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Anatomical Substantiation of the Thoracodorsal Nerve as a Donor Nerve and the Musculocutaneous Nerve as a Recipient Nerve

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ABSTRACT

Aim. To identify the correspondence in the diameter of the thoracodorsal and musculocutaneous nerves, depending on the level of branching.

Materials and Methods. Using 121 preparations of the brachial plexus from 105 corpses of men and women aged 40–97 years, the diameter of the thoracodorsal nerve was measured at five levels, and the diameter of the musculocutaneous nerve was determined at two levels. For each parameter, the median and the interquartile range *Me* [Q_1; Q_3] were determined. The significance of differences between the groups was found by the Mann – Whitney test. The differences were considered significant at $p < 0.05$. The correlation was evaluated by the Spearman's rank correlation coefficient. At $0.7 \leq r_s < 0.9$, the correlation was regarded as strong, at $0.5 \leq r_s < 0.7$ – as moderate.

Results. The diameter of the thoracodorsal nerve varied throughout its length: in the initial section, it was 1.66 [1.66; 1.99] mm, before branching – 3.00 [2.65; 3.50] mm, at the first- and second-order extramuscular branches – 4.2 [3.2; 5.0] mm and 5.25 [4.50; 6.50] mm, at the first-order intramuscular branches – 4.00 [3.50; 4.66] mm. The diameter of the musculocutaneous nerve in the initial section was 3.0 [2.6; 3.3] mm, and before the coracobrachialis muscle – 2.7 [2.4; 3.0] mm.

The total diameter of the extra- and intramuscular branches of the thoracodorsal nerve was equal to or greater than the thickness of the musculocutaneous nerve in 90.1–95.0% of cases. Excess total diameter of the branches of the thoracodorsal nerve (0.05–8.0 mm) and fascicular dissection make it possible to preserve 1–2 first- and second-order extramuscular branches and 1–4 first-order intramuscular branches.

Conclusion. The diameter of the thoracodorsal nerve in the initial section is smaller than that of the musculoskeletal nerve, but the total thickness of its extra- and intramuscular branches is equal to or greater by 0.05–8.0 mm in 90.1–95.0% of cases. Different levels of branching of the thoracodorsal nerve contribute to extended transfer, and an excess diameter with fascicular dissection will preserve the function of the latissimus dorsi muscle.

Keywords: thoracodorsal nerve, musculocutaneous nerve, levels of branching, latissimus dorsi muscle, fascicular dissection

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Анатомическое обоснование грудоспинного нерва как нерва-донора и мышечно-кожного нерва как нерва-реципиента

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РЕЗЮМЕ

Цель – выявить соответствие диаметров у грудоспинного и мышечно-кожного нервов в зависимости от уровня ветвления.

Материалы и методы. На 121 препарате плечевого сплетения от 105 трупов мужчин и женщин в возрасте 40–97 лет измерен диаметр грудоспинного нерва на пяти, а мышечно-кожного – двух уровнях. У каждого показателя определена медиана межквартильного интервала *Me* [Q_1; Q_3]. Значимость различий в группах находили по *U*-тесту Манна – Уитни. Различия считались значимыми при $p < 0,05$. Сопряженность оценивали по коэффициенту Спирмена. При значении $0,7 \leq rs < 0,9$ связь расценивали как сильную, $0,5 \leq rs < 0,7$ – средней силы.

Результаты. Диаметр грудоспинного нерва изменяется на всем протяжении: в начальном отделе – 1,66 [1,66; 1,99] мм, перед разделением на ветви – 3,00 [2,65; 3,50] мм, на уровне внемышечных ветвей первого и второго порядков – 4,2 [3,2; 5,0] мм и 5,25 [4,50; 6,50] мм, внутримышечных ветвей первого порядка – 4,00 [3,50; 4,66] мм. Диаметр мышечно-кожного нерва в начальном отделе равен 3,0 [2,6; 3,3] мм, а перед клювовидно-плечевой мышцей – 2,7 [2,4; 3,0] мм. Общий диаметр вне- и внутримышечных ветвей грудоспинного нерва равен или больше толщины мышечно-кожного в 90,1–95,0%. Избыток общего диаметра ветвей грудоспинного нерва (0,05–8,0 мм) и фасцикулярная диссекция позволят сохранить по 1–2 внемышечные ветви первого и второго порядков, 1–4 внутримышечные ветви первого порядка.

