact test was used to analyze categorical data and Student *t* test was used for continuous variables. A one-way ANOVA was used to determine differences in the observed versus expected radicular pattern. A logistic regression model assessed the effect of demographic variables on presentation with a nonstandard radicular pattern.

RESULTS: Overall, 239 cervical levels were identified. The observed pattern of pain and numbness followed the standard pattern in only 54% (129 of 239; $p=.35$). When a nonstandard radicular pattern was present, it differed by 1.68 dermatomal levels from the standard ($p<.0001$). Neck pain on the radiculopathy side was the most prevalent symptom; it was found in 81% (193 of 239) of patients and did not differ by cervical level ($p=.72$). In a logistic regression model, none of the demographic variables of interest were found to significantly impact the likelihood of presenting with a nonstandard radicular pattern.

CONCLUSIONS: Observed patterns of cervical radiculopathy only followed the standard pattern in 54% of patients and did not differ by the cervical level involved. Cervical radiculopathy often

FDA device/drug status: Not applicable.

Author disclosures: **SJM:** Nothing to disclose. **JMR:** Royalties: Biomet (D), Stryker (F), LWW (B). Consulting: Synthes (C). Speaking/Teaching Arrangements: Zimmer Biomet (C), DePuy (B). Board of Directors: Cervical Spine Research Society (nonfinancial). **EOB:** Nothing to disclose. **WS:** Nothing to disclose. **JK:** Nothing to disclose. **TMN:** Nothing to disclose. **RA:** Nothing to disclose.

The disclosure key can be found on the Table of Contents and at www.TheSpineJournalOnline.com.

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presents with a nonstandard pattern. Surgeons should think broadly when identifying causative levels because they frequently may not adhere to textbook descriptions in actual clinical practice. We observed III level of evidence. © 2018 Elsevier Inc. All rights reserved.

Keywords: ACDF; Anterior cervical discectomy and fusion; Cervical radiculopathy; Cervical spine; Netter diagram; Pain pattern.

Introduction

Traditionally, it is taught that cervical radiculopathy presents in a reproducible dermatomal and myotomal pattern attributable to the involved cervical root level [1–3]. Thus, for example, a C6 radiculopathy is classically described as symptoms radiating from the neck down the arm, terminating in the thumb and index finger. If advanced imaging shows root compression consistent with the clinically suspected level, a specific diagnosis can be made. Identification of the exact root level(s) causing radiculopathy can be important in all patients but is absolutely critical in those who elect to have surgery for refractory symptoms.

In clinical practice, however, patients may present with radicular symptoms that do not perfectly fit the standard, textbook “Netter diagram” patterns based on the description by Keegan and Garrett [13]. Under these circumstances, proper identification of levels to target surgically can be difficult in those who fail nonoperative care. Uncertainty can lead to unnecessarily treating a level that is not actually causing symptoms or no surgery at all in a patient who might benefit from it for fear that the proper symptom generator cannot be identified.

Brachial plexus variability is one potential cause of symptom variability in cervical radiculopathy. Anatomic dissections suggest that a typical “textbook” brachial plexus is only observed in 37%–77% [4–6]. Additionally, a number of anatomic studies have demonstrated considerable variation in the intradural connection of rootlets, which can potentially impact the ability to accurately localize the level of cervical pathology on the basis of clinical signs and symptoms [7–11]. While the anatomic variability makes a compelling rationale for clinical symptom variability, clinically based assessments of cervical radicular patterns remain limited. One study reported more than two-thirds (69.7%) of cervical radiculopathy patients exhibited non-dermatomal radiculopathy symptoms [12]. While these data are intriguing, this study included patients with evidence of multilevel disease, therefore leading to uncertainty as to which level is responsible for the observed patterns and confounding the results of the study.

