Archives of the Balkan Medical Union **vol. 57, no. 4, pp. 363-371**
Copyright © 2022 Balkan Medical Union **December 2022**

ORIGINAL PAPER

VARIANT ANATOMY OF THE TIBIAL NERVE IN POSTERIOR CALF MUSCLES IN HUMAN FETUSES

Tetiana V. KOMAR[1], Tatyana V. KHMARA[2]✉, Tetiana V. PROTSAK[2], Igor I. ZAMORSKII[3], Petro V. SARAFYNIUK[4]

[1] Department of Pathological Anatomy, Bukovinian State Medical University, Chernivtsi, Ukraine
[2] Department of Human Anatomy named after M.H. Turkevych, Bukovinian State Medical University, Chernivtsi, Ukraine
[3] Department of Pharmacology, Bukovinian State Medical University, Chernivtsi, Ukraine
[4] Department of Biology, Vinnytsia State Pedagogical University named after Mykhailo Kotsyubynsky, Vinnytsya, Ukraine

Received 28th Sept 2022, Accepted 25th Nov 2022
https://doi.org/10.31688/ABMU.2022.57.4.05

Abstract

Introduction. The knowledge of general patterns of intramuscular distribution of nerves in each muscle of the thigh and lower leg during different periods of human ontogenesis is necessary for doctors of different specialties.

The objective of the study was to establish the features of the intramuscular distribution of nerves in the muscles of the calf in human fetuses aged 4-8 months.

Materials and methods. A macroscopic study of the calf muscles innervation was carried out on 38 human fetuses aged 4-8 months using anatomical dissection methods, vascular injection, and morphometry.

Results. It has been established that the nerve branches go mainly at an acute angle from the tibial nerve to the calf muscles and enter their thickness within the upper third of the calf. The direction of intramuscular nerves, as well as the type of their branching in the same muscle can be different, which is associated with the structural and functional organization of the calf muscles. In five human fetuses there was atypical

Résumé

Anatomie variante du nerf tibial dans les muscles postérieurs du mollet chez les fœtus humains

Introduction. La connaissance des modèles généraux de distribution intramusculaire des nerfs dans chaque muscle de la cuisse et de la jambe dans diverses périodes de l'ontogenèse humaine est nécessaire pour les médecins de diverses spécialités.

L'objectif de l'etude a été d'établir les caractéristiques de la distribution intramusculaire des nerfs dans les muscles du groupe postérieur de la jambe chez les foetus humains âgés de 4 à 8 mois.

Matériels et méthodes. La recherche macroscopique des caractéristiques de l'innervation des muscles du groupe postérieur de la jambe a été réalisée sur 38 foetus humains en âge de 4-8 mois en utilisant les méthodes de préparation anatomique, d'injection vasculaire et de morphométrie.

Résultats. Il a été établi que les branches nerveuses allant du nerf tibial aux muscles du groupe postérieur

✉ Address for correspondence: Tatiana V. KHMARA
Human Anatomy Department, Bukovinian State Medical University, Chernivtsi, Ukraine
Address: 1a, Aksenina St. apt. 16, Chernivtsi 58001, Ukraine
E-mail: khmara.tv.6@gmail.com; Phone: +38 099 751 65 50

topography of the sciatic nerve and its branches, as well as various types of branching of the tibial nerve in the thickness of the superficial and deep muscles of the calf.

Conclusions. The greatest concentration of the nerve branches has been noted in the penetration area and in the central parts of the calf muscles. High branching and penetration of the nerves into the muscles of the calf provides favourable conditions for the transposition of these muscles for plastic purposes.

Keywords: calf muscles, topography, tibial nerve, innervation, fetus.

de la jambe partent le plus souvent sous un angle aigu et pénètrent dans leur épaisseur dans le tiers supérieur de la jambe. La direction des nerfs intramusculaires, ainsi que le type de ramification dans le même muscle, peuvent être différents, ce qui est associé à l'organisation structurelle et fonctionnelle des muscles du groupe postérieur de la jambe. 5 foetus humains avaient une topographie atypique du nerf sciatique et de ses branches, ainsi que divers types de nerfs tibiaux ramifiés dans l'épaisseur des muscles superficiels et profonds du groupe postérieur de la jambe.

Conclusions. La concentration maximale de branches nerveuses a été observée dans la zone de pénétration et dans les parties centrales des muscles du groupe postérieur de la jambe. Une bifurcation importante et la pénétration des nerfs dans les muscles du groupe postérieur de la jambe créent des opportunités favorables pour la transposition de ces muscles à des buts plastiques.

Mots-clés: muscles de la jambe, topographie, nerf tibial, innervation, fœtus.

INTRODUCTION

Injuries of the sciatic nerve and its branches are usually accompanied by pronounced paresis or muscle paralysis of the lower extremity posterior surface, while the anatomical variability of the calf nerves makes it difficult to diagnose several diseases due to atypical clinical symptoms[1]. The knowledge of the general patterns of the intramuscular distribution of nerves in each muscle of the thigh and lower leg during different periods of human ontogenesis is necessary for doctors of various specialties to perform diagnostic manipulation and to choose treatment and rehabilitation tactics[2]. Recovery of severe post-traumatic defects of soft and osseous tissues remains an urgent problem for traumatologists and orthopedists[3]. Fundamental knowledge of the anatomical features of the tibial and common fibular nerves is necessary when applying new, modern methods of knee arthroplasty[4]. Not less attention is also paid to expanding the possibilities of using musculoskeletal plastics after amputation of the tibia with preserving the ability to perform high-quality prosthetics and preventing reamputation[5]. It has been proven that among all methods of tendon repair, tendon-muscular transpositions, using the muscles of the lateral group of the shin as well as the long flexor of the hallux and the long flexor of the toes, are the most reliable[6].