Заключение. Диаметр грудоспинного нерва в начальном отделе меньше, чем у мышечно-кожного, но общая толщина его вне- и внутримышечных ветвей равна или больше на 0,05–8,0 мм в 90,1–95,0%. Разные уровни ветвления грудоспинного нерва способствуют протяженному переносу, а избыток диаметра с фасцикулярной диссекцией позволит сохранить функцию широчайшей мышцы спины.

Ключевые слова: грудоспинной нерв, мышечно-кожный нерв, уровни ветвления, широчайшая мышца спины, фасцикулярная диссекция

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

Источник финансирования. Авторы заявляют об отсутствии финансирования при проведении исследования.

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INTRODUCTION

Despite the encouraging and predictable results of surgical treatment for injured nerves, questions regarding the choice of a donor remain relevant. [1, 2]. Countless studies specify the main requirements that potential nerve donors must meet [3–5]. First of all, they must be sufficient in length, match the diameter of the recipient, and minimally disrupt the function of the muscles innervated by the donor nerve. [6].

Thoracodorsal nerve (TDN) is a mixed nerve that contains a sufficient amount of sensory (85%) and motor (15%) fibers and has a convenient location and optimal size, which allows it to be used as a donor, including for transfer to the position of the damaged musculocutaneous nerve (MCN) [7–9]. The anatomy of the TDN has been studied in great detail. It has been established that this nerve is formed from the spinal nerves C7, C8 and less frequently from C6–C8. Its length ranges from 12.3 to 14.1 cm, with a diameter of 2.1 to 3.0 mm. The number of extramuscular branches is 1–4, and the number of myelinated fibers ranges from 1,530 to 9,974. [8, 10, 11]. However, despite the conducted research, there is no information about the diameter of the TDN at different levels of branching, which complicates its selection as a donor nerve.

Considering the above, the aim of this study was to identify the correspondence of the diameters of TDN and MCN depending on the level of branching.

MATERIALS AND METHODS

Anatomical dissection was conducted on 105 human cadavers (66 men and 39 women) aged 40–97 years, with 121 specimens of the brachial plexus (105 from the right side and 16 from the left) at the Department of Forensic Examination of the Krasnoyarsk Regional Bureau of Forensic Medical Expertise and at the Department of Operative Surgery and Topographic Anatomy of the Krasnoyarsk State Medical University named after Professor V.F. Voyno-Yasenetsky. The time from the death of individuals to the examination was up to 20 hours, and the bodies were stored in a refrigeration chamber at a temperature of 3–5 °C. The cause of death for all individuals was systemic disease without head, neck, upper limbs, and thorax injuries. The research protocol was approved by the Ethics Committee at Krasnoyarsk State Medical University named after Professor V.F. Voyno-Yasenetsky (Minutes No. 127/24 dated September 25, 2024).

Anatomical layer-by-layer dissection of all elements of the brachial plexus was performed on the human corpses with the isolation of TDN and MCN (Figure). Special attention was paid to the extra- and intramuscular branches of TDN. Using an NTB-4B microscope (China), the epineurium was removed from TDN and MCN, leaving the perineurium intact. The length of various segments of TDN along its entire length was measured with an electronic caliper.

The diameter of TDN was measured at five levels using the eyepiece scale of the microscope: 1 – immediately after branching from the posterior bundle; 2 – before splitting into extramuscular branches; 3 – after splitting into first-order extramuscular branches; 4 – after splitting into second-order extramuscular branches; 5 – after splitting into first-order intramuscular branches. At the last three levels, the total diameter of all branches was determined.

