UDC: 611.972.013.018-053.15
DOI: 10.24061/2413-4260.XVI.2.60.2026.30

TOPOGRAPHIC ANATOMY OF TRANSVERSE SECTIONS OF THE ARM IN HUMAN FETUSES

T. Khmara, O. Koval, T. Pankiv, I. Oliinyk, I. Tsumanets[1]

Bukovinian State Medical University
(Chernivtsi, Ukraine),
Lesya Ukrainka Volyn National University[1]
(Lutsk, Ukraine)

Abstract.
This study delineates the topographic and anatomical characteristics of the transverse sections of the brachial region in human fetuses across various stages of intrauterine development. Patterns in the formation of spatial relationships between muscles, fasciae, vessels, and nerves, along with their age-related morphometric variations, were established.

Study Objective. *To determine the syntopic relationships of the muscles, vessels, and nerves within the brachial region of human fetuses and to systematize data regarding the fetal anatomy of upper limb structures.*

Materials and Methods. *Thirty-three human fetuses with a crown-rump length (CRL) ranging from 136.0 mm to 310.0 mm were examined using topographic-anatomical sectioning. The study received approval from the Bioethics Commission of the Bukovinian State Medical University (Protocol No. 3, November 20, 2025); no violations of ethical or legal standards were identified during the research. Statistical analysis was performed using standard methods of variation statistics. Quantitative data are presented as mean and standard deviation. Differences and relationships between variables were assessed through appropriate statistical methods, with statistical significance set at $p < 0.05$. Research Project: «Morphofunctional features of the development of organs and systems within topographic anatomical regions in human ontogenesis» (State Registration No. 0125U002137, implementation period: January 1, 2025 – December 31, 2029).*

Results. *The topographic organization of the brachial region was found to be established during the early stages of intrauterine development, remaining stable throughout the fetal period. A distinct division into anterior (flexor) and posterior (extensor) osteofascial compartments, delineated by intermuscular septa, was identified. Consistent changes in the position of the median nerve relative to the brachial artery – shifting from lateral to medial – were observed. A significant correlation was established between gestational age and both the transverse diameter of the arm and its cross-sectional area ($r = 0.86$; $p < 0.01$), accompanied by a reduction in the distance between the brachial artery and the median nerve. Variations in the anatomy of neurovascular structures were detected in 9.1% of cases.*

Conclusions. *The findings hold significance for prenatal diagnostics, neonatal surgery, and traumatology, and are applicable to the educational process.*

Keywords: *Brachial Region; Transverse Sections; Neurovascular Structures; Morphometric parameters; Brachial plexus; human skeletal development; Prenatal Diagnosis.*

Introduction

The investigation of topographic and anatomical relationships of organs and structures in human fetuses is crucial for understanding their normal development and variations with potential clinical significance in prenatal diagnostics. Modern studies in fetal anatomy have elucidated patterns in the formation and syntopic relationships of individual organs and structures, thereby contributing to the refinement of surgical techniques and diagnostic approaches in pediatric and reconstructive surgery. Similar approaches are employed in investigations of the axillary and brachial regions, wherein precise localization of neurovascular structures relative to osseous and muscular landmarks is paramount for surgical planning [1, 2].

Contemporary anatomical research underscores the necessity of comprehensive investigation into the topographic anatomy of the upper limb at all stages of human ontogenesis, particularly during the fetal period. General patterns of upper limb development are described in the literature, commencing in the 5th week of embryonic development with the formation of paired mesodermal buds. These structures differentiate into the skeletal and muscular primordia of the arm, forearm, and hand, thereby facilitating subsequent analysis of their spatial relationships via the examination of transverse sections of the upper limb at different levels in human fetuses [3, 4].

The utilization of advanced imaging technologies, such as magnetic resonance microscopy (MRM), is of particular importance in modern perinatal medicine for the investigation of fetal upper limb topography [5]. These methods facilitate the acquisition of highly detailed images of transverse sections of the fetus during early developmental stages (8-12 weeks of gestation), a factor critical for precise determination of the onset of ossification of long bones of the upper limb. These data correlate with histological findings, thereby establishing an integrated morphological profile of upper limb development in humans [3, 6, 7].