Currently, there are limited data on the variability with which cervical radiculopathy presents in real world situations and how often the actual presentation might deviate from the standard, textbook descriptions. Such information would be useful to surgeons making diagnoses as to a causative root level. The purposes of this study were therefore

to examine cervical radiculopathy patterns in a surgical population undergoing single-level anterior cervical discectomy and fusion (ACDF) for refractory radiculopathy and to determine how often patients present with standard versus nonstandard patterns. Single-level disease was chosen in order to correlate the presenting symptoms with an isolated root level.

Methods

After institutional review board approval, a retrospective review was performed of the records of all patients with single-level radiculopathy who underwent ACDF by six surgeons at an academic medical center between March 2011 and March 2016. The electronic medical records were reviewed to obtain data consistent with the study’s inclusion criteria. The inclusion criteria were the following: adult patient >18 years of age, advanced imaging demonstrating root compression at the level of surgery, no identifiable cervical spinal cord compression on advanced imaging, refractory symptoms involving the upper limb and neck (however, neck pain alone was not an indication for surgery), and at least a 75% reduction in preoperative symptoms after primary single-level ACDF by the 6-month postoperative follow-up.

All patients included in this study underwent an appropriate trial of nonoperative treatment for at least 3 months, unless there was a progressive or severe neurologic deficit. The operative indications included advanced imaging (magnetic resonance imaging (MRI) or CT-myelogram (computed tomography)) evidence of cervical root compression by disc material or osteophytes at the level thought to be causing symptoms. Generalized, nonspecific axial neck pain only was never an indication for surgery. A standard, plated, single-level ACDF with allograft was performed in all cases with direct foraminal decompression.

Epidemiologic variables were collected including age, sex, weight, body mass index (BMI), laterality of symptoms, duration of symptoms prior to operative intervention, and the presence of diabetes mellitus (DM). The observed pattern of radiculopathy at presentation, including associated neck, shoulder, upper arm, forearm, and hand pain and/or numbness, was determined from chart review and patient derived pain diagrams that were available in all patients in this study. This observed pattern was compared to a standard textbook pattern of radiculopathy as defined by the Keegan and Garrett dermatomal map [13] used in the Netter anatomic drawings [14]. Patients were then

categorized as either standard or nonstandard based on adherence of their radiculopathy to this standard.

GraphPad Prism v6.5 (La Jolla, CA, USA) was utilized for statistical analysis with independent sample *t* test for continuous variables and Fisher exact test for categorical data. In those patients with nonstandard radicular patterns, a one-way ANOVA was used to determine differences in the observed versus expected radicular pattern. A binary logistic regression model was used to determine the effect of demographic variables on presentation with a nonstandard radicular pattern. A *p* value <.05 was considered statistically significant.

Results

Patient characteristics and demographics

The records of 239 patients were found to meet the inclusion criteria of the study and were reviewed. Baseline patient characteristics can be found in Table 1. Overall, 239 cervical levels were included in this study (C3–C4: 15; C4–C5: 24; C5–C6: 108; C6–C7: 85; C7–T1: 7). The average age, weight, BMI, gender, and duration of symptoms did not significantly differ between those patients with a standard radicular pattern and those with a nonstandard pattern. The laterality of symptoms was found to be significantly different between the two groups, with 51% in the standard group demonstrating right-sided symptoms, while only 28% in the nonstandard group had right-sided symptoms (*p*=.0003).

Radiculopathy patterns

The Figure demonstrates the radicular pattern map used in this study. There were 129 (54%) cervical levels that fit the standard, and 110 (46%) cervical levels that differed from the standard (Table 2). At C5–C6 and C6–C7, two of the most common levels operated upon for radiculopathy, nonstandard patterns of presentation were seen in 50.9% and 44.7%, respectively. There was no statistical difference with respect to cervical level (*p*=.35). When a nonstandard radicular pattern was present, it differed by 1.68 dermatomal levels, either cranially or caudally, from the standard (*p*<.0001) (Table 3).

