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Anatomical variations and coding of the intra-trunk pathways in the thoracodorsal nerve

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ABSTRACT

Aim. To study anatomical variations of the intra-trunk pathways in the thoracodorsal nerve bundles and to develop a system for their coding.

Materials and methods. After fixation in a 2% solution of acetic acid using the MBS-10 stereomicroscope, we performed macro- and microscopic intra-trunk dissection of thoracodorsal nerve bundles in 121 specimens obtained from 105 corpses of males and females who died at the age of 40–97 years. Using the obtained findings, we compiled a database in the MS Excel 12.0 software and determined the number of anatomical variations in absolute and relative (% from 121 specimens) units.

Results. The study revealed that the thoracodorsal nerve is a mixed nerve, which consists of 1 motor and 1–3 sensory bundles that variously pass through the spinal nerves, trunks, and the axillary nerve with the formation of 20 intra-trunk pathways. In 77% of cases, sensory bundles arising from the thoracodorsal nerve pass through the posterior bundle, the posterior division, the middle trunk, and the C7 spinal nerve or the inferior trunk and the C8 spinal nerve. In 22% of cases, the thoracodorsal nerve has one or, rarely, two duplicate sensory pathways besides the main one. In 93% of cases, the motor bundle to the thoracodorsal nerve passes through the C7 spinal nerve and the middle trunk, the posterior division, and the posterior bundle. Coding the anatomical variations of the intra-trunk pathways in the direction of sensory bundle «posterior bundle → posterior division → trunk → spinal nerve; motor bundle ← posterior bundle ← posterior division ← trunk ← spinal nerve allows to briefly yet clearly and fully display the morphological diversity of the nerve anatomy.

Conclusion. The identified anatomical variations of the intra-trunk pathways can be useful in the diagnosis of injuries and diseases. They expand indications for the use of spinal nerves, trunks of the brachial plexus, and the thoracodorsal nerve in reconstructive surgery.

Keywords: thoracodorsal nerve, intra-trunk pathways, sensory bundles, motor bundle, mixed bundle, anatomical variations, codes

Conflict of interest. The authors declare the absence of obvious and potential conflicts of interest related to the publication of this article.

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Вариантная анатомия и коды внутриствольных путей грудоспинного нерва

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РЕЗЮМЕ

Цель – изучить варианты внутриствольных путей пучков грудоспинного нерва и разработать систему их кодирования.

Материалы и методы. После фиксации в 2%-м растворе уксусной кислоты с помощью стереоскопической лупы МБС-10 выполнено макромикроскопическое внутриствольное препарирование пучков грудоспинного нерва на 121 препарате плечевого сплетения от 105 трупов мужчин и женщин в возрасте 40–97 лет. Из полученных показателей в программе MS Excel 12 сформирована база данных и проведено определение количества встречающихся вариантов строения в абсолютных и относительных (% от 121 препарата) единицах.

Результаты. Проведенное исследование позволило выявить, что грудоспинный нерв является смешанным нервом, состоит из 1–3 чувствительных и одного двигательного пучков, которые неодинаково проходят через спинномозговые нервы, стволы, подмышечный нерв с образованием 20 внутриствольных путей. В 77% случаев чувствительные пучки от грудоспинного нерва проходят через задний пучок, заднее разделение, средний ствол и спинномозговой нерв С7 или нижний ствол и С8. В 22% у грудоспинного нерва кроме основного имеется еще один, редко – два дублирующих чувствительных пути. Двигательный пучок до грудоспинного нерва в 93% проходит через спинномозговой нерв С7 и средний ствол, заднее разделение и задний пучок. Кодирование вариантов внутриствольных путей в направлении чувствительный пучок → задний пучок → заднее разделение → ствол → спинномозговой нерв; двигательный пучок ← задний пучок ← заднее разделение ← ствол ← спинномозговой нерв позволяет кратко, наглядно и полно отобразить все морфологические разнообразия строения.

Заключение. Выявленные варианты внутриствольных путей могут быть полезны при диагностике травм и заболеваний, расширяют показания использования спинномозговых нервов и стволов плечевого сплетения, грудоспинного нерва в реконструктивных операциях.

Ключевые слова: грудоспинный нерв, внутриствольные пути, чувствительные пучки, двигательный пучок, смешанный пучок, варианты, коды

Конфликт интересов. Авторы декларируют отсутствие явных и потенциальных конфликтов интересов, связанных с публикацией настоящей статьи.