Numerous studies are dedicated to the topography of peripheral nerve plexuses in fetuses, particularly the brachial plexus, and their relationships with surrounding structures. The application of dissection methods in human fetuses enables the identification of variations in the topographic and anatomical relationships of nerve trunks within the arm, which possesses clinical significance in assessing the etiologies of upper limb paresis postnatally and in planning surgical interventions during the neonatal period [8].

Furthermore, studies in fetal topographic anatomy identify key landmarks utilized to describe the spatial relationships of neurovascular structures in the brachial region. These landmarks encompass the surface features of tendons and muscles, intermuscular grooves, and bony prominences, thereby enabling the creation of projection maps of anatomical structures onto the fetal skin surface. This is important not only for anatomical comprehension but also for the development of standardized approaches to prenatal diagnostic procedures, including ultrasonographic examination [9].

Anatomical variability, specifically the variability in the arrangement of blood vessels, nerves, and fasciae within the anterior and posterior regions of the arm, is of particular interest [10]. Variations in the topography of these structures are associated with intrauterine development and may exert a direct impact on the manifestation of clinical syndromes or complications following injuries. Such variability highlights the necessity of aggregating data on topographic relationships from large embryonic and fetal samples to establish morphometric standards applicable in anthropometric and clinical studies.

It is also imperative to note that topographic anatomy is intrinsically linked to embryological processes that determine the phased formation of neurovascular structures, muscle masses, and articular surfaces. Embryological studies investigating the development of the upper limb at the molecular and cellular levels expand the understanding of how early developmental defects may manifest as variations in topographic structures in human fetuses and newborns [11-13].

The systematization of data on the topographic anatomy of transverse sections of the arm in human fetuses facilitates the identification of scientific gaps, specifically the insufficient number of large samples with comprehensive morphometric descriptions of structures, as well as the imperative to integrate modern three-dimensional reconstruction methods with traditional dissection techniques. This underscores the practical importance of further research in this field for clinical medicine, the development of prenatal diagnostic methods, and the advancement of morphological knowledge [14-17].

An improved understanding of the brachial region also contributes to the assessment of injuries and trauma of the upper limb, including damage to vessels and nerves, which is particularly important in the setting of military actions and emergency situations [16, 17], where rapid and precise anatomical interpretation enables more effective surgical care and rehabilitation.

Study Objective

To determine the syntopy of muscles, vessels, and nerves of the brachial region in human fetuses, as well as to generate systematized data on the fetal anatomy of the components of the upper limb that can be used in the educational process and clinical practice.

Materials and Methods

The study was performed on 33 human fetuses with a crown-rump length (CRL) of 136.0-310.0 mm without signs of congenital malformations. To investigate the topographic and anatomical features of the structures of the brachial region in fetuses at different stages of development, the method of topographic anatomical sectioning was used. The brachial region was examined at the levels of the upper, middle, and lower thirds of the arm.

Topographic-anatomical sections were performed in the horizontal plane according to the method of MI Pirogov. Fixed and pre-decalcified specimens were rinsed in running water for 24-48 hours (depending on specimen size), after which sections 5-15 mm thick were obtained using a specialized knife for topographic-anatomical sectioning. The obtained sections were rinsed again and immersed in a 5% formalin solution for preservation and further demonstration.

At the macroscopic level, the spatial relationships of osseous structures, muscles, vessels, and nerves of the brachial region were analyzed. Based on the topographic-anatomical sections, schematic images were created and used to systematize and generalize the obtained morphological data.

In each section, the transverse diameter of the brachial region was determined as the maximum distance between the lateral and medial surfaces, as well as the thickness of the brachial fascia and the distance between the brachial artery and the median nerve in the middle third of the arm. Measurements were performed using an electronic caliper with an accuracy of 0.01 mm, as well as on calibrated digital images.

The cross-sectional area of the arm was determined by digital planimetry: each section was photographed with a scale ruler, the images were imported into ImageJ software, the scale was calibrated, and the external contour of the soft tissues was outlined using the Polygon Selection Tool, after which the area was calculated in mm^2. At least three measurements were performed for each fetus, followed by calculation of the mean value. Statistical analysis was carried out using methods of variation statistics with determination of $M \pm SD$, minimum and maximum values, Student's t-test, and Pearson correlation analysis; differences were considered significant at $p < 0.05$.