The research dealing with the study of the innervation of the shin muscles are relevant, as long-term disruption of the connection between the peripheral nerve and muscle leads to the development of muscle atrophy[7]. The literature available to us describes 3 types of distribution of the branches of the tibial nerve in the calf muscles: variant 1 – a single trunk of the nerve is divided into several small branches; variant 2 – a double trunk of a nerve or two independent branches parallel each other or located at an acute angle; variant 3 – the division of the nerve into several branches going to each muscle at a different angle[8]. At the same time, the number of variants for dividing the tibial nerve can be much larger. The direction of intramuscular nerve trunks may not coincide with the direction of the muscle bundles. The main nerve trunks often branch out by loose type, while their branches are formed by the main type[9]. Knowing the lumbosacral plexus nerve topography samples will help to improve the methods of surgical treatment of injuries to the peripheral nerves of the lower extremity [10,11]. In particular, the muscular branch of the tibial nerve innervating the soleus muscle in order to restore traumatic damage to the deep fibular nerve is known to be translocated[12].

Using ultrasound and magnetic resonance imaging has been spread lately to study peripheral nerves of the lower extremities[13,14], since these technologies allow quick diagnosing neuropathies, which are especially common in patients with diabetes mellitus[15,16]. Pathological changes in walking and posture may also be associated with an impairment of the lower extremities' muscular innervation, because the tibial muscles perform the main balancing function of the ankle joint[17].

Therefore, data on individual and age-related anatomical variability of branching of nerves in the calf muscles in human fetuses of different age groups need to be clarified, systematized, and supplemented, which will allow practitioners to better understand the observed discrepancy between the clinical course of certain diseases and traditional anatomical data. In addition, the methods of fetal surgery make it possible to carry out intrauterine correction of the malformations of the fetus[18,19]. This underlines the relevance of the study of anatomical variability of organs and structures in human fetuses of different ages.

The objective of the study was to identify the features of intramuscular distribution of nerves in the calf muscles in 4–8-month-old human fetuses.

Materials and methods

The study involved 38 human fetuses aged 4–8 months, 81.0–310.0 mm of parietal-coccygeal length (PCL) to find out the features of innervation of the calf muscles using the specimens of their lower extremities by means of fine dissection methods, vascular injection, and morphometry. Specimens of fetuses from the Museum of the Department of Human Anatomy named after M.H. Turkevych and the Department of Histology, Cytology and Embryology of Bukovinian State Medical University were involved in the study[19,20]. The research was carried out in compliance with the basic bioethical provisions of the Council of Europe Convention on Human Rights and Biomedicine (dated 04.04.1997), the Helsinki Declaration of the World Medical Association on the Ethical Principles of Scientific Medical Research with Human Participation (1964–2013), the Order of the Ministry of Health of Ukraine Nº 690 dated September 23, 2009, and taking into account the methodological recommendations of the Ministry of Health of Ukraine "Procedure for extracting biological objects from dead persons whose bodies are subjected to forensic examination and pathological anatomical research, for scientific purposes" (2018)[19-20]. The Commission on Biomedical Ethics of Bukovinian State Medical University has not revealed any violations of bioethical and moral norms during the scientific study.

Results and discussion

In human fetuses, all the muscles of the calf have a predominantly constant source of innervation – the tibial nerve. The nerves branching out from the main trunk of the tibial nerve, are sent to individual muscles, and some of them, after breaking up, give up their muscle branches to several adjacent muscles. In most of the experimental fetuses the nerves to the muscles of the calf leave the main trunk most often in the proximal part of the lower leg, penetrating into the corresponding muscles without going beyond this level. In the region of the popliteal fossa, the tibial nerve is located superficially and laterally to the popliteal vein, which, in turn, extends laterally and posteriorly from the popliteal artery.

The gastrocnemius muscle is abundantly supplied with intramuscular nerves all over. The implantation porta of the muscular branches from the tibial nerve in the medial head of the gastrocnemius muscle are located 2.5–5.0 mm above the entrance gate of the nerves of the lateral head. The nerve entrance in each head of the gastrocnemius muscle lies near the places of entry of the main arteries. In the thickness of each head nerves are located ahead of the arteries. The direction of intramuscular nerve trunks does not coincide with the direction of the muscle bundles. It should be noted that the main nerve trunks brunch out by the loose type, and the branches going in the downward direction from these trunks are divided according to the main type. It should be emphasized that there are more intramuscular nerve connections in the lateral head of the gastrocnemius muscle than those in the medial head of the muscle.

At the level of the lower corner of the popliteal fossa, the tibial nerve usually brunches out into two parts: the anterior and posterior ones. The anterior branch of the tibial nerve is distributed in the thickness of the lateral and medial parts of the soleus muscle, and the posterior branch of the tibial nerve plunges into the thickness of the posterior surface of the muscle. In this case, the nerves, as a rule, approach the soleus muscle at an acute angle relative to the long axis of the muscle. The branching of the lateral trunk, coming from the anterior branch of the tibial nerve, occurs predominantly by the loose type, and the medial trunk of the anterior branch is distributed by the mixed type. In the intramuscular distribution of the nerve trunks, coming from the posterior branch of the tibial nerve, the main type of branching prevails. The direction of the large intramuscular nerve trunks and their branches does not coincide with the direction of the muscle bundles. In the intramuscular distribution of nerves, one can distinguish the medial, intermediate, and lateral regions, which corresponds to the parts of the soleus muscle of the same name. The intramuscular nerve trunks of all three areas of the soleus muscle are connected by means of connecting nerve trunks. It should be noted that communication is best developed in the distal part of the soleus muscle. We consider to be interesting the fact that in the middle and lower thirds of the muscle belly the intramuscular nerve trunks form loops and arcades. In the thickness of the soleus muscle, the arteries lie ahead of the nerves.

