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Anatomic grounds for the transposition of the thoracodorsal nerve in case of neurotization of brachial plexus nerve damage

Gorbunov N.S.[1,2], Kober K.V.[1], Protasyuk E.N.[1], Rostovtsev S.I.[1], Samotesov P.A.[1]

[1] *Professor V.F. Voino-Yasenetsky Krasnoyarsk State Medical University (KrasSMU)
1, Partizan Zheleznyak Str., Krasnoyarsk, 660022, Russian Federation*

[2] *Scientific Research Institute of Medical Issues of the North
3i, Partizan Zheleznyak Str., Krasnoyarsk, 660022, Russian Federation*

ABSTRACT

The aim. To identify topographic, anatomic, and constitutional features of thoracodorsal and musculocutaneous nerves of brachial plexus.

Materials and methods. Anthropometry of 45 corpses was carried out to determine height; length of the trunk and upper extremities; circumference of the neck, thoracic cage, shoulder and forearm; lateral dimensions of shoulders, thoracic cage and pelvis; anteroposterior size of the thoracic cage; and neck size. Morphometry of all brachial plexus components (length, thickness of nerves and angles of their origin) was performed after its anatomical preparation.

Results. The cephalic type of brachial plexus with participation of C4 spinal nerve was found in 7% of cases. The caudal type with inclusion of Th2 spinal nerve was found in 4% of cases. In 4% of cases, there was no musculocutaneous nerve, at the same time the shoulder biceps innervates the median nerve. In 93% of cases, the thoracodorsal nerve originates from posterior secondary bundle along lower posterior surface, in 7% of cases, it is an axillary nerve branch. Neck circumference is directly correlated with thoracodorsal nerve length: the larger the neck circumference is, the greater the nerve length is. In females, linear regression equations were derived, which allow to estimate thoracodorsal nerve length knowing the thoracic cage width.

Conclusion. The length of the thoracodorsal nerve determines the possibility of its transplantation into the musculocutaneous position. Neck circumference and, in females, the width of the thoracic cage, for reliability, should be used as external size biomarkers for donor and recipient nerves.

Key words: brachial plexus, morphometry, thoracodorsal nerve, musculocutaneous nerve, transposition.

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✉ *Kober Kristina V.,* e-mail: k-kober@mail.ru.

Анатомическое обоснование транспозиции грудоспинного нерва при невротизации поврежденных нервов плечевого сплетения

Горбунов Н.С.[1, 2], Кобер К.В.[1], Протасюк Е.Н.[1], Ростовцев С.И.[1], Самотесов П.А.[1]

Красноярский государственный медицинский университет (КрасГМУ) им. проф. В.Ф. Войно-Ясенецкого Россия, 660022, г. Красноярск, ул. Партизана Железняка, 1

[2] Научно-исследовательский институт (НИИ) медицинских проблем Севера Россия, 660022, г. Красноярск, ул. Партизана Железняка, 3и

РЕЗЮМЕ

Цель. Выявление топографо-анатомических и конституциональных особенностей грудоспинного и мышечно-кожного нервов плечевого сплетения.

Материалы и методы. Проведена антропометрия 45 трупов с определением роста, длины туловища и верхней конечности, окружности шеи, грудной клетки, плеча и предплечья, поперечных размеров плеч, грудной клетки и таза, переднезаднего размера грудной клетки, обхвата шеи. После анатомического препарирования плечевого сплетения проведена морфометрия всех его компонентов (длины, толщины нервов и углов их отхождения).

Результаты. Цефалический тип плечевого сплетения с участием спинального нерва С4 установлен в 7%, каудальный тип с включением спинального нерва Th2 – в 4% случаев. В 4% случаев отсутствует мышечно-кожный нерв, двуглавую мышцу плеча при этом иннервирует срединный нерв. В 93% случаев грудоспинной нерв отходит от заднего вторичного пучка по задненижней поверхности, в 7% это ветвь подмышечного нерва. Обхват шеи имеет прямые значимые корреляции с длиной грудоспинного нерва – чем больше обхват шеи, тем больше длина нерва. У женщин выведены уравнения линейной регрессии, на основании которых можно вычислить предположительную длину грудоспинного нерва при известном значении ширины грудной клетки.

Заключение. Длина грудоспинного нерва является определяющей детерминантой возможности его пересадки в позицию мышечно-кожного. В качестве внешнего биомаркера размеров нерва-донора и нерва-реципиента целесообразно использовать размеры обхвата шеи и для достоверности у женщин – ширину грудной клетки.