The study was conducted in accordance with the fundamental bioethical principles of the Council of Europe Convention on Human Rights and Biomedicine (April 4, 1997), the World Medical Association Declaration of Helsinki on ethical principles for medical research involving human subjects (1964-2013), Order of the Ministry of Health of Ukraine No. 690 dated September 23, 2009, as well as the methodological guidelines of the Ministry of Health of Ukraine «Procedure for the removal of biological materials from deceased persons whose bodies are subject to forensic medical examination and pathological examination for scientific purposes» (2018).

The study was approved by the Bioethics Commission of the Bukovinian State Medical University (Protocol No. 3, November 20, 2025); no violations of ethical or legal standards were identified during the research.

The study is part of the comprehensive research topic of the Department of Anatomy, Clinical Anatomy and Operative Surgery entitled»Sex- and age-related patterns of ontogenetic transformations and morphometric parameters of organs and structures under normal and experimental conditions. Morphofunctional and anthropometric features of the musculoskeletal system of athletes» (state registration No. 0125U001531).

Results and Discussion

During intrauterine development of the fetal upper limb, a gradual formation of topographic and anatomical relationships between muscles, fascial structures, intermuscular septa, and neurovascular elements of the brachial region form gradually. Analysis of transverse sections of the arm in human fetuses at different gestational ages demonstrates preservation of the basic spatial organization of this anatomical region of the upper limb, along with the progressive formation of structural details, which is of fundamental importance for both age-related morphology and clinical practice (Fig. 1).

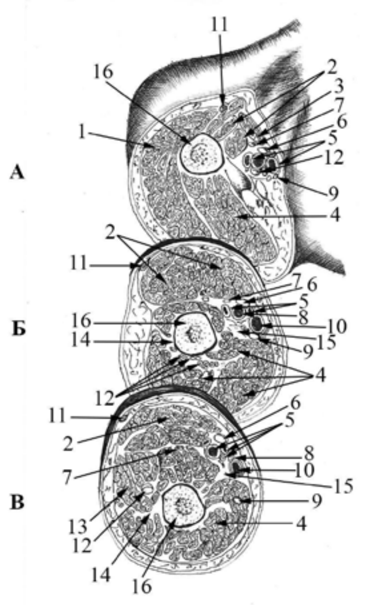

Fig. 1. Transverse sections of the right brachial region at the level of the upper (A), middle (B), and lower (C) thirds of a human fetus with a crown-rump length (CRL) of 265.0 mm (schematic representation):

1 – deltoid muscle; 2 – biceps brachii muscle; 3 – coracobrachialis muscle; 4 – triceps brachii muscle; 5 – brachial artery and veins; 6 – median nerve; 7 – musculocutaneous nerve; 8 – medial cutaneous nerves of the arm and forearm; 9 – ulnar nerve; 10 – basilic vein; 11 – cephalic vein; 12 – radial nerve, deep brachial artery and vein; 13 – brachioradialis muscle; 14 – lateral intermuscular septum of the arm; 15 – medial intermuscular septum of the arm; 16 – humerus.

In transverse sections of the brachial region, two main muscle groups are clearly identified, arranged according to the ventro-dorsal principle. The anterior group is represented by flexor muscles, whereas the posterior group consists of extensor muscles. The spatial separation of these groups is ensured by a system of intermuscular septa: medially, by the medial bicipital groove; laterally, by the lateral intermuscular septum. In the distal parts of the arm, an additional medial intermuscular septum is formed, which extends to the medial epicondyle of the humerus and contributes to the final separation of osteofascial compartments.

In the upper and middle thirds of the arm, the main neurovascular structures are located in the medial bicipital groove. At the same time, the intermuscular septum is not yet fully developed, and the groove is partially filled with loose connective and subcutaneous adipose tissue surrounding the nerve trunks and vessels. The lateral and medial intermuscular septa originate from the brachial fascia and attach to the humerus, forming enclosed anatomical spaces for the anterior and posterior muscle groups.