The branches of the tibial nerve often plunge into the thickness of the plantar muscle from the inner surface of the muscle belly. The nerve porta is in the upper third of the muscle belly. The direction of intramuscular trunks coincides with the direction of the muscle bundles. At the same time, the intramuscular trunks do not form neural connections in the thickness of the plantar muscle belly.

The tibial nerve gives 3-4 short from 1.0 mm to 2.8 mm long muscle branches at an acute angle to the popliteal muscle. The places, where the latter enter, are located on the border of the transition of the middle third to the lower third of the muscle belly, while 2-3 branches go to the middle third of the belly of the popliteal muscle. The intramuscular distribution of nerves in the popliteal muscle is dominated by the main type of branching.

From the popliteal fossa, the tibial nerve goes into the canalis cruropopliteus, whose opening is limited by the popliteal muscle anteriorly, and by a slightly pronounced tendinous arch of the soleus muscle posteriorly. In the canalis cruropopliteus, the tibial nerve is accompanied by posterior tibial artery and veins. Muscle branches from the tibial nerve enter the thickness of the posterior tibial muscle from the side of its dorsal surface in the upper third of the muscle belly. The direction of intramuscular nerve trunks does not coincide with the direction of intramuscular arteries. Throughout the muscle belly of the posterior tibial muscle, the intramuscular nerve trunks are located behind the arterial branches. The nerves branch segmentally. Intramuscular neural connections are poorly developed or absent at all.

The main trunk of the tibial nerve is located on the back of the long flexor of the big toe. In its direction, going downwards and laterally, it crosses the muscle belly. From the tibial nerve to the long flexor of the big toe 2-4 nerve branches from the posterior surface of the muscle belly come at an acute angle. The entrances of the nerve branches are in the upper, middle and lower third of the muscle belly of the long flexor of the big toe. At the same time, in the thickness of the muscle belly the direction of the intramuscular nerves does not coincide with the direction of the intramuscular arteries. Intramuscular nerves do not form in the thickness of the muscle belly of the nervous connections. In the picture of intramuscular branching of nerves, the main one is the most common, mixed, and loose ones are rare.

The branches from the tibial nerve approach the long flexor of the toes from the posterior surface of the muscle belly. The entrances of the nerves are in the upper third of the muscle belly. In the thickness of the muscle belly, the direction of the intramuscular nerves does not coincide with the direction of the intramuscular arteries. In the picture of the intramuscular distribution of nerves, the main branching of these branches prevails. Intramuscular nerve trunks often form loops and arcades in the thickness of the muscle belly of the long flexor of the toes. The direction of the large nerve trunks does not coincide with the direction of the muscle bundles.

After that, the tibial nerve goes between the lateral edge of the long flexor of the toes and the medial edge of the long flexor of the big toe, reaching the posterior surface of the medial ankle, where it divides into the medial and lateral plantar nerves.

While studying typical and variant anatomy of the nerves of the calf muscles in human fetuses aged 4-8 months, we found some variants of their topography. In particular, in 5 fetuses we found not only atypical topography variants of the sciatic nerve and its branches – the tibial and common fibular nerves, but also various types of branching of these nerves in the thickness of the superficial and deep calf muscles.

In a fetus with 180.0 mm of PCL, the tibial and common fibular nerves emerge as independent nerve trunks from the pelvic cavity through the suprapiriform foramen together with the inferior gluteal nerve and the posterior cutaneous nerve of the thigh. The tibial nerve from under the lower edge of the gluteus maximus muscle goes down to the popliteal fossa, and it is 40.0 mm long. In the popliteal fossa, the tibial nerve is represented by 2 trunks: the medial, with larger diameter, and the lateral one, which are parallel to each other (Fig. 1). One branch, which is 6.0 mm long, leaves the medial trunk of the tibial nerve innervating the medial head of the gastrocnemius muscle. The innervation of the lateral head of the gastrocnemius muscle is provided by the muscle branch, 8.0 mm long, which leaves the lateral trunk of the tibial nerve. This branch divides into branches of the following order in the thickness of the muscle belly and they extend at different angles.

At the level of the popliteal fossa posterior corner 4 muscle branches extend from the lateral trunk of the tibial nerve: the medial branch, 10.0 mm long, which crosses the medial trunk of the tibial nerve and at an acute angle down to the front surface of the tibia, mainly innervating the medial edge of the long flexor of toes; the middle branch goes down, parallel to the medial trunk of the tibial nerve, while it is 12.0 mm long; the other two branches, 6.0 and 4.0 mm long, enter the thickness of the long flexor of the big toe in the region of the middle and lower third of the muscle belly at acute angles have a downward direction coinciding with the direction of the main