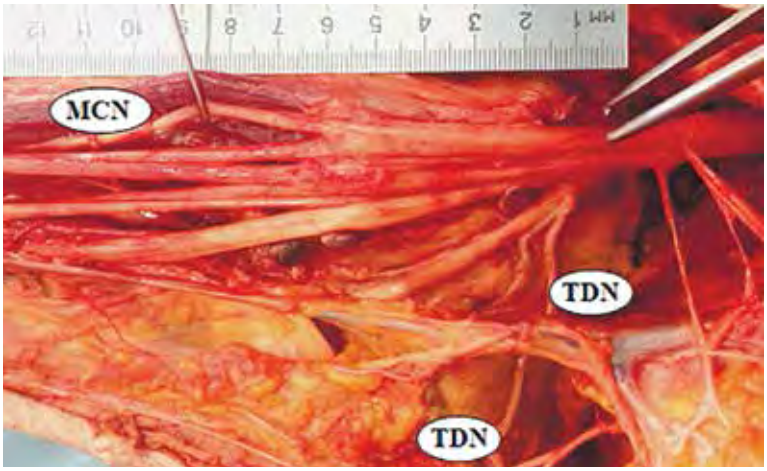

Figure. Musculocutaneous nerve (MCN) and thoracodorsal nerve (TDN) nerves in the right brachial plexus of the male corpse aged 62 years

The diameter of MCN was measured at two levels: 1 – after branching from the lateral bundle; 2 – before entering the coracobrachialis muscle.

After measuring the diameters of the nerves in each brachial plexus specimen (n = 121), a paired comparison was made between the thickness measurements of the donor nerve – TDN at five levels and the corresponding measurements of the recipient nerve – MCN at two levels. The absolute and relative (%) number of specimens where the diameter of the donor nerve was equal to, greater than or less than that of the recipient nerve was determined.

The conclusions of the study were obtained on the basis of statistical processing of data obtained from the entire sample population, since no significant gender, age, or bilateral features of the TDN and MCN diameters (from p = 0.08 to p = 1.0) were revealed. All obtained data were entered into MS Excel 12.0 software (Microsoft Corporation, USA). Using Statistica for Windows 12.0 (StatSoft, USA), normality of distribution was tested using the Shapiro – Wilk test, and thereafter non-parametric methods were employed. Minimum and maximum values, as well as the median and the interquartile range Me [Q_1; Q_3] were determined for each parameter. The significance of differences between nerve diameters was assessed using the Mann – Whitney U-test. The differences were considered significant at $p < 0.05$. The correlation between the diameter of TDN and the length of its segments was evaluated using the Spearman's rank correlation coefficient (rs). A coefficient value of $0.7 \leq rs < 0.9$ indicated a strong correlation, while $0.5 \leq rs < 0.7$ indicated a moderate correlation.

RESULTS

The conducted study revealed that the diameter of the TDN significantly changes along its entire length up to the latissimus dorsi muscle. After branching from the posterior bundle of the brachial plexus, the diameter of the TDN ranges from 0.83 to 3.33 mm, with a median of 1.66 [1.66; 1.99] mm. In the distal section, the diameter of the TDN increases and reaches 3.00 [2.65; 3.50] mm ($p < 0.001$) before splitting into extramuscular branches, at a distance of 9.5 [8.3; 11.0] cm from the point of origin. After the splitting, the total diameter of the first-order extramuscular branches at a distance of 12.5 [11.5; 14.3] cm is 4.2 [3.2; 5.0] mm ($p < 0.001$), while for the second-order branches at 14.1 [11.5; 15.5] cm, it is 5.25 [4.50; 6.50] mm ($p < 0.001$), and for the first-order intramuscular branches at 18.7 [16.3; 21.0] cm, it is 4.00 [3.50; 4.66] mm ($p < 0.001$). Correlation analysis revealed a strong but insignificant correlation between the length and diameter of the TDN (rs = 0.828; p = 0.083).

The diameter of the MCN after branching from the lateral bundle varies from 1.5 to 5.0 mm, with a median of 3.0 [2.6; 3.3] mm, and at a distance of 6.0 [4.5; 7.8] cm, before reaching the coracobrachialis muscle, it makes 2.7 [2.4; 3.0] mm ($p < 0.001$). Statistical analysis showed that these values are greater than the diameter of the TDN in the initial segment ($p < 0.001$), equal to and smaller than the TDN diameter before splitting into branches (p = 0.167 and $p < 0.001$), and smaller than the TDN diameter at all subsequent levels ($p < 0.001$).