In the middle third of the arm, within the flexor compartment, the biceps brachii muscle is located superficially. Beneath it, the brachialis muscle lies, closely adjacent to the diaphysis of the humerus. In the posterior muscular compartment, the long head of the triceps brachii is found superficially; the lateral head is positioned laterally, whereas the medial head is in direct contact with the posterior surface of the humerus and is covered by other muscles.

The brachial artery, together with two accompanying veins, occupies a central position in the medial bicipital groove. A larger lumen is observed in one vein because of basilic vein inflow. The median nerve is located ventral to the brachial artery, whereas the musculocutaneous nerve passes beneath the biceps brachii muscle, occupying a lateral position. Near the brachial veins, medial to the brachial artery, the medial cutaneous nerve of the forearm is identified. The ulnar nerve, together with the superior ulnar collateral artery, is located in the portion of the groove closer to the triceps brachii muscle. At the junction of the middle and lower thirds of the arm, the ulnar nerve passes through the medial intermuscular septum and enters the posterior compartment.

On the posterior surface of the humerus, between the heads of the triceps brachii muscle, the middle collateral artery is observed, accompanied by veins, which represents a branch of the profunda brachii artery. Duplication of the medial cutaneous nerve of the forearm was observed in some cases, particularly in a fetus with a CRL of 305.0 mm, indicating individual anatomical variability (Fig. 2). In the lateral region of the arm, at the boundary between the anterior and posterior muscle groups, the radial nerve lies in close relation to the humerus and is accompanied by the radial collateral artery.

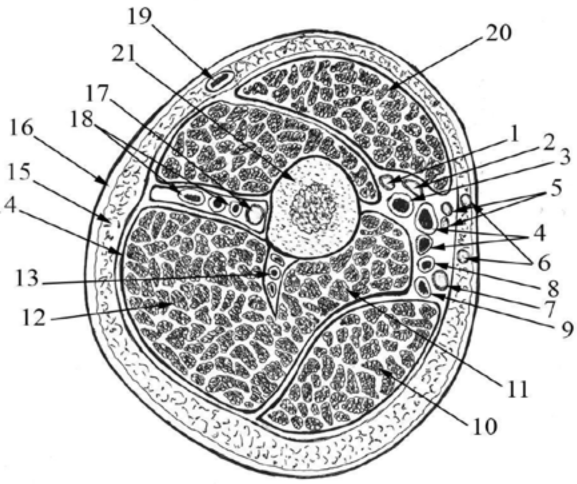

Fig. 2. Transverse section of the right brachial region at the level of the middle third in a human fetus with a crown-rump length (CRL) of 305.0 mm (schematic representation):
1 – musculocutaneous nerve; 2 – median nerve; 3 – brachial artery; 4 – brachial veins; 5 – medial cutaneous nerves of the forearm; 6 – medial cutaneous nerve of the arm; 7 – ulnar nerve; 8 – superior ulnar collateral artery; 9 – inferior ulnar collateral artery; 10 – long head of the triceps brachii muscle; 11 – medial head of the triceps brachii muscle; 12 – lateral head of the triceps brachii muscle; 13 – middle collateral artery; 14 – brachial fascia; 15 – subcutaneous tissue; 16 – skin; 17 – radial nerve; 18 – profunda brachii artery and vein; 19 – cephalic vein; 20 – biceps brachii muscle; 21 – humerus.

Externally, the muscular compartments are surrounded by a well-developed brachial fascia, above which layers of subcutaneous connective tissue and skin are located. In the subcutaneous layer of the medial bicipital groove, the medial cutaneous nerve of the arm is identified, whereas in the projection of the lateral bicipital groove, a transverse section of the cephalic vein is clearly visualized.

The present study confirms that the accuracy of reproducing the spatial relationships of anatomical structures of the fetal brachial region is a key criterion in morphological research, and that the validity of anatomical models depends on their correspondence to gross specimens.