Источник финансирования. Исследование поддержано Красноярским краевым фондом науки.

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INTRODUCTION

The brachial plexus has been studied in detail and is characterized by significant anatomical variations [1, 2]. However, in clinical practice, anatomical variations of the brachial plexus are more common than reported and account for 50% of all features of the nervous system [3]. Despite great uncertainty of the somatotopic arrangement, sensory and motor nerve fibers tend to group into bundles [4], which are studied in sections by histologic, histochemical, and immunohistochemical methods [5, 6]. In clinical practice, the knowledge of anatomical variations of the intra-trunk pathways in the nerve bundles from organs to the central parts of the nervous system is in demand [7, 8]. This is especially relevant due to advances in microsurgical technologies used in peripheral nerve bundles [9, 10]. A detailed comparison and ligation of unfunctional bundles in accordance with their intra-trunk topography are the key to successful restoration of nerve mobility and sensitivity in full [11, 12].

Despite the active use of the thoracodorsal nerve in the clinical practice [13, 14], few studies have been devoted to its fascicular anatomy [15–17]. However, existing works do not describe the features of the path of each thoracodorsal nerve bundle along its entire length with account of functional affiliation.

The aim of this study was to investigate anatomical variations of the intra-trunk pathways in the thoracodorsal nerve bundles and to develop a system for their coding.

MATERIALS AND METHODS

The study was conducted at the Department of Postmortem Examination of the Krasnoyarsk Regional Bureau of Forensic Medical Examination using 121 brachial plexus specimens obtained from 105 corpses of males and females who died at the age of 40–97 years. Most of the examined corpses were male (76–69%); 29–31% were female. The cause of death in all cases was somatic symptom disorder without head, neck, upper limb, and chest injuries.

The brachial plexus was studied on the right side in all corpses, and bilaterally in 16 corpses. The predominant choice of the side was associated with a large number of right-sided injuries and surgical interventions.

Anatomical variations in the thoracodorsal nerve were studied using macro- and microscopic intra-trunk dissection. At the first stage, layer-by-layer anatomical dissection was carried out with isolation of a fragment of the cervical and thoracic spine, radicu-

lar filaments, anterior (motor) and posterior (sensory) roots, anterior branches of the spinal nerves, trunks, posterior divisions, posterior bundles, and axillary and thoracodorsal nerves.

The isolated brachial plexus specimen was placed for 1–3 days in a 10% neutral buffered formalin solution and then fixed in a 2% acetic acid solution. The choice of acetic acid is associated with its ability to counteract the shrinkage effect and dissolution of collagen in the epi- and perineurium [18].

At the second stage, macro- and microscopic intra-trunk dissection of the thoracodorsal nerve bundles along the entire length of the brachial plexus (from the latissimus dorsi muscle to the spinal cord) was performed using the MBS-10 stereomicroscope. Special attention was paid to identifying spinal nerve roots through which the thoracodorsal nerve bundles passed, which made it possible to identify their functional affiliation: motor bundles passed through the anterior roots, and sensory bundles passed through the posterior roots.

The article presents the study results after investigating 121 brachial plexus specimens obtained from 105 corpses without gender distinction and bilateral affiliation. This is due to the fact that we did not identify statistically significant gender and bilateral differences in the incidence of anatomical variations of intra-trunk pathways in the thoracodorsal nerve.

All identified features of the intra-trunk pathways in the thoracodorsal nerve were input into the MS Excel 12.0 program (Microsoft Corporation, USA), and the number of anatomical variations in absolute and relative (% from 121 specimens) units was determined.

RESULTS

The macro- and microscopic dissection revealed that the thoracodorsal nerve has clear fascicular anatomy and consists of a different number (1–4) of bundles. Further proximal dissection of these bundles made it possible to determine their functional affiliation and anatomical variations of the intra-trunk pathways. The functional affiliation of the bundles in the thoracodorsal nerve was determined on the basis of their passage through the roots of the spinal nerve: through the posterior roots – sensory bundles, through the anterior roots – motor bundles (Figure).