Ключевые слова: плечевое сплетение, морфометрия, грудоспинной нерв, мышечно-кожный нерв, транспозиция.

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

Источник финансирования. Авторы заявляют об отсутствии финансирования.

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INTRODUCTION

Currently, microsurgical treatment of brachial plexus injuries is guided by the modern concept “from distal to proximal”, which implies the restoration of nervous regulation as close to paralyzed muscle as possible [1–3]. In this regard, the development and implementation of neurotization of damaged nerves using nerve transfer technology is underway, which requires a detailed study of anatomic features of donor and recipient nerves [4–6].

The most common type of brachial plexus injury is avulsion from the upper trunk. It is known that the upper trunk is formed by the fusion of C5 and C6 spinal nerves, further suprascapular and subclavian nerves branch from it in a distal direction. The lateral secondary bundle (C5, C6, C7) is then formed taking some of the nerve fibers from C7, with musculocutaneous nerve and lateral root of the median nerve as final branches [7]. In case of upper trunk avulsion, significant violation of upper extremity function occurs in which innervation is lost by suprascapular and musculocutaneous nerves, as a result of which there is shoulder abduction and external rotation, shoulder adduction and flexion, and forearm flexion, respectively. It appears useless to restore integrity at the level of the upper extremity, since degenerative processes in distal parts of nerves advance regeneration in the proximal segment of the upper trunk, which leads to irreversible muscle atrophy. Evidently, effective treatment of brachial plexus injuries is impossible without the use of distal nerve transfers. In this regard, there is increased practical interest in the thoracodorsalnerve, which is used not only in reconstructive surgery, but also as a donor nerve in case of brachial plexus peripheral nerve damage. This is the reason for conducting numerous studies revealing various anatomic features of this nerve.

Transplantation of thoracodorsal (TDN) and intercostal nerves to the damaged musculocutaneous nerve is being performed successfully [8, 9]. However, intraoperative access and the tunnel during the transposition of the thoracodorsal nerve are traumatic and useless, if the parameters of donor and recipient nerve do not suit [10, 11]. In this regard, the need for preoperative diagnosis of thoracodorsal (donor) and musculocutaneous (recipient) nerve size is quite obvious [12]. However, published studies do not include information about the possibility of determining true sizes of the musculocutaneous and thoracodorsal nerve at the preoperative stage, as well as sizes of other nerves in a particular patient to select the optimal transplantation method [13, 14]. Nevertheless, it has been proved that constitutional features of the human body structure determine its anatomical varieties that influence body and system functioning, which is important for clinical practice [15].

Thus, the aim of this study was to identify topographic, anatomical, and constitutional features of thoracodorsal and musculocutaneous nerves of the brachial plexus.

MATERIALS AND METHODS

The study was conducted on 45 female and male corpses of the second period of adulthood (36–60 years). Most of the studied corpses were male (n = 31 (69%)). There were 14 (31%) female corpses. The cause of death in all cases was somatic diseases without upper extremity, chest, neck or head damage.

The first stage included anthropometric corpse examinations: determination of height, length of the trunk and upper extremities; neck, thoracic cage, shoulder and forearm circumferences; lateral dimensions of shoulders, thoracic cage and pelvis; the anteroposterior size of the thoracic cage.

Anatomical preparation of the brachial plexus with subsequent instrumental measurements was the next step. Sequential measurement of the length, thickness and angles of all elements of the brachial plexus was carried out, as well as measurement with reference to the coordinate point, the clavicle center. The measurement of thoracodorsal nerve length was carried out from the place of its origin (posterior cord) to its entry into the latissimus dorsi muscle. In case there was a nerve split into branches prior to the muscle, the nerve aggregate length before and after branching was taken into account. Measurement of musculocutaneous nerve length was carried out from the place of formation (lateral cord) to coracobrachialis muscle perforation. After isolation and fixation in 10% neutral formalin solution, brachial plexus elements were measured under the MBS-10 stereoscopic magnifier.

Based on the obtained indicators, a database was made in MS Excel 9.0 program. The statistical processing of the results was carried out using Statistica for Windows 6.0. The article includes only indicators that follow normal distribution according to Shapiro – Wilk test. This allowed to use parametric statistical methods, including descriptive statistics, correlation (r – correlation coefficient, p – achieved significance level) and regression analyses, variant analyses carried out by means of the sigma deviation method. When describing the studied indicators, the following values were used: mean value (M) and standard deviation (σ), which are presented in the form of $M \pm \sigma$. Based on sigma deviations of neck circumference, thoracodorsal and musculocutaneous nerves length, as well as on formation level of the latter, all the corpses were divided into three types. When testing static hypotheses, differences were considered significant at $p < 0.05$.