In human fetuses, the highest concentration of intramuscular vessels and neural branches is observed in the upper and middle thirds of the brachial region. The sequence of branching of arterial and neural structures correlates with the topographic and anatomical features of individual arm muscles and the stages of their morphofunctional development. The spatial position of the median nerve undergoes consistent changes along the length of the arm: in the upper third, it is located lateral to the brachial artery; in the middle third, it crosses it anteriorly; and in the lower third, it consistently occupies a medial position relative to the artery.

A comparative analysis of transverse sections of the arm at the levels of the upper and middle thirds revealed no significant differences in the overall topographic organization, indicating relative stability of the anatomical organization of this region at these stages of intrauterine development.

The medial and lateral intermuscular septa, originating from the brachial fascia and attaching to the humerus, form two distinct anatomical compartments – the anterior and posterior osteofascial compartments. In the anterior compartment, the biceps brachii muscle is located superficially, directly beneath the brachial fascia. The biceps brachii is separated from the deeper muscle layer –the coracobrachialis (proximally) and the brachialis (distally) –by the brachial fascia. The musculocutaneous nerve passes in the space between the biceps brachii and brachialis muscles.

In the medial part of the anterior surface of the arm, beneath the medial edge of the biceps brachii muscle, a neurovascular bundle is formed. This bundle consists of the brachial artery, usually two accompanying veins, and the median nerve, which at this level occupies a lateral and ventral position relative to the artery. Medial to the neurovascular bundle, beneath the brachial fascia, the basilic vein and the medial cutaneous nerve of the forearm are located. The ulnar nerve is identified on the anterior surface of the brachialis muscle, posterior and medial to the brachial artery.

The posterior osteofascial compartment contains the triceps brachii muscle. In this muscle, near the humerus, the radial nerve and the profunda brachii artery pass. The deep layer of the brachial fascia encloses each head separately of the triceps brachii muscle, ensuring their anatomical separation. In the subcutaneous layer on the anteromedial surface of the arm, the cephalic vein is identified above the fascia, whereas on the posterior and lateral surfaces of the arm, the posterior cutaneous nerve of the arm is observed.

At the level of the lower third of the arm, several neurovascular structures are clearly identified in the subcutaneous connective tissue above the brachial fascia. These include: on the anteromedial surface – the basilic vein and the medial cutaneous nerve of the forearm; on the anterolateral surface – the cephalic vein; and on the posterolateral surface – the posterior cutaneous nerve of the forearm.

In the anterior osteofascial compartment of the arm, the brachialis and biceps brachii muscles are located. Along the medial margin of the biceps brachii muscle run the brachial artery with its accompanying veins, as well as the median nerve, which occupies a medial position relative to the vessels. Laterally, in the interval between the biceps brachii and brachialis muscles, the musculocutaneous nerve is observed. More deeply, beneath the brachialis muscle, between it and the lateral intermuscular septum of the arm, the radial nerve is identified; at this level, this nerve has shifted from the posterior osteofascial compartment to the anterior one. In the medial part of the posterior osteofascial compartment, between the triceps brachii muscle and the medial intermuscular septum, the ulnar nerve is found; at this stage of development, this nerve passes from the anterior compartment.

In human fetuses of four to five months of gestation, two functionally distinct muscle groups of the arm are clearly formed (Fig. 3).

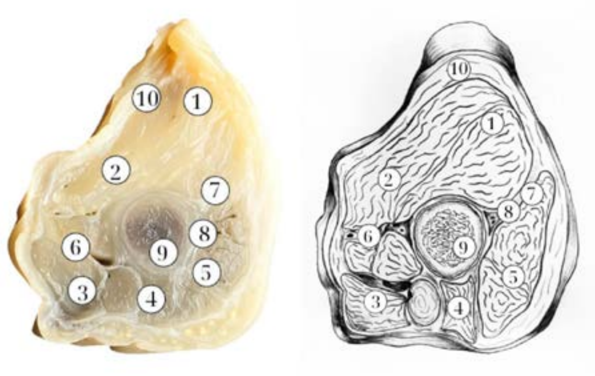

Fig. 3. Transverse section of the right brachial region at the level of the upper third in a human fetus with a crown-rump length (CRL) of 160.0 mm (A – photograph of the gross specimen; B – schematic illustration):

1 – biceps brachii muscle; 2 – brachialis muscle; 3 – lateral head of the triceps brachii muscle; 4 – medial head of the triceps brachii muscle; 5 – long head of the triceps brachii muscle; 6 – lateral intermuscular septum; 7 – medial intermuscular septum; 8 – neurovascular bundle: brachial artery, median nerve, basilic vein; 9 – humerus; 10 – subcutaneous tissue.