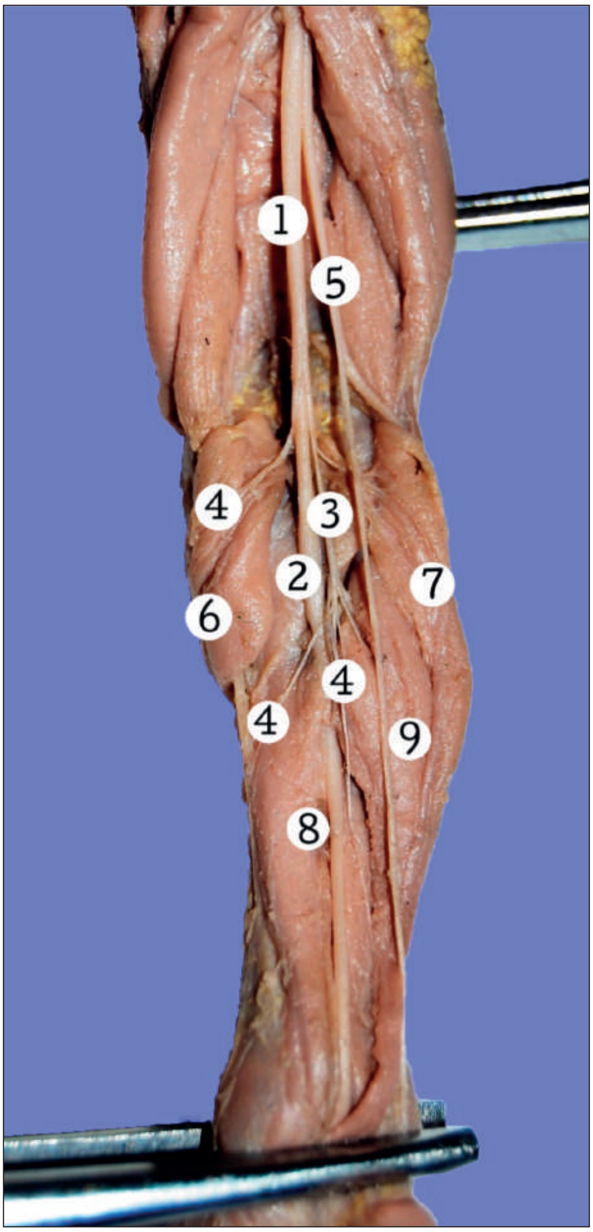

Fig. 1. Innervation of the calf muscles in a fetus with 180 mm of PCL. Gross specimen. Augm.1.7^{x}:
1 – tibial nerve; 2 – medial trunk of the tibial nerve; 3 – lateral trunk of the tibial nerve; 4 – muscular branches of the tibial nerve; 5 – common fibular nerve; 6 – medial head of the gastrocnemius muscle; 7 – lateral head of the gastrocnemius muscle; 8 – long flexor of toes; 9 – long flexor of the big toe.

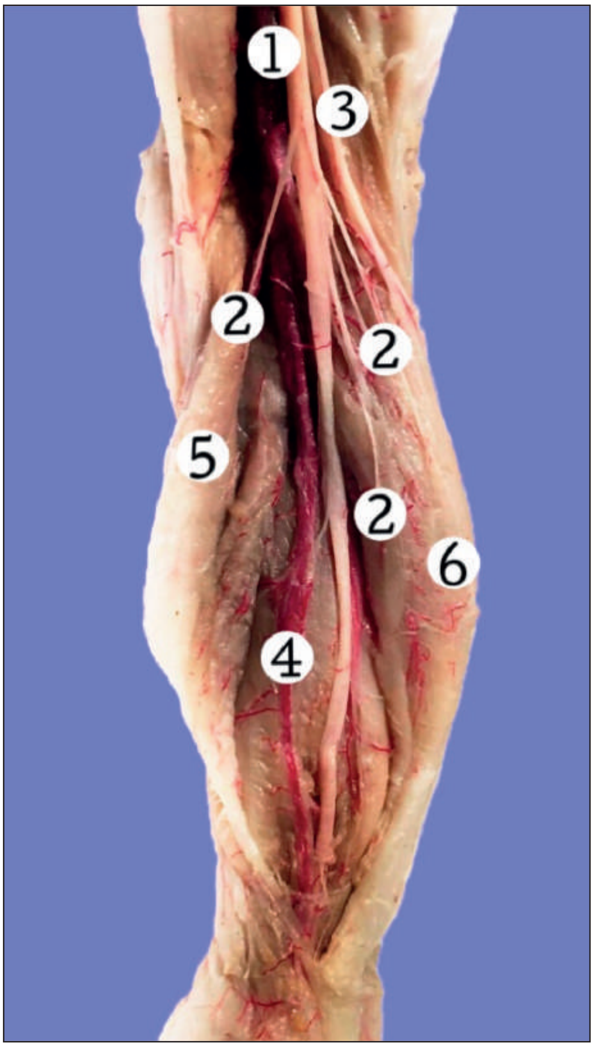

Fig. 2. Nerves and arteries of the right calf in a fetus with 190.0 mm of PCL. Gross specimen. Augm. 1.8^{x}
1 – tibial nerve; 2 – muscle branches of the tibial nerve; 3 – common fibular nerve; 4 – posterior tibial artery; 5 – the medial head of the gastrocnemius muscle; 6 – the lateral head of the gastrocnemius muscle.

arterial trunks. Lateral to the tibial nerve passes the common fibular nerve, which is 43.0 mm long to the middle of the popliteal fossa. At the level of the middle of the popliteal fossa, the common fibular nerve divides into two nerves – the superficial and deep fibular nerves.

In a fetus with 190.0 mm of PCL, the branching of the trunk of the right sciatic nerve into the tibial and common fibular nerves was observed at the level of the middle third of the thigh. The extrapelvic part of the right sciatic nerve is 21.0 mm long, the tibial nerve is 57.0 mm, and the common fibular nerve is 21.0 mm long. After separation from the sciatic nerve, the tibial nerve follows downwards, being located in the middle of the posterior surface of the tibia (Fig. 2). At the level of the upper angle of the popliteal fossa, the upper medial muscle branch, 17.0 mm long, leaves from the tibial nerve and penetrates into the thickness of the medial calf muscle at an acute angle. From the tibial nerve, 15.0 mm caudally to the superior medial muscular branch, the lower medial muscular branch, 10.0 mm long, arises. The latter passes along the posterior surface of the long flexor of the toes and crosses the posterior tibial artery. Innervation of the lateral head of the gastrocnemius muscle is performed by 3 lateral muscular branches, whose entrances lie in the upper and middle third of the muscle belly. The lateral muscle branches are 18.0, 13.0 and 10.0 mm long.