The precisely established functional affiliation of each thoracodorsal nerve bundle made it possible to determine their number. In 98% of cases (119 / 121), 1–3 sensory bundles and only one motor bundle were

observed in the thoracodorsal nerve. In two plexuses out of 121, sensory and motor bundles in the thoracodorsal nerve were tightly intertwined, and it was not possible to determine their number via intra-trunk dissection. In 119 plexuses where the isolated fascicular anatomy of the thoracodorsal nerve was determined, most often (77% – 92 / 121) one bundle was sensory, and the other one was motor, less often (22% – 26 / 121) two bundles were sensory and one bundle was motor. In one plexus out of 121, there were three sensory and one motor bundles.

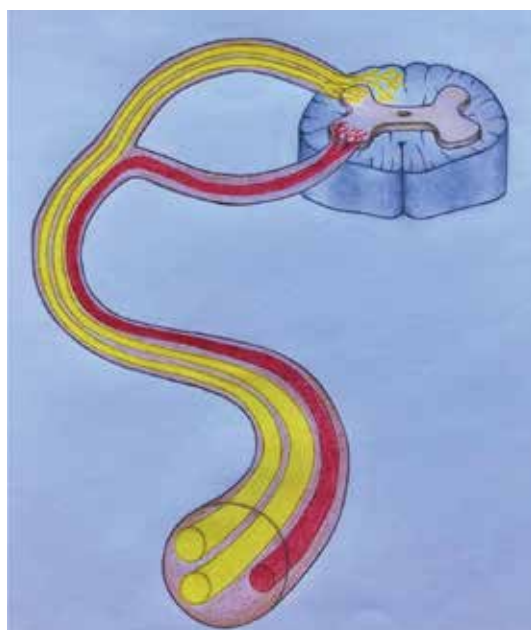


Figure. Schematic representation of the sensory (indicated in yellow) and motor (red) bundles of the thoracodorsal nerve: 1 – spinal cord, 2 – posterior (sensory) root, 3 – anterior (motor) root, 4 – spinal nerve.

In 94% of cases (114 / 121), sensory and motor bundles from the thoracodorsal nerve passed into the posterior bundle of the brachial plexus, and in seven plexuses out of 121, they passed first into the axillary nerve and then also into the posterior bundle. It was further established that the thoracodorsal nerve bundles variously passed in the anterior branches of three spinal nerves: C6, C7, and C8.

Studying the path of each bundle throughout the entire latissimus dorsi muscle to the spinal cord identified 20 anatomical variations of the intra-trunk pathways in the thoracodorsal nerve. To clearly demonstrate the identified pathways, we developed a system for coding the anatomical variations in the direction: sensory bundle → posterior bundle → posterior division → trunk → spinal nerve; motor bundle ← pos-

terior bundle ← posterior division ← trunk ← spinal nerve (Table). As seen from the Table, the first three variations are more common (72% – 87 / 121), variations 4–8 are less common (18% – 22 / 121), and the remaining twelve variations are rare and occur in a single case each (10% – 12 / 121).

Table

Codes for anatomical variations of the intra-trunk pathways in the thoracodorsal nerve, <i>n</i> = 121		
Variation number	Code	Number
1	SB→PB→PD→MT→C7; MB←PB←PD←MT←C7	43
2	SB→PB→PD→IT→C8; MB←PB←PD←MT←C7	30
3	SB→PB→PD→MT→C7; SB→PB→PD→IT→C8; MB←PB←PD←MT←C7	14
4	SB→PB→PD→IT→C8; MB←PB←PD←IT←C8	7
5	SB→PB→PD→MT→C7; SB→PB→PD→MT→C7; MB←PB←PD←MT←C7	5
6	SB→PB→PD→ST→C6; MB←PB←PD←MT←C7	4
7	SB→PB→PD→ST→C6; SB→PB→PD→IT→C8; MB←PB←PD←MT←C7	4
8	SB→Ax→PB→PD→IT→C8; MB←Ax←PB←PD←IT←C8	2
9	SB→PB→PD→ST→C7; MB←PB←PD←ST←C7	1
10	SB→PB→PD→IT→C8; MB←PB←PD←ST←C7	1
11	SB→Ax→PB→PD→IT→C8; MB←Ax←PB←PD←MT←C7	1
12	SB→Ax→PB→PD→IT→C8; MB←Ax←PB←PD←IT←C7	1
13	SB→Ax→PB→PD→MT→C7; SB→Ax→PB→PD→MT→C7; MB←Ax←PB←PD←MT←C7	1
14	SB→Ax→PB→PD→ST→C6; MB←Ax←PB←PD←MT←C7	1
15	SB→PB→PD→ST→C6; MB←PB←PD←IT←C7	1
16	SB→PB→PD→MT→C6; SB→PB→PD→IT→C8; MB←PB←PD←MT←C7	1
17	SB→PB→PD→BC→C6; SB→PB→PD→MT→C7; MB←PB←PD←MT←C7	1
18	MB1DPBDDMTDC7	1
19	MB1DAxDPBDDMTDC7	1
20	SB→PB→PD→BC→C6; SB→PB→PD→MT→C7; SB→PB→PD→IT→C8; MB←PB←PD←MT←C7	1