RESULTS

After anatomical preparation, it was found that C5, C6, C7, C8, and Th1 roots of spinal cord segments are involved in the formation of the brachial plexus in 89% (40/45) of cases. The cephalic type of the brachial plexus with the participation of C4 spinal nerve was found in 7% (3/45), and the caudal type with the inclusion of Th2 spinal nerve was found in 4% (2/45) of cases. There was one case when C4 and C5 spinal nerves were combined into the primary superior trunk, while C6 and C7 nerves were combined into the primary middle trunk. Variability of brachial plexus long branch formation was determined. There is no musculocutaneous nerve in 4% (2/45) of cases, while the median nerve innervates biceps brachii. In 93% (42/45) of cases, the thoracodorsal nerve originates from the posterior cord along the lower posterior surface, in 7% (3/45) of cases, it is a branch of the axillary nerve, located on the front surface.

To assess the possibility of transposition of healthy nerves to damaged ones, it is necessary to know their size. The length of the thoracodorsal nerve before entering the broadest dorsum muscle ranges from 7.0 cm to 18.9 cm; the average value is 13 cm, $n = 45$. Based on sigma deviations (13.0 ± 2.6) of length, the thoracodorsal nerve is divided into three types before entering the latissimus dorsi muscle. The types are the following: short nerve < 10.4 cm – 11% (5/45), medium-length nerve 10.4–15.6 cm – 74% (33/45), long nerve > 15.6 cm – 15% (7/45). The length of the musculocutaneous nerve up to coracobrachialis muscle perforation varies from 2.0 cm to 17 cm, and the average value is 6.8 cm, $n = 45$.

Taking into account the risks of invasive interventions, the inefficiency of transposition due to lack of length and, consequently, nerve tension with such complications as vellication and causalgia, it is necessary to develop non-invasive and reliable methods of detecting thoracodorsal nerve size. In this regard, the conducted correlation analysis revealed direct significant interconnection ($r = 0.317$, $p = 0.033$) of thoracodorsal nerve length and neck circumference. The length of the thoracodorsal nerve significantly increases with the length of neck circumference.

The anthropometric study revealed neck circumference varying from 26 cm to 39 cm, the average values are 32.8 cm, $n = 45$. Based on sigma deviations (32.8 ± 3.2) of neck circumference, all the corpses were divided into three groups: neck circumference < 29.6 cm – 15.5% (7/45), neck circumference 29.6–36.1 cm – 69% (31/45), and neck circumference > 36.1 cm – 15.5% (7/45). It was found that in individuals with neck circumference > 36.1 cm in 71% (5/7) of cases, the thoracodorsal nerve is long, and in 29% (2/7) of cases it is of average length. Whe the neck circumference varies between 29.6–36.1 cm, medium-length thoracodorsal nerve occurs in 78% (24/31) of cases, short nerve – in 16% (5/31) and long nerve – in 6% (2/31) of cases. In individuals with neck circumference < 29.6 cm, short (50%) and medium-length (50%) thoracodorsal nerves are found in equal proportion (Fig. 1).

Table 1 shows that there are significant differences in thoracodorsal nerve length in individuals with different neck circumference. The larger the neck circumference is, the longer the thoracodorsal nerve is and vice versa.

Table 1

The thoracodorsal nerve length (in cm) in individuals with different neck circumference (*n* = 45)

Parameter	Neck circumference > 36.1 cm	Neck circumference 29.6–36.1 cm	Neck circumference < 29.6 cm	*p*
Thoracodorsal nerve length	14.2	13.4	12.3	< 0.05

Based on sigma deviations (6.8 ± 3.2) of muscular-cutaneous nerve length to coracobrachial muscle perforation, three following types were determined: short nerve < 3.6 cm – 13% (6/45), medium-length nerve 3.6–10.0 cm – 65% (29/45), and long nerve > 10.0 cm – 22% (10/45). Three levels are marked according to the distance from the clavicle center to the place of musculocutaneous nerve formation taking into account sigma deviations (7.4 ± 2.1): high level < 5.3 cm – 7% (3/45), medium level – from 5.3 to 12.7 cm – 80% (36/45), low level > 12.7 cm – 13% (6/45). There is direct correlation ($r = 0.30$, $p = 0.049$) between the length of thoracodorsal and musculocutaneous nerves.