Table 1
Baseline demographic data

	Standard	Nonstandard	<i>p</i> Value
Number (<i>n</i>)	129	110	–
Age	53.77±11.15	51.34±10.77	.09
Weight	186.8±45.03	184.17±37.24	.63
BMI (Body mass index)	28.3±5.8	28.3±4.8	>.99
Gender (male)	65 (50.4%)	54 (49.1%)	.84
Laterality (right)	66 (51.2%)	31 (28.2%)	.0003
Duration of symptoms	19.04±28.86	23.12±35.48	.32

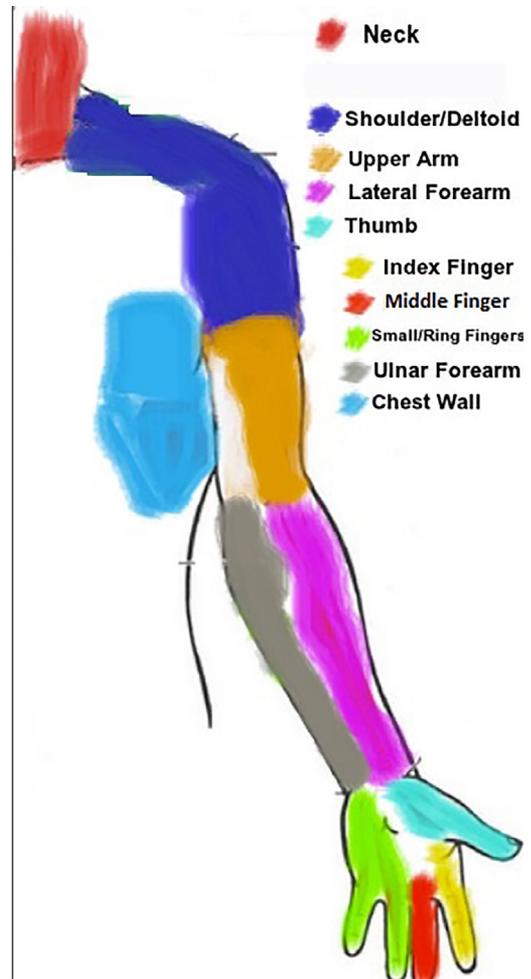


Figure. Schematic representation of the observed standard radicular patterns.

Table 2
Radicular symptoms present in nonstandard versus standard patterns

Level	Nonstandard pattern	Standard pattern	<i>p</i> Value
C3–C4	4 (26.7%)	11 (73.3%)	
C4–C5	9 (37.5%)	15 (62.5%)	
C5–C6	55 (50.9%)	53 (49.1%)	
C6–C7	38 (44.7%)	47 (55.3%)	
C7–T1	4 (57.1%)	3 (42.9%)	
Total	110 (46%)	129 (54%)	.35

Table 3
ANOVA analysis for average number of levels of difference from the expected standard

Level	Number	Mean	SD	<i>p</i> Value
C3–C4	6	1.67	0.52	
C4–C5	8	1.25	0.71	
C5–C6	55	1.29	0.46	
C6–C7	38	1.42	0.5	
C7–T1	4	2.75	0.5	
Total	111	1.68	0.54	<.0001

Table 4
Presence of ipsilateral neck pain on the side of radiculopathy by cervical disc level

Level	No neck pain	Neck pain	p Value
C3–C4	2 (13.3%)	13 (86.7%)	
C4–C5	7 (29.2%)	17 (70.8%)	
C5–C6	21 (19.4%)	87 (80.6%)	
C6–C7	15 (17.6%)	70 (82.4%)	
C7–T1	1 (14.3%)	6 (85.7%)	
Total	46 (19%)	193 (81%)	.72

Ipsilateral neck pain on the side of radiculopathy was found to be the most prevalent presenting symptom (Table 4). Overall, ipsilateral neck pain was found in 193 of 239 (81%) of the patients and did not differ by cervical level ($p=.72$). Shoulder pain was reported in 142 of 239 (59.4%) of patients and did not differ by cervical level ($p=.21$) (Table 5).