Note: SB – sensory bundle; MB – motor bundle; MB – mixed bundle; Ax – axillary nerve; PB – posterior bundle of the brachial plexus; PD – posterior division; ST – superior trunk; MT – middle trunk; IT – inferior trunk; C6, C7, C8 – ventral branches of spinal nerves; →, ←, D – direction of nerve impulse conduction

The coding system allows to briefly yet clearly and fully display all the anatomical variations of the intra-trunk pathways in the thoracodorsal nerve. So, the first anatomical variation is deciphered as follows: the thoracodorsal nerve has a two-bundle structure, where the sensory and motor bundles pass along the C7 spinal nerve, then through the middle trunk, its posterior division, and the posterior bundle.

The study showed that the sensory bundles of the thoracodorsal nerve passed through most components of the brachial plexus. The sensory bundles primarily passed through the C7 spinal nerve and the middle trunk (42% – 51 / 121), as well as through the C8 spinal nerve and the inferior trunk (35% – 42 / 121). It is possible that they are the main sensory pathways in the thoracodorsal nerve. In 22% of cases (26 / 121), the thoracodorsal nerve had one more duplicate sensory pathway besides the main one, and one plexus out of 121 had two duplicate sensory pathways.

Unlike sensory bundles, the motor pathway was not duplicated and passed through the C7 spinal nerve (93% – 112 / 121) and the middle trunk (89% – 108 / 121), less often – through the C8 spinal nerve (nine plexuses out of 121) and the inferior trunk (11 plexuses out of 121), rarely – through the C7 spinal nerve and the superior trunk (two plexuses out of 121).

Thus, using macro- and microscopic dissection of the thoracodorsal nerve, 20 anatomical variations of intra-trunk pathways were identified. Duplicate pathways of sensory bundles were revealed. To illustrate the entire structural diversity and simplify the use of anatomical variations in clinical practice, a coding system for the identified intra-trunk pathway variations was proposed. The obtained data on intra-trunk pathway variations in the thoracodorsal nerve can be used in reconstructive surgery and in clinical practice to diagnose injuries and diseases.

DISCUSSION

The macro- and microscopic intra-trunk dissection revealed that the thoracodorsal nerve is a mixed nerve with clear fascicular anatomy which contains mostly sensory bundles (1–3) and only one motor bundle. These results confirm the findings obtained by B. Gesslbauer et al. (2017), who, using the immunofluorescence method, counted 6,904 ($\pm$ 3,070) axons in the thoracodorsal nerve, of which 5,977 ($\pm$ 3,066) were sensory and 927 ($\pm$ 79) were motor [17]. This predominance of sensory fibers and bundles over motor ones in the nerve allows to get complete informa-

tion about the state of the latissimus dorsi muscle and to constantly coordinate and correct its contractions.

The determination of the functional affiliation of the thoracodorsal nerve bundles was achieved due to their thorough dissection along the entire length of the brachial plexus after fixation in a 2% acetic acid solution. W. Lu et al. (2008) used a similar technique but managed to dissect the thoracodorsal nerve bundles only to the level of the brachial plexus trunks [15]. We managed to trace the path of the thoracodorsal nerve bundles further – in the spinal nerves and their anterior (motor) and posterior (sensory) roots. We did not find similar works in the available literature.

Such an anatomical approach has two advantages over histochemical, electrophysiological, and instrumental methods and allows not only to accurately determine the functional affiliation of each bundle, but also to trace their path along the entire length of the brachial plexus (from the latissimus dorsi muscle to the spinal cord). As a result, 20 anatomical variations of the intra-trunk pathways in the thoracodorsal nerve were identified. Moreover, variable and stable regions were established. The posterior divisions, the posterior bundle, and the roots of the spinal nerves are stable regions (sensory bundles pass through the posterior roots, motor bundles pass through the anterior roots), while the spinal nerves and trunks are variable ones.