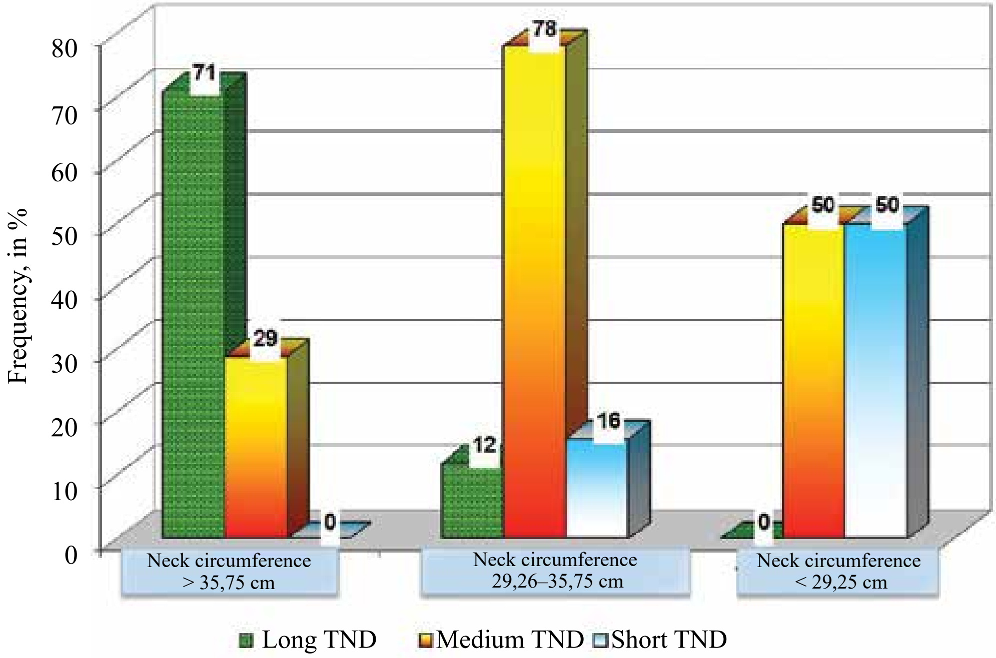

Fig. 1. Constitutional features of the thoracodorsal nerve.

Furthermore, in individuals with short musculocutaneous nerve, in five cases, medium-length pectoral-spinal nerve is observed, and in one case, short nerve is identified. In people with long musculocutaneous nerve, in seven cases there is medium-length thoracic back nerve, and in three people, there is a long one.

In the case of paired comparison of thoracodorsal and musculocutaneous nerve lengths, it was found that in 80% (36/45) of the studied corpses, the nerve length allows for successful transplantation of the thoracodorsal nerve to the position of the musculocutaneous nerve. In 20% (9/45) of cases, transposition of the thoracodorsal nerve to the position of the musculocutaneous nerve for neurotization of the damaged musculocutaneous nerve is not possible due to the lack of length of the former and low level of formation of the latter.

When comparing corpses by gender, males did not reveal any significant correlation between the length of the thoracodorsal nerve and anthropometric data. A significant inverse correlation between the length of the thoracodorsal nerve and the width of the thoracic cage ($r = -0.6$, $p = 0.03$) is revealed in females. The more the width of the thoracic cage is, the shorter the length of the thoracodorsal nerve is. Regression analysis revealed linear features (Fig. 2) and the equation of the relationship between the length of the thoracodorsal nerve and the width of thoracic cage (thoracodorsal nerve length, in cm = 20.1536–0.2846 × thoracic cage width, in cm). Knowing thoracic cage width by means of the revealed equation, one can determine the length of the thoracodorsal nerve can be determined.

Furthermore, there was a direct correlation between musculocutaneous nerve length and thoracodorsal nerve length ($r = 0.52$, $p = 0.05$) in females. Regression analysis revealed linear features and equation of correlation between musculocutaneous nerve length and thoracodorsal nerve length (musculocutaneous nerve length, in cm = –1.6129 + + 0.6496 × thoracodorsal nerve length, in cm) (Fig. 3). These equations make it possible to determine the length of the donor nerve and the recipient nerve without invasive interventions in females.

To assess the accuracy of the equation for determining the length of the thoracodorsal nerve with the known width of the thoracic cage, a comparative analysis was performed (Table 2). It was revealed that the length of the thoracodorsal nerve, measured after anatomical preparation, does not significantly differ from the indicators obtained using the proposed equation ($p = 0.07$). Furthermore, the spread in values from the regression equation to the actual length of the thoracodorsal nerve is 1.5 cm.