A large proportion had symptoms only proximally, with no distal radiation (Table 6). Overall, 46 of 239 (19.2%) patients presented with isolated neck and/or shoulder pain with no distal radiation. Consistent with expected standard patterns, isolated neck and/or shoulder pain without distal radiation was most common at the C3–C4 level, occurring in 60% ($p=.001$). However, even in those undergoing surgery at C5–C6 and C6–C7, where standard patterns would predict symptoms distal to the shoulder, isolated neck and/or shoulder pain without distal radiation was present in 16.7% and 13.3%, respectively. Conversely, in those undergoing surgery at C3–C4 and C4–C5, where standard patterns would not predict symptoms distal to the shoulder, distal symptoms were present in 40% and 66.7%, respectively.

Table 5
Presence of shoulder pain on the side of radiculopathy by cervical disc level

Level	No shoulder pain	Shoulder pain	p Value
C3–C4	6 (40%)	9 (60%)	
C4–C5	6 (25%)	18 (75%)	
C5–C6	40 (37%)	68 (63%)	
C6–C7	41 (48.2%)	44 (51.8%)	
C7–T1	4 (56.1%)	3 (42.9%)	
Total	97 (40.6%)	142 (59.4%)	.21

Table 6
Presence of isolated neck and/or trapezial and/or shoulder pain with no distal radicular symptoms

Level	Isolated neck/trap/shoulder	Distal radicular symptoms	p Value
C3–C4	9 (60%)	6 (40%)	
C4–C5	8 (33.3%)	16 (66.7%)	
C5–C6	18 (16.7%)	90 (83.3%)	
C6–C7	10 (13.3%)	75 (86.7%)	
C7–T1	1 (14.3%)	6 (85.7%)	
Total	46 (19.2%)	193 (80.8%)	.0001

Table 7
Results of the binary logistic regression

	Wald	95% CI for EXP(B)		p Value
		Lower	Upper	
Age	2.885	0.997	1.05	.089
Weight	0.184	0.986	1.022	.668
BMI	0.135	0.864	1.105	.713
Gender (male:female)	0.259	0.367	1.802	.611
Laterality (bilateral)	0.11	0.138	16.137	.741
Laterality (left)	1.268	0.379	36.39	.26
Laterality (right)	3.308	0.848	83.03	.069
Duration of symptoms	1.727	0.985	1.003	.189
DM	0.793	0.561	4.667	.373

Contrary to the standard pattern, 9 of 24 (37.5%) of C4–C5 patients had symptoms below the elbow.

Overall, the binary logistic regression model was statistically significant ($\chi^2=16.5$, $p=.04$), indicating that the model itself is valid for the analysis being performed. However, none of the demographic variables of interest were found to significantly impact the likelihood of presenting with a non-standard radicular pattern (Table 7).

Discussion

Traditional, textbook teaching holds that cervical radiculopathy presents with a reproducible symptom pattern according to established anatomic maps. However, the results of this study confirm that presentation in clinical practice may vary widely from these standard, expected patterns. Out of 239 patients, the observed pattern of cervical radiculopathy adhered to the standard pattern in only 54% (129 of 239). Furthermore, this variance was not affected by the level of the cervical pathology but occurred at every level. Proximal cervical levels often presented with distal symptoms, and distal cervical levels often presented with only proximal symptoms. It is important for practitioners to be aware not only of the standard “Netter-diagram” patterns but also of this variability when treating patients with cervical radiculopathy, in particular when identifying operative levels in those requiring surgery.

While considerable data exist describing both nerve rootlet variability as well as brachial plexus variants, there remains a paucity of literature documenting the radicular patterns in single-level cervical pathology. In the present study, when a nonstandard radicular pattern was present, the variance was on average 1.68 levels from the expected pattern. Naturally occurring variants in cervical nerve rootlet anatomy are one possible explanation for this variation. Tanaka et al. [7] in a cadaveric anatomic study of the cervical nerve roots found that over 50% of the time there were intradural intersegmental connections of the dorsal rootlets between C5 and C6 and between C6 and C7. Kuba et al. [15] reported similar findings with C5–C6 and C6–C7 being the most common levels with rootlet anastomosis. On the basis of the variability found in their cadaveric study,

Karatas et al. [11] noted that the true pathologic level may be one higher or lower than what the symptoms dictate, and that careful assessment of the neurologic, physiological, and radiological findings should always be undertaken.