The anterior group is represented by flexor muscles – the biceps brachii, brachialis, and coracobrachialis – whereas the posterior group is formed by the triceps brachii muscle (Fig. 4). These muscle masses are separated by the lateral and medial intermuscular septa, which arise from the brachial fascia and attach to the humerus, forming the anterior and posterior osteofascial compartments.

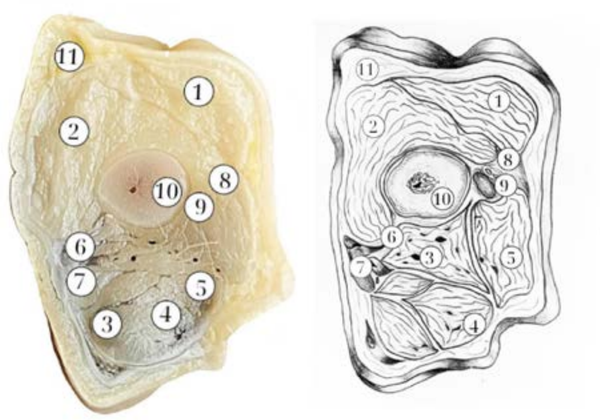

Fig. 4. Transverse section of the right brachial region at the level of the middle third in a human fetus with a crown-rump length (CRL) of 160.0 mm (A – photograph of the gross specimen; B – schematic illustration):

1 – biceps brachii muscle; 2 – brachialis muscle; 3 – lateral head of the triceps brachii muscle; 4 – medial head of the triceps brachii muscle; 5 – long head of the triceps brachii muscle; 6 – lateral intermuscular septum; 7 – ulnar nerve; 8 – medial intermuscular septum; 9 – neurovascular bundle: brachial artery, median nerve, basilic vein; 10 – humerus; 11 – subcutaneous tissue.

In the anterior compartment, the biceps brachii muscle is located superficially; beneath it, in close contact with the humerus, the brachialis muscle lies. The musculocutaneous nerve passes between these muscles (Fig. 5). The posterior compartment contains the triceps brachii muscle, differentiated into long, lateral, and medial heads, with the medial head directly adjacent to the posterior surface of the humerus.

ISSN 2226-1230 (PRINT) ISSN 2413-4260 (ONLINE)

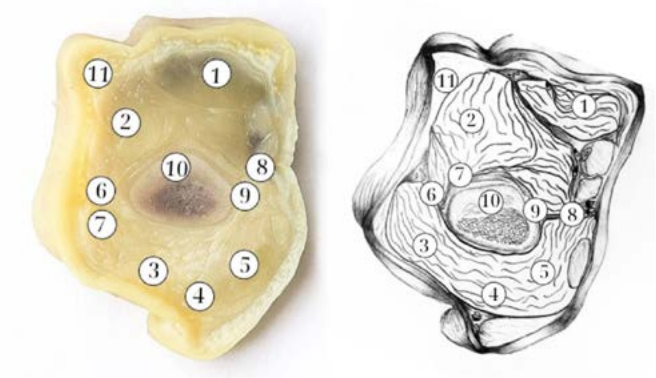

Fig. 5. Transverse section of the right brachial region at the level of the lower third in a human fetus with a crown-rump length (CRL) of 160.0 mm (A – photograph of the gross specimen; B – schematic illustration):
1 – biceps brachii muscle; 2 – brachialis muscle; 3 – lateral head of the triceps brachii muscle; 4 – medial head of the triceps brachii muscle; 5 – long head of the triceps brachii muscle; 6 – lateral intermuscular septum; 7 – ulnar nerve; 8 – medial intermuscular septum; 9 – neurovascular bundle: brachial artery, median nerve, basilic vein; 10 – humerus; 11 – subcutaneous tissue.