In pairwise comparisons of the two nerves in each specimen of the brachial plexus, it was established that TDN is qualified as a donor nerve at the level of first- and second-order extramuscular branches and first-order intramuscular branches, with total diameters that are equal to or greater by 0.05–8.0 mm than the diameter of the MCN in the initial segment in 90.1–92% of cases and before reaching the coracobrachialis muscle in 93.4–95% of cases (Table).

Choosing TDN with branches at different levels expands the surgeon's options and allows for selecting a longer and appropriately sized donor nerve, transferring it as close as possible to the denervated muscle, which will shorten the path and time for regeneration. A positive aspect of using TDN as a donor nerve is that its excess diameter of 0.05–8.0 mm allows for fascicular dissection and transfer of individual branches, thereby preserving the function of the latissimus dorsi muscle.

Table

Compliance of Diameters of TDN and MCN at Different Levels, *n (%)*

Diameter of TDN at the level:	Diameter of MCN at the level:	
	initial segment	in front of the coracobrachialis muscle
– Initial section (n = 121): matches or is greater by 0.06–1.82 mm,	7 (5.8)	10 (8.3)
smaller by 0.01–3.51 mm.	114 (94.2)	111 (91.7)
– Before splitting (n = 113): matches or is greater by 0.06–2.8 mm,	69 (61.1)	81 (71.7)
smaller by 0.1–2.0 mm.	44 (38.9)	32 (28.3)
– First-order extramuscular branches (n = 113): matches or is greater by 0.1–4.3 mm,	102 (90.3)	106 (93.8)
smaller by 0.05–1.2 mm.	11 (9.7)	7 (6.2)
– Second-order extramuscular branches (n = 64): matches or is greater by 0.3–8.0 mm,	59 (92)	61 (95)

End of table

Diameter of TDN at the level:	Diameter of MCN at the level:	
	initial segment	in front of the coracobrachialis muscle
smaller by 0.1–2.5 mm.	5 (8)	3 (5)
– First-order extramuscular branches (n = 121): matches or is greater by 0.05–4.66 mm,	109 (90.1)	113 (93.4)
smaller by 0.07–1.87 mm.	12 (9.9)	8 (6.6)

DISCUSSION

Restoration of flexion function in the elbow joint for patients with brachial plexus injury is of primary importance [12, 13]. To restore the function of the elbow flexor muscles, the clinical practice of transferring bundles from the ulnar and median nerves has shown excellent functional results [14, 15]. If the motor function of these nerves is not preserved, alternative donor nerves include intercostal nerves, the phrenic nerve, the accessory nerve, the medial pectoral nerve, the contralateral spinal C7, and the TDN [10, 16–18].

We have chosen TDN as the donor nerve for transfer to the position of the MCN for two reasons. First of all, existing studies have demonstrated that the lengths of TDN with extramuscular branches are sufficient for transfer to the position of MCN in 95% of cases [8]. Secondly, there are conflicting data regarding the diameter and sufficiency of the fiber ratio between these two nerves [7, 10].

Although TDN has fewer motor fibers than the MCN, there is evidence that normal muscle activity can be achieved with approximately 30% innervation of motor neurons [19]. In TDN, the number of motor fibers is 58% from that in MCN, and, therefore, it is sufficient to maintain the function of the shoulder flexors. In another study, when comparing the number of axons with clinical outcomes for elbow flexion strength recovery, a threshold ratio of motor fibers in the donor nerve to the recipient nerve was recommended at 0.7:1.0 [20]. For TDN, this ratio is 0.6:1.0, which is below the required norm. A double transfer of bundles from the ulnar and median nerves has been developed for restoring elbow flexion [21]. Considering these results, it can be suggested to use TDN as an additional donor nerve.

On the other hand, the number of axons is proportional to the diameter of the nerve, and, therefore, the thickness of the donor and recipient must match [6]. M.S. Sporer et al. noted without specifying to which nerve TDN is transferred that its length and cross-sectional area are not suitable for fascicular transfer [22].