Variability in brachial plexus anatomy can also possibly explain some of the variation in the clinical presentation of radicular symptoms. The brachial plexus is comprised of the ventral rami of the C5–T1 spinal roots. Based on anatomic dissections of the plexus, a “typical” plexus is only observed 37%–77% of the time [4–6]. The two most common variants of the brachial plexus include prefixation and postfixation. Prefixation of the plexus occurs when the C4 nerve root provides considerable contribution to the plexus with the T1 nerve root providing minimal to no contribution. A postfixated plexus occurs when the plexus receives little to no contribution from the C5 nerve root and instead receives considerable innervation from the T2 nerve root. Overall, a prefixed plexus occurs more frequently than a postfixated plexus (26%–48% vs. 4%) [4–6,16–19]. Functionally, a prefixed or postfixated brachial plexus can shift the observed pattern of cervical radiculopathy one level cranial or caudal depending on the anatomic variant present [20].

A recent study by Rainville et al. reported on a case series of patients with MRI confirmed C6 or C7 nerve root compression with symptoms consistent with cervical radiculopathy [21]. The authors found that arm pain symptoms in these patients were diffuse in nature and not distinctly different between those patients with C6 or C7 nerve compression. Furthermore, patterns of weakness were not significantly different between the two groups. The authors concluded that given the degree of overlap in the presentation of C6 and C7 radiculopathy, practitioners should exercise caution when predicting root involvement based on symptoms.

There was a significant difference in laterality of symptoms, with right-sided symptoms arising in 51% of the standard group versus 28% in the nonstandard group. The reason for this finding cannot be determined from the present study, although a speculative etiology may include differences in the embryologic development of brachial plexus and spinal cord neuroanatomy, among other factors.

Ipsilateral neck pain, interscapular pain, and pain that radiates into the shoulder occurred frequently in patients in this study, irrespective of spinal level. Ipsilateral neck pain was found in 81% of the patients and was not found to differ by the level of spinal pathology. Similarly, shoulder pain was found in nearly 60% of the patients and also did not differ by the level of pathology. Isolated ipsilateral neck and/or shoulder pain without any distal radicular symptoms was less common but still observed in 19% of all patients. This presentation most commonly occurred at the C3–C4 (60%) and C4–C5 (33%) levels, where it could be considered consistent with the standard pattern. However, levels that are classically thought to present with symptoms distal to the shoulder, such as C5–C6 and C6–C7, did not do so 17% and 13% of the time in this study, presenting

only with neck and/or trapezial and/or shoulder symptoms. Conversely, we found that 40% of those with C3–C4 pathology had distal radicular symptoms, and 37.5% of those with C4–C5 pathology had additional symptoms distal to the elbow. Neither of these findings is consistent with a standard pattern.

There are potential limitations to be considered in evaluating our results. First, this is a retrospective study that relied on electronic medical record review and patient-derived pain diagrams to determine the presenting pattern of radiculopathy. Being a retrospective study, the patients were not prospectively reviewed to assess adherence to inclusion criteria, and there certainly could have been heterogeneity in interpretation of the MRI findings among the six treating surgeons. The MRI sequence was also not standardized in this series, as patients presented with MRIs were not only from our institution but from a multitude of outside institutions, potentially affecting interpretation as well. Second, we used a 75% or greater reduction in preoperative symptoms as an inclusion criterion for the study, with the 75% or greater improvement used as an indicator that the correct level of pathology had been addressed. However, it remains possible that radiculopathy at other levels could account for the remaining up to 25% of symptoms left unresolved in those who did not get 100% relief. Third, it is also possible that portions of the reported symptoms may be related to pathology other than radiculopathy. For example, segmental spondylosis may contribute to neck, shoulder, and trapezial symptoms. However, given the 75% postoperative improvement criterion, it remains likely that the symptoms are referable to the operative level, whether due to nerve root compression, spondylosis, or some combination of the two. Furthermore, surgery was never performed in this series for generalized, diffuse axial pain. In order to be indicated for surgery, any neck pain had to be unilateral and ipsilateral to demonstrable root compression, and it had to radiate to at least the shoulder area. Therefore, we believe the findings of this study remain relevant to clinical decision-making when ascribing symptoms to a cervical level demonstrating root compression.