The fetus with 205.0 mm of PCL was also found to have a high branching of the right sciatic nerve trunk into the tibial and common fibular nerves, namely, 20.0 mm above the popliteal fossa. The tibial nerve in the popliteal fossa is located more superficially and more medially than the popliteal artery (Fig. 3). The tibial nerve is 75.0 mm long, and the common peroneal nerve is 42.0 mm long. In the proximal part of the tibia, from the main trunk of the tibial nerve, at different angles, six muscle branches extend to the muscles of the calf which in their thickness divide into branches of the following order. The medial head of the gastrocnemius muscle is innervated by three branches, 10.0, 13.0 and 17.0 mm long, which penetrate the anterior and posterior surfaces of the muscle. Two muscle branches, 12.0 and 6.0 mm long, go into the thickness of the lateral head of the gastrocnemius muscle. The nerves of the lateral head form intramuscular nerve connections. The direction of intramuscular nerve trunks does not coincide with the direction of the muscle bundles but coincides with the direction of the intramuscular arteries.

In a fetus with 230.0 mm of PCL, the branching of the left sciatic nerve into the tibial and common peroneal nerves was observed 5.0 mm above the upper corner of the popliteal fossa. The common peroneal nerve, 20.0 mm long, occupies a superficial position, crosses the tibial nerve and goes obliquely down and laterally, adjacent to the medial edge of the long head of the biceps femoris. After which the common fibular nerve reaches the region of the head of the fibula, bends around the neck of the latter and divides into two final branches – the superficial and deep fibular nerves. The tibial nerve is located laterally from the popliteal vein, which, in turn, passes behind the popliteal artery. From the popliteal fossa, the tibial nerve goes into the canalis cruropopliteus. The length of the tibial nerve to the canalis cruropopliteus is 30.0 mm (Fig. 4). A branch 10.0 mm long goes from the tibial nerve to the lateral head of the gastrocnemius muscle from the posterior surface of the muscle belly at an acute angle. It should be noted that the branch of the tibial nerve, which innervates the long flexor of the toes, enters its muscle belly in the region of the upper third, parallel to the medial dermal nerve of the calf. A muscular branch 10.0mm long goes to the medial head of the gastrocnemius muscle at an acute angle. At the same time, in the thickness of the muscle bellies of the above listed muscles, the direction of the intramuscular nerves coincides with the direction of the intramuscular arteries. Then, the tibial nerve goes between the lateral edge of the long flexor of the toes and the medial edge of the long flexor of the big toe, reaching the posterior surface of the medial ankle. On the border of the superficial and deep muscles of the calf, the tibial nerve gives the medial cutaneous nerve of the calf, 25.0 mm long. The latter, together with the lateral cutaneous nerve of the calf, a branch of the common peroneal nerve, innervates the skin of the posterior surface of the calf.

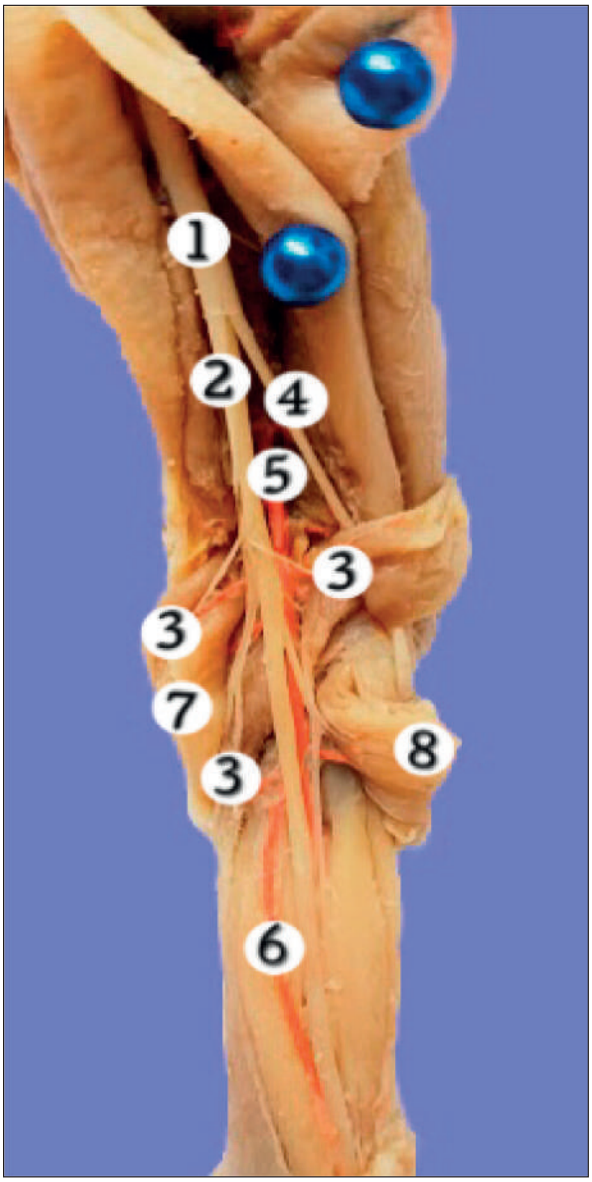

Fig. 3. Nerves and arteries of the calf with 205.0 mm of PCL. Gross specimen. Augm. 1.6^x
1 – sciatic nerve; 2 – tibial nerve; 3 – muscle branches of the tibial nerve; 4 – common fibular nerve; 5 –– popliteal artery; 6 – posterior tibial artery; 7 – medial head of the gastrocnemius muscle; 8 – lateral head of the gastrocnemius muscle.