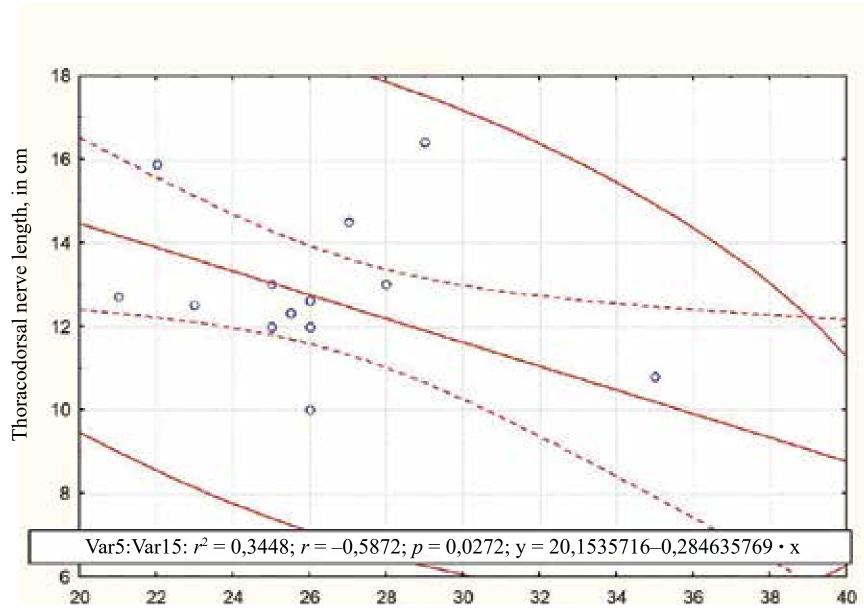

Fig. 2. Features and equation of relationship of the thoracic cage width and the thoracodorsal nerve length in females

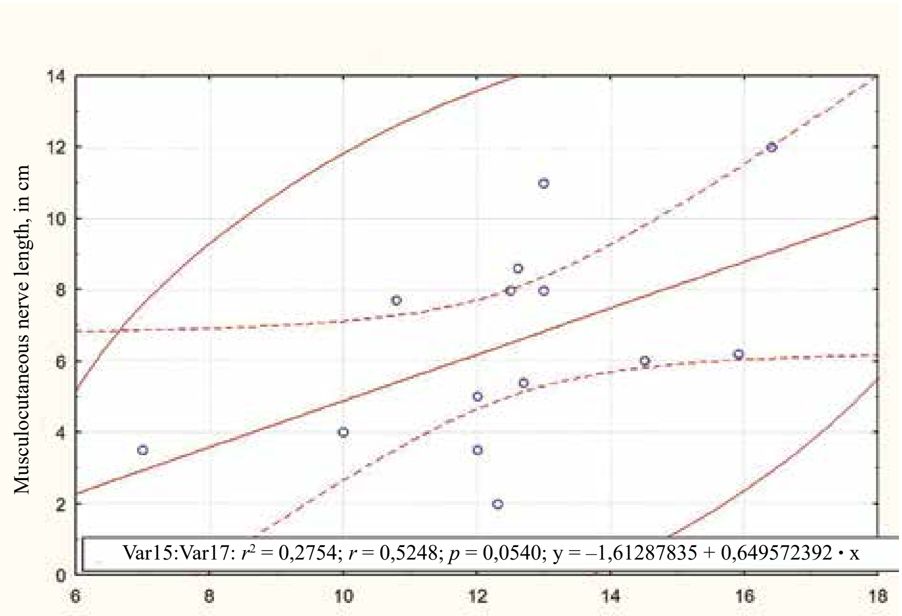

Fig. 3. Features and equation of correlation between the length of thoracodorsal and musculocutaneous nerves in females

Table 2

Comparison of the results of the experimental study in females

Parameter	Thoracodorsal nerve length, cm (after preparation)	Thoracodorsal nerve length, cm (according to the equation)
Mean value	13.6	12.6
Standard deviation	2.57	1.20
Achieved significance level (p)	0.07	