In those presenting with nonstandard radicular complaints, careful assessment is required to determine the causative level(s). Findings on neurologic exam, such as motor weakness, sensory abnormalities, and reflex changes, are obviously of importance, but they are limited in that not all patients with cervical radiculopathy demonstrate neurologic findings. Reproduction of symptoms with Spurling maneuver, if present, implies a cervical source but does not identify a causative level. Detailed physical examination of the upper extremities should be performed, including assessment for common compressive neuropathies of the elbow and wrist such as cubital or carpal tunnel syndrome. Although additional information may be gleaned from

responses to selective nerve root injections and electrodiagnostic studies, there remains no clear evidence that either of these can be used reliably as predictive tests. We therefore do not routinely rely on electrodiagnostic tests when trying to identify a causative level(s) in cervical radiculopathy, although they may be helpful in evaluating nonspinal etiologies, such as peripheral neuropathy and compression (eg, carpal tunnel, cubital tunnel, etc.). In the end, identifying the causative level(s) in cervical radiculopathy remains a clinical process requiring both judgment and experience. We believe that the findings of this study will be useful when trying to reconcile non-standard symptoms with physical findings and imaging.

In conclusion, standard patterns of cervical radiculopathy were found in only 54% of patients undergoing single-level ACDF. This divergence from the accepted standard highlights the need for careful assessment of associated neurologic, physical, radiological, and other findings, as a nonstandard clinical pattern is frequently encountered. It is not only possible, but actually relatively common, for patients with C3–C4 or C4–C5 radiculopathy to complain of distal symptoms that seemingly do not make “sense.” Similarly, we found that it is also relatively common for patients with C5–C6 or C6–C7 radiculopathy to complain only of proximal symptoms. In order to appropriately treat patients presenting with cervical radiculopathy, practitioners must think broadly when identifying causative levels because they frequently do not adhere to the accepted standard in actual clinical practice.

Acknowledgment

There were no sources of funding for this study.