The main number of variations are associated with the unequal passage of sensory and motor bundles through the superior, middle, and inferior trunks, and C6, C7, and C8 spinal nerves. The isolation of the remaining six variations is associated with the passage of the thoracodorsal nerve bundles through the axillary nerve. According to R. Rastogi et al. (2013), the thoracodorsal nerve departed from the axillary nerve in 23% of cases [19], and according to our data, it occurred in seven out of 121 plexuses.

The predominant path for the sensory bundles is the middle trunk and C7 (42%) or the inferior trunk and C8 (35%), and for the motor bundles – C7 (93%) and the middle trunk (89%). This is somewhat different from the findings obtained by W. Lu et al. (2008), who found that more than 52% of motor fibers in the thoracodorsal nerve originate in C7 [15]. According to K. S. Lee (2007), most often (in 60%) the thoracodorsal nerve originates in two spinal nerves C7 and C8, less often – in C6, C7, and C8 (25%), C6 and C7 (10%), and C7 (5%) [20]. We identified one more variation where only the C8 spinal nerve is involved in the formation of the thoracodorsal nerve, which occurred in nine out of 121 plexuses and has not been

described in the literature. Our data differ from the results obtained by W. Lu et al. (2008), which identified only three variations of the path of the thoracodorsal nerve bundles through the trunks: superior and middle (5%), all three trunks (85%), middle and inferior (10%) [15]. According to our data, the passage of bundles through all three trunks was detected only in five plexuses out of 121. Apparently, all observed differences are associated with regional and ethnic features or different amount of studied material.

The study revealed that the thoracodorsal nerve has a single motor pathway and duplicate sensory pathways, which occur in 22% of cases. There is no information in the literature about duplicate sensory pathways in the thoracodorsal nerve.

To illustrate the entire structural diversity, as well as to simplify the use of anatomical variations in clinical practice, we developed a coding system for the identified variations of intra-trunk pathways in the direction: sensory bundle » posterior bundle « posterior division « trunk « spinal nerve; motor bundle ! posterior bundle ! posterior division ! trunk ! spinal nerve.

On the basis of the obtained data, we determined the regularity of the intra-trunk pathway formation in the thoracodorsal nerve. It is characterized by a larger number of variations of sensory bundles in the proximal parts of the brachial plexus. Possibly, embryonic growth of neuronal processes in the rudiment of the arm early along the path is very susceptible to obstacles, which leads to intra-trunk diversity of sensory bundles [21]. A more stable intra-trunk path of the motor bundle is due to the fact that dendrites grow faster and axons orient themselves according to them [22]. Young motor fibers move along existing tracts and encounter fewer obstacles [23].

The identified anatomical variations of the intra-trunk pathways can be useful in the diagnosis of injuries and diseases. They expand indications for the use of spinal nerves, trunks of the brachial plexus, and the thoracodorsal nerve in reconstructive surgery.

CONCLUSION

1. The thoracic nerve is a mixed nerve, which consists of one motor and 1–3 sensory bundles that variously pass through the spinal nerves, trunks, and the axillary nerve with the formation of 20 intra-trunk pathways.

2. In most cases, sensory bundles from the thoracodorsal nerve pass through the posterior bundle, the posterior division, and the middle trunk to the C7 spinal nerve (42%) or the inferior trunk and the C8

spinal nerve (35%). In 22% of cases, the thoracodorsal nerve has one or, rarely, two duplicate sensory pathways besides the main one.

3. The path of the motor bundle to the thoracodorsal nerve is not duplicated and in most cases passes through the C7 spinal nerve (93%) and the middle trunk (89%) and then through the posterior division and the posterior bundle.

4. Coding anatomical variations of the intra-trunk pathways in the thoracodorsal nerve makes it possible to briefly yet clearly and fully display the entire morphological diversity of the nerve anatomy.

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Authors' contribution

Gorbunov N.S. – scientific supervisor of the study, final approval of the manuscript for publication. Kober K.V., Kasparov E.V., Rostovtsev S.I., Protasyuk E.N. – carrying out of the research, collection and analysis of the data.

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