Considering the contradictory literature data, we studied the diameter of TDN on 121 specimens of the brachial plexus from 105 human cadavers at five levels, while for MCN, the diameter was studied at two levels. It was established that the diameter of TDN varied from 0.83 to 3.33 mm, with a median of 1.66 [1.66; 1.99] mm. Comparing our data with known studies revealed inconsistencies in results. For example, M. Samardzic et al. found that in 15 cadavers, the diameter of TDN ranged from 2.1 to 3.0 mm [23]. After removing the epineurium and in some cases perineurium on 20 specimens from 17 cadavers, K.S. Lee found that the diameter of TDN ranged from 1.16 to 1.92 mm, with a median of 1.45 [1.33; 1.65] mm, which was significantly ($p < 0.001$) smaller than our findings [24]. M. Dancker et al. identified on 28 specimens from 14 cadavers that the diameter of TDN and the lower subscapular nerve was 2.5 ± 0.4 mm (range of 1.6–3.5 mm) [25].

The diameter of MCN in the initial segment varied from 1.5 to 5.0 mm, with a median of 3.0 [2.6; 3.3] mm, which was significantly greater ($p < 0.001$) than that of TDN at a ratio of 0.6:1.0. Previous studies also report conflicting results. For instance, V. Macchi et al. determined that in 6 cadavers, the average diameter of MCN before branching was 1.96 ± 0.2 mm, while in a trunk variant (6 cadavers), it was 2.86 ± 0.3 mm [26]. H. Namazi et al. found that on 10 specimens of the brachial plexus, the diameter of MCN was 1.8 ± 0.7 mm [27]. E. Clarke et al. reported diameters of MCN of 2.49 mm on one cadaver and of 4.87 mm on another [28]. L. Foroni et al. determined on 26 cadavers that the diameter of the nerve ranged from 2 to 4 mm [29]. According to A. Hansasuta et al., after dissecting 35 specimens from 18 human cadavers, it was found that the diameter varied from 3.0 to 5.5 mm, with a median of 4.3 mm [30]. J.P. Lee et al. established sex differences showing that in men (n = 6), the diameter of MCN was 4.3 ± 1.1 mm (range of 2.5–6.0), while in women (n = 6), it was 3.1 ± 1.5 mm (range of 1.6–4.0) [31].

The variability in the measurements is clearly related to the different number of specimens, levels of measurement, and the dissection techniques used, where some researchers remove the epineurium while others preserve the nerve sheath.

The conducted study revealed that the closer to the latissimus dorsi muscle, the significantly greater the total diameter of the extra- and intramuscular branches of TDN ($p < 0.001$), which is sufficient for transfer to the position of MCN. The significant predominance

of the diameters of TDN branches (0.05–8.0 mm) in 90.1–95.0% of cases allows the surgeon to approach fascicular transfer individually while maximizing the preservation of latissimus dorsi function. Thus, the excess total diameter of TDN will allow, through fascicular dissection, to preserve 1–2 first-order extramuscular branches (diameter of 1.00 [0.75; 1.25] mm) from 2–4 ones, 1–2 second-order branches (diameter of 0.75 [0.5; 1.0] mm) from 2–4 ones, and 1–4 first-order intramuscular branches (diameter of 0.57 [0.5; 0.66] mm) from 2–7 ones.

Therefore, the conducted study demonstrates that TDN as a donor nerve exceeds MCN as a recipient nerve in diameter at the levels of extra- and intramuscular branches, and its fascicular dissection with account for the branching level will allow for the preservation of latissimus dorsi function.

CONCLUSION

The diameter of the thoracodorsal nerve at the initial section is smaller than that of the musculocutaneous nerve, but the overall thickness of its extra- and intramuscular branches is equal to or greater by 0.05–8.0 mm in 90.1–95.0% of cases. Different branching levels of the thoracodorsal nerve contribute to extensive transfer, and the excess diameter with fascicular dissection will allow for the preservation of latissimus dorsi muscle function.

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