References

- [1] Crette S, Fehlings MG. Clinical practice. Cervical radiculopathy. *N Engl J Med* 2005;353:392–9. doi: [10.1056/NEJMc043887](https://doi.org/10.1056/NEJMc043887).
- [2] Ellenberg MR, Honet JC, Treanor WJ. Cervical radiculopathy. *Arch Phys Med Rehab* 1994;75:342–52.
- [3] Fouyas IP, Statham PF, Sandercock PA. Cochrane review on the role of surgery in cervical spondylotic radiculomyelopathy. *Spine* 2002;27:736–47.
- [4] Lee HY1, Chung IH, Sir WS, Kang HS, Lee HS, Ko JS, et al. Variations of the ventral rami of the brachial plexus. *J Korean Med Sci* 1992;7:19–24. doi: [10.3346/jkms.1992.7.1.19](https://doi.org/10.3346/jkms.1992.7.1.19).
- [5] Matejcik V. Variations of nerve roots of the brachial plexus. *Bratisl Lek Listy* 2005;106:34–6.
- [6] Uysal II, Seker M, Karabulut AK, Büyükmumcu M, Ziylan T, et al. Brachial plexus variations in human fetuses. *Neurosurgery* 2003;53:676–84. discussion 684.
- [7] Tanaka N1, Fujimoto Y, An HS, Ikuta Y, Yasuda M, et al. The anatomic relation among the nerve roots, intervertebral foramina, and intervertebral discs of the cervical spine. *Spine* 2000;25:286–91.
- [8] Perneckzy A, Sunder-Plassmann M. Intradural variant of cervical nerve root fibres. Potential cause of misinterpreting the segmental location of cervical disc prolapses from clinical evidence. *Acta Neurochir (Wien)* 1980;52:79–83.
- [9] Pallie W, Manuel JK. Intersegmental anastomoses between dorsal spinal rootlets in some vertebrates. *Acta Anat (Basel)* 1968;70:341–51.
- [10] Pallie W. The intersegmental anastomoses of posterior spinal rootlets and their significance. *J Neurosurg* 1959;16:188–96. doi: [10.3171/jns.1959.16.2.0188](https://doi.org/10.3171/jns.1959.16.2.0188).
- [11] Karatas A1, Caglar S, Savas A, Elhan A, Erdogan A, et al. Microsurgical anatomy of the dorsal cervical rootlets and dorsal root entry zones. *Acta Neurochir (Wien)* 2005;147:195–9. discussion 199. doi: [10.1007/s00701-004-0425-y](https://doi.org/10.1007/s00701-004-0425-y).
- [12] Murphy DR1, Hurwitz EL, Gerrard JK, Clary R, et al. Pain patterns and descriptions in patients with radicular pain: does the pain necessarily follow a specific dermatome? *Chiropr Osteopat* 2009;17:9. doi: [10.1186/1746-1340-17-9](https://doi.org/10.1186/1746-1340-17-9).
- [13] Keegan JJ, Garrett FD. The segmental distribution of the cutaneous nerves in the limbs of man. *Anat Rec* 1948;102:409–37.
- [14] Netter FH. *Atlas of human anatomy*. 6th ed. Philadelphia: Saunders/Elsevier; 2015.
- [15] Kubo Y1, Waga S, Kojima T, Matsubara T, Kuga Y, Nakagawa Y, et al. Microsurgical anatomy of the lower cervical spine and cord. *Neurosurgery* 1994;34:895–902; discussion 901–2.
- [16] Tubbs RS1, Loukas M, Shoja MM, Ardalani MR, Apaydin N, Myers C, et al. Contributions of the fourth spinal nerve to the brachial plexus without prefixation. *J Neurosurg Spine* 2008;8:548–51. doi: [10.3171/SPI/2008/8/6/548](https://doi.org/10.3171/SPI/2008/8/6/548).
- [17] Matejcik V. Aberrant formation and clinical picture of brachial plexus from the point of view of a neurosurgeon. *Bratisl Lek Listy* 2003;104:291–9.
- [18] Loukas M, Louis Jr. RG, Wartmann CT. T2 contributions to the brachial plexus. *Neurosurgery* 2007;60:ONS13–8 discussion ONS18. doi: [10.1227/01.NEU.0000249234.20484.2A](https://doi.org/10.1227/01.NEU.0000249234.20484.2A).
- [19] Johnson EO, Vekris M, Demesticha T, Soucacos PN, et al. Neuroanatomy of the brachial plexus: normal and variant anatomy of its formation. *Surg Radiol Anat* 2010;32:291–7. doi: [10.1007/s00276-010-0646-0](https://doi.org/10.1007/s00276-010-0646-0).
- [20] Kuzma SA, Doberstein ST, Rushlow DR. Postfixed brachial plexus radiculopathy due to thoracic disc herniation in a collegiate wrestler: a case report. *J Athl Train* 2013;48:710–5. doi: [10.4085/1062-6050-48.5.03](https://doi.org/10.4085/1062-6050-48.5.03).
- [21] Rainville J, Joyce AA, Laxer E, Pena E, Kim D, Milam RA, et al. Comparison of symptoms from C6 and C7 radiculopathy. *Spine (Phila Pa 1976)* 2017;42:1545–51. doi: [10.1097/BRS.0000000000002353](https://doi.org/10.1097/BRS.0000000000002353).