At this stage of intrauterine development, the brachial artery is already accompanied by two veins. Gradual changes are observed in the topography of the median nerve: in the upper third of the arm, it lies lateral to the artery, in the middle third, it crosses it anteriorly, and in the lower third, it assumes a stable medial position. The ulnar nerve in the proximal parts of the arm passes posterior and medial to the brachial artery, and more distally, it enters the posterior osteofascial compartment through the medial intermuscular septum. The general pattern of topographic relationships is already established at this stage; however, the muscles and fasciae remain relatively thin, and the subcutaneous tissue contains a minimal amount of adipose tissue.

In fetuses at six to seven months of gestation, a further increase in muscle mass is observed along with thickening of the brachial fascia (Fig. 6).

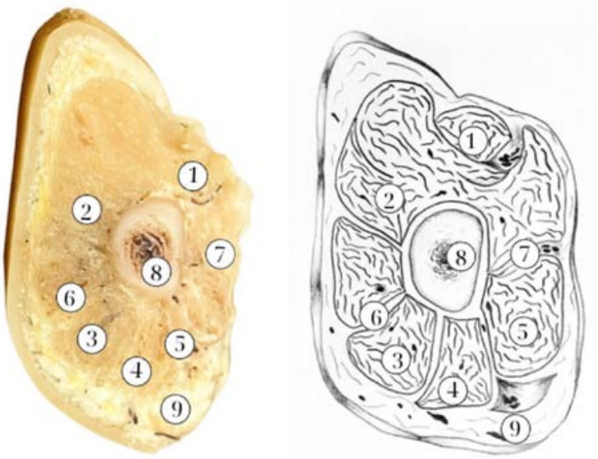

Fig. 6. Transverse section of the right brachial region at the level of the upper third in a human fetus with a crown-rump length (CRL) of 210.0 mm (A – photograph of the gross specimen; B – schematic illustration):
1 – biceps brachii muscle; 2 – brachialis muscle; 3 – lateral head of the triceps brachii muscle; 4 – medial head of the triceps brachii muscle; 5 – long head of the triceps brachii muscle; 6 – lateral intermuscular septum; 7 – medial intermuscular septum; 8 – humerus;9 – subcutaneous tissue.

In the anterior osteofascial compartment, the biceps brachii muscle increases in size, whereas the brachialis muscle surrounds the humerus more closely. The musculocutaneous nerve continues to pass between these structures; however, muscle growth decreases the distance between the nerve and the fascia (Fig. 7). In the posterior compartment, more distinct differentiation of the long, lateral, and medial heads of the triceps brachii muscle is observed, and the spaces between these heads clearly delineate the course of the profunda brachii artery and the radial nerve, which lie in close contact with the posterior surface of the humerus.

In the middle third of the arm, the median nerve is located anterior to the brachial artery, and in the lower third, it assumes a medial position. At the level of the lower third of the arm, the ulnar nerve passes through the medial intermuscular septum and enters the posterior osteofascial compartment. The neurovascular bundle of the arm in the middle and lower thirds appears more compact because of thickening of the fascia and an increase in the volume of the adjacent muscles (Fig. 8).

In fetuses at eight months of gestation, the morphological structure of transverse sections of the arm approaches that of newborns. The muscles reach their maximal development among the studied age groups, the fascial structures become denser, and the subcutaneous tissue contains well-defined fat layers (Fig. 9).