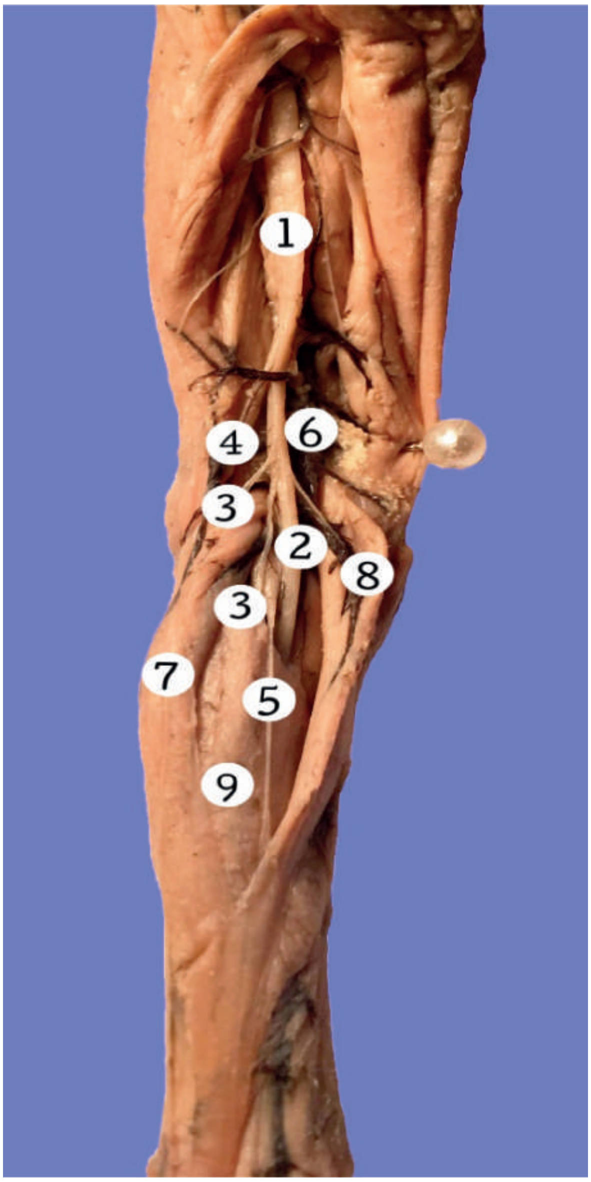

Fig. 4. Nerves and arteries of the left calf in a fetus with 230.0 mm of PCL. Gross specimen. Augm.1.5^x: 1 – sciatic nerve; 2 – tibial nerve; 3 – muscle branches of the tibial nerve; 4 – common fibular nerve; 5 – the medial cutaneous nerve of the calf; 6 – popliteal artery; 7 – lateral head of the gastrocnemius muscle; 8 – the medial head of the gastrocnemius muscle; 9 – long flexor of toes.

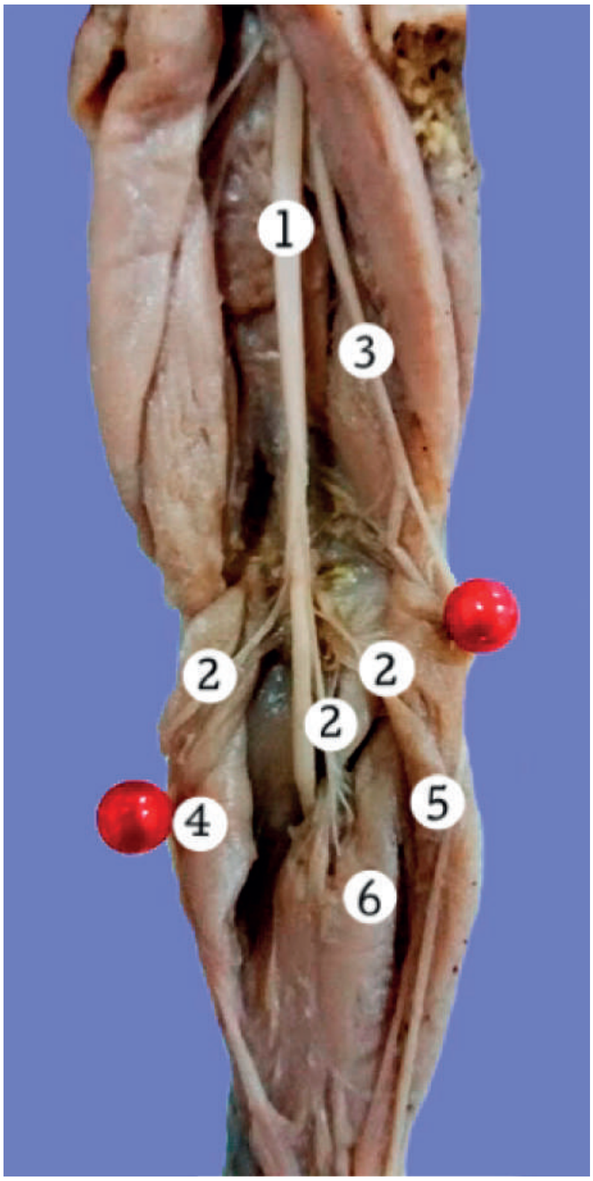

Fig. 5. Innervation of the calf muscles in a fetus with 260.0 mm of PCL. Gross specimen. Augm.1.4^x: 1 – tibial nerve; 2 – muscle branches of the tibial nerve; 3 – common fibular nerve; 4 – the medial head of the gastrocnemius muscle; 5 – the lateral head of the gastrocnemius muscle; 6 – long flexor of the big toe.