DISCUSSION

It is known that when the trunk or cord of the brachial plexus is damaged, it is impossible to restore nervous regulation at the place of its rupture. The conduction of nerve impulses from these structures of the brachial plexus to forming nerves is violated. In this regard, transplantation of donor nerves to damaged recipient nerves is widely used for the absolute restoration of extremity functions. The present study has shown that in 20% of cases it is impossible to carry out the transfer of the thoracodorsal nerve to the position of the musculocutaneous nerve due to large diastasis. Therefore, other sources of neurotization are necessary in such cases. According to the data by a number of other authors, such cases are rare and, despite the potential of modern diagnostics, the mismatch of nerve length during transposition is found during the operation, which is accompanied by nerve tension with subsequent complications, increase in operation time, and sometimes useless and traumatic interventions [12]. It is worth noting that in surgical practice while suturing nerves, the maximum permissible tension is the one at which the nerve segments can be pulled together by simultaneous tying of two 8/0 sutures, which corresponds to diastasis up to 2.0–2.5 cm [16].

In previous studies, anatomical features of the thoracodorsal nerve were examined from the point of its use as distal nerve transfer [17]. In most cases, the thoracodorsal nerve is formed from the posterior cord (C7, C8), which coincides with our results. In 93% of cases, it departs from the posterior cord, and in 7% of cases, it is a branch of the axillary nerve. Therefore, its transfer is effective in case of nerve damage that is formed from spinal nerves C5 and C6, which, according to statistics, are more likely to rupture during injuries of the brachial plexus [11]. The thoracodorsal nerve is located under the lateral edge of the latissimus dorsi muscle, superficially from the vascular pedicle. This makes it possible to isolate the nerve along its way to the entrance to the muscle. Our data showed that the average length of the thoracodorsal nerve before entering the broadest back muscle is 13.0 cm. According to the data of other studies, this value does not exceed 12.3 cm [7]. It is worth noting that when transplanting the distal end of the thoracodorsal nerve, the latissimus dorsi muscle does not lose its function, since it has an additional source of innervation, which is the subscapular nerve.

According to the results of the study, transposition of donor nerve to recipient nerve depends on the nerve length correspondence. According to M. Samardzić [9], nerve lengths and their cross-sectional area correspondence are of great importance for transposition, but nerve length correspondence is crucial.

It was found in the present study that neck circumference and, in women, chest width are required to determine the reliable true size of thoracodorsal and musculocutaneous nerves.

Thus, anatomical and topographic features of the thoracodorsal nerve make it most suitable for transposition in case of peripheral upper limb nerve damage, while the ability to determine the true size of the thoracodorsal and musculocutaneous nerves before surgery will allow to choose an optimal transplantation method for a particular patient and improve treatment results significantly.

CONCLUSION

Based on the study, the following conclusions have been made.

1. There is a significant direct correlation between the length of the thoracodorsal nerve and neck circumference in humans ($r = 0.317$, $p = 0.033$).

2. In 20% of cases in humans, nerve size does not allow for transplantation of the thoracodorsal nerve to the position of the musculocutaneous nerve.

3. In females, there is a significant inverse correlation between the thoracodorsal nerve length and the thoracic cage width ($r = 0.6$, $p = 0.03$). Equation of relationship between the width of the thoracic cage and the length of the thoracodorsal nerve (length of the thoracodorsal nerve, in cm = 20.1536 – 0.2846 × width of the thoracic cage, in cm) was revealed.

The length of the thoracodorsal nerve determines the possibility of its transplantation into the musculocutaneous position. It is reasonable to use neck circumference and, in females, the width of the thoracic cage as external size biomarkers for the donor and recipient nerves.

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Authors contribution

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Authors information

Gorbunov Nikolai S., Dr. Sci. (Med.), Professor, Head of the Department of Operative Surgery and Topographic Anatomy, KrasSMU, Scientific Research Institute of Medical Issues of the North, Krasnoyarsk, Russian Federation. ORCID 0000-0003-4809-4491.

Kober Kristna V., Resident, KrasSMU, Krasnoyarsk, Russian Federation. ORCID 0000-0001-5209-182X.

Protasyuk Ekaterina N., Student, KrasSMU, Krasnoyarsk, Russian Federation. ORCID 0000-0002-1204-7821.

Rostovtsev Sergei I., Dr. Sci. (Med.), Associate Professor, Department of Anesthesiology and Resuscitation, KrasSMU, Krasnoyarsk, Russian Federation. ORCID 0000-0002-1462-7379.

Samotesov Pavel A., Dr. Sci. (Med.), Professor, Department of Operative Surgery and Topographic Anatomy, KrasSMU, Krasnoyarsk, Russian Federation. ORCID 0000-0002-1022-4070.

(✉) **Kober Kristina V.,** e-mail: k-kober@mail.ru.

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