In a fetus with 260.0 mm of PCL, there is a high variant of the right sciatic nerve trunk branching into the tibial and common peroneal nerves, namely, 15.0 mm below the foramen infrapiriform. The extrapelvic part of the right sciatic nerve is 23.0 mm, the tibial nerve is 55, and the common fibular nerve is 38.0 mm long. In the region of the popliteal fossa, the tibial nerve gives off three muscular branches at an acute angle: the medial, middle and lateral ones, 11.0, 15.0 and 9.0 mm long, respectively, which enter the thickness of the heads of the triceps muscle of the lower leg from the side of their dorsal surfaces in the region of the proximal third of their muscle belly **(Fig. 5).** The entrance of the medial muscle branch from the tibial nerve into the medial head of the gastrocnemius muscle is located 4.0 mm above that of the lateral muscle branch into the lateral head of the gastrocnemius muscle. It should be emphasized that thera are more neural connections in the lateral head of the gastrocnemius muscle of the intramuscular muscle than in the medial head of this muscle. The long flexor of the big toe is innervated by the middle muscle branch of the tibial nerve, which is located parallel to the main trunk of the nerve and slightly lateral to the latter. In the thickness of the long flexor of the big toe the middle muscular branch gives up five branches of the following order, 5.5 ± 0.8 mm long. The direction of the intramuscular nerve trunks does not coincide with the direction of the muscle bundles. It should be noted that in this fetus the main nerve trunks brunch by the main type and their brunches divides by the loose type.

The picture of the intramuscular distribution of nerves and their interrelationship in the thickness of the calf muscles is characterized by pronounced anatomical variability, which is closely related to the structural features of the muscles and the topography of the intramuscular arteries.

The nerves are unevenly distributed in the thickness of the calf muscles. Most nerves in the posterior region of the lower leg enter the muscle at an acute angle to the long axis of the muscle. In the picture of intramuscular branching of nerves, there is a trunk, loose and mixed forms. The direction of the intramuscular nerves, as well as the type of their branching in the same muscle can be different. The gate of entry of nerves can be located both on the front and on the back of the muscle belly. The direction of the intramuscular nerve trunks may not coincide with the direction of the muscle bundles or intramuscular arteries[21].

Anatomically substantiated are the incisions that consider not only the intramuscular distribution of nerves and arteries, but also the structural features of various parts of the superficial and deep calf muscles. From this point of view, the most favourable conditions are found in the gastrocnemius and soleus muscles, in which using longitudinal incision is sparing, since the course of nerves and blood vessels is considered, and the muscle bundles between the aponeurotic plates in the sagittal plane are preserved[22].

From our point of view, the high branching and penetration of nerves into the calf muscles provides favourable opportunities for the transposition of these muscles for plastic purposes, which is consistent with the data of some researchers[10,23].

When performing incisions of the deep layer of the calf muscles, one should consider differences in the features of the structure and distribution of the nerves in their upper sections and on the rest of the muscle belly. Cutting out muscle flaps in the proximal muscle should cover the innervation area. At the same time, innervation, blood supply and the structure on the rest of the muscle belly are preserved. As for the middle and distal parts of these muscles, consisting of short oblique muscle bundles, here the longitudinal cuts are sparing only in relation to the nervous elements, but violate the muscle structure and integrity of the segmentally penetrating arteries, which makes these cuts irrational.

Considering the peculiarities of these muscles (pinnation in the frontal plane, the presence of nerves in the superficial and deep layers of muscles), the incisions, cutting out the flaps in the frontal plane, as if dissecting the muscle into the front and rear halves will be more rational[24].

Conclusions

The direction of intramuscular nerves, as well as the type of their branching in the same muscle can be different, which is associated with the structural and functional organization of the calf muscles. Relatively long nerve trunks, forming the main form of branching (gastrocnemius and soleus muscles, middle and distal muscles of the deep layer), are mainly directed to areas of pinnate muscles formed by short oblique muscle bundles. Sections of muscles or muscles formed by longitudinal muscle bundles with different length are innervated by relatively short nerve trunks forming a loose form of branching (plantar and popliteal muscles, upper sections of the muscles of the deep layer).

The nerve branches from the tibial nerve to the calf muscles often leave at an acute angle and enter their thickness within the upper third of the lower leg. Places of nerve penetration also do not go beyond this level and are located on surfaces facing the bones of the lower leg (in the muscles of the superficial layer), or in the direction of the skin (in the muscles of the deep layer).

Nerves in the calf muscles are unevenly distributed. The greatest concentration of the nerve branches is noted in the penetration area and in the central parts of the calf muscles.

The high branching and penetration of nerves into the calf muscles provide favourable conditions for the transposition of these muscles for plastic purposes.

Author Contributions:

T.V.Komar is responsible for the data acquisition, anatomical investigations and data analyzing, design and writing the manuscript. T.V.Khmara is responsible for the conception, reviewed, and edited the manuscript. T.V.Protsak, I.I. Zamorskii, and P.V. Sarafyniuk aided to the design, reviewed, and edited the manuscript. All authors contributed equally to the present work. All authors contributed to the critical revision of the article for valuable intellectual content. All the authors have read and agreed with the final version of the article.

Compliance with Ethics Requirements:

"The authors declare no conflict of interest regarding this article"

"The authors declare that all the procedures and experiments of this study respect the ethical standards in the Helsinki Declaration of 1964, as revised in 2013, as well as the national law"

"No funding for this study"

References

1. Piccinini G, Coraci D, Fernandez Marquez EM, Vulpiani MC, Padua L. A case of double anatomic variation: diagnostic efficacy of combination of ultrasound and neurophysiology. *World Neurosurg*. 2018; 120: 112-6.
2. Xu J, Zhong WR, Cheng L, Wang CY, Wen G, Han P, Chai YM. The combined use of a neurocutaneous flap and the Ilizarov technique for reconstruction of large soft tissue defects and bone loss in the tibia. *Ann Plast Surg*. 2017; 78(5): 543-8.
3. Silverman ER, Vydyanathan A, Gritsenko K, Shaparin N, Singh N, Downie SA, Kosharskyy B. The anatomic relationship of the tibial nerve to the common peroneal nerve in the popliteal fossa: implications for selective tibial nerve block in total knee arthroplasty. *Pain Res Manag*. 2017; 261: 1-6.
4. Czerniecki JM, Thompson ML, Littman AJ, et al. Predicting reamputation risk in patients undergoing lower extremity amputation due to the complications of peripheral artery disease and/or diabetes. *Br J Surg*. 2019; 106(8): 1026-34.
5. Lui TH, Chan WC, Maffulli N. Endoscopic flexor hallucis longus tendon transfer for chronic Achilles tendon rupture. *Sports Med Arthrosc Rev*. 2016; 24(1): 38-41.
6. Mao H, Shi Z, Wapner KL, Dong W, Yin W, Xu D. Anatomical study for flexor hallucis longus tendon transfer in treatment of Achilles tendinopathy. *Surg Radiol Anat*. 2015; 37(6): 639-47.
7. Liu H, Thompson LV. Skeletal muscle denervation investigations: selecting an experimental control wisely. *Am J Physiol Cell Physiol*. 2019; 316(3): C456-C461.
8. Yu D, Yin H, Han T, Jiang H, Cao X. Intramuscular innervations of lower leg skeletal muscles: applications in their clinical use in functional muscular transfer. *Surg Radiol Anat*. 2016; 38(6): 675-85
9. Hislop M, Tierney P. Anatomical variations within the deep posterior compartment of the leg and important clinical consequences. *J Sci Med Sport*. 2004; 7(3):392-9.
10. Tubbs RS, Loukas M, Shoja MM. Bergman's comprehensive encyclopedia of human anatomic variation. *John Wiley & Sons, Hoboken*, NJ, USA, 2016;357–360.
11. Houschyar KS, Momeni A, Pyles MN, Cha JY, Maan ZN, Duscher D. The role of current techniques and concepts in peripheral nerve repair. Plastic surgery international. *Plast Surg Int*. 2016; 2016: 4175293.
12. Chen H, Meng D, Yin G, Hou C, Lin H. Translocation of the soleus muscular branch of the tibial nerve to repair high common peroneal nerve injury. *Acta Neurochir (Wien)*. 2019; 161(2): 271-277.
13. Bayrak IK, Oytun Bayrak A, Türker H, Akpınar ÇK, Bolat N. Diagnostic value of ultrasonography in peroneal neuropathy. *Turk J Med Sci*. 2018; 48(6): 1115-20.
14. Wilson TJ, Maldonado AA, Amrami KK, Glazebrook KN, Moynagh MR, Spinner RJ. The anatomic location and importance of the tibialis posterior fascicular bundle at the sciatic nerve bifurcation: report of 3 cases. *J Neurosurg*. 2018;131(6):1869-75.
15. Vaeggemose M, Pham M, Ringgaard S, et al. Magnetic resonance neurography visualizes abnormalities in sciatic and tibial nerves in patients with type 1 diabetes and neuropathy. *Diabetes*. 2017; 66(7): 1779-88.
16. Dikici AS, Ustabasioglu FE, Delil S, et al. Evaluation of the tibial nerve with shear-wave elastography: a potential sonographic method for the diagnosis of diabetic peripheral neuropathy. *Radiology*. 2017; 282(2): 494-501.
17. Bavdek R, Zdolšek A, Strojnik V, Dolenec A. Peroneal muscle activity during different types of walking. *J Foot Ankle Res*. 2018; 11: 50.
18. Rossi AC. Indications and outcomes of intrauterine surgery for fetal malformations. *Curr Opin Obstet Gynecol*, 2010;22(2): 159-165.
19. Khmara TV, Okrym II, Zamorskii II, Novychenko SD, Hahen OY, Dronyk II. Age and individual anatomical variability of intercostal nerves in human fetuses. *Rom J Morphol Embryol*. 2019;60(2):635-642.
20. Hryhorieva PV, Khmara TV, Palamar AO, Sykyrytska TB, Leka MY. Anatomical variability of cutaneous nerves of anterior femoral region in human fetuses. *Wiad Lek*, 2021;74(2):207-212.
21. Bas O, Bilgic S, Salbacak A, Sonmez OF, Erkut A. Variations of the superficial peroneal nerve and its terminal branches in the Turkish newbornfetuses. *Turk Neurosurg*. 2012; 22(1): 62-7.
22. Prakash, Bhardwaj AK, Singh DK, Rajini T, Jayanthi V, Singh G. Anatomic variations of superficial peroneal nerve: clinical implications of a cadaver study. *Ital J Anat Embryol*. 2010; 115(3): 223-8.
23. Tzika M, Paraskevas GK, Kitsoulis P. The accessory deep peroneal nerve: a review of the literature. *Foot (Edinb)*. 2012; 22(3): 232-4.
24. Kurtoglu Z, Aktekin M. Uluutku MH. Branching patterns of the common and superficial fibular nerves in fetus. *Clin Anat*. 2006; 19(7): 621-6.