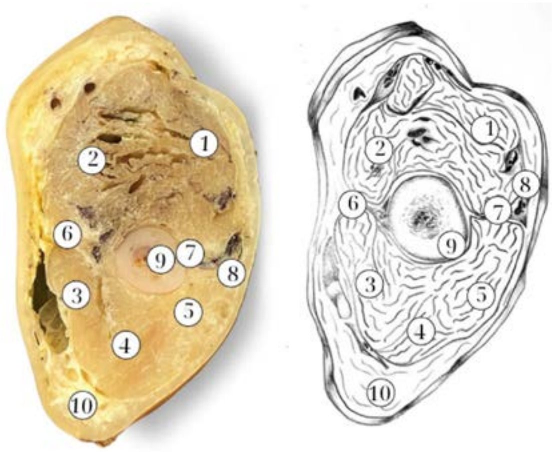

Fig. 7. Transverse section of the right brachial region at the level of the middle third in a human fetus with a crown-rump length (CRL) of 210.0 mm (A – photograph of the gross specimen; B – schematic illustration):
1 – biceps brachii muscle; 2 – brachialis muscle; 3 – lateral head of the triceps brachii muscle; 4 – medial head of the triceps brachii muscle; 5 – long head of the triceps brachii muscle; 6 – lateral intermuscular septum; 7 – medial intermuscular septum; 8 – neurovascular bundle: brachial artery, median nerve, basilic vein; 9 – humerus; 10 – subcutaneous tissue.

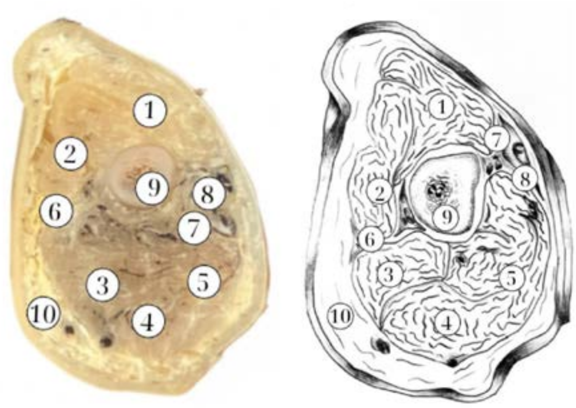

Fig. 8. Transverse section of the right brachial region at the level of the lower third in a human fetus with a crown-rump length (CRL) of 210.0 mm (A – gross specimen; B – schematic illustration):
1 – biceps brachii muscle; 2 – brachialis muscle; 3 – lateral head of the triceps brachii muscle; 4 – medial head of the triceps brachii muscle; 5 – long head of the triceps brachii muscle; 6 – lateral intermuscular septum; 7 – medial intermuscular septum; 8 – neurovascular bundle: brachial artery, median nerve, basilic vein; 9 – humerus; 10 – subcutaneous tissue.

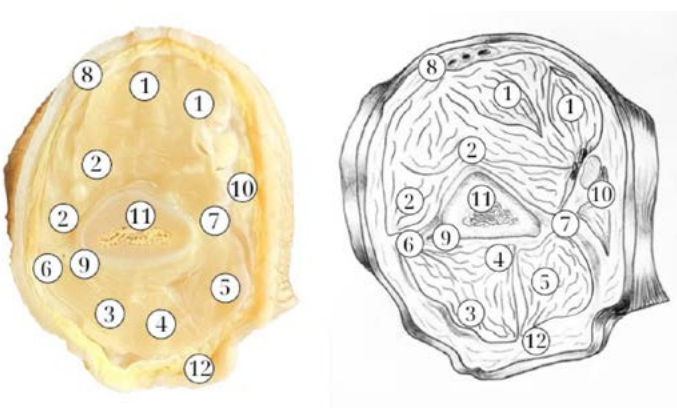

Fig. 9. Transverse section of the right brachial region at the level of the upper third in a human fetus with a crown-rump length (CRL) of 265.0 mm (A – gross specimen; B – schematic illustration):
1 – biceps brachii muscle; 2 – brachialis muscle; 3 – lateral head of the triceps brachii muscle; 4 – medial head of the triceps brachii muscle; 5 – long head of the triceps brachii muscle; 6 – lateral intermuscular septum; 7 – medial intermuscular septum; 8 – cephalic vein; 9 – profunda brachii artery and radial nerve; 10 – neurovascular bundle: brachial artery, median nerve, basilic vein; 11 – humerus; 12 – subcutaneous tissue.

In the anterior compartment, the biceps brachii muscle is distinctly separated from the brachialis muscle by the deep layer of the brachial fascia, whereas the musculocutaneous nerve maintains its position between them. In the posterior osteofascial compartment, the triceps brachii muscle is well developed, its heads are distinctly differentiated, and the middle collateral artery – a branch of the profunda brachii artery – passes between the long and lateral heads, accompanied by veins (Fig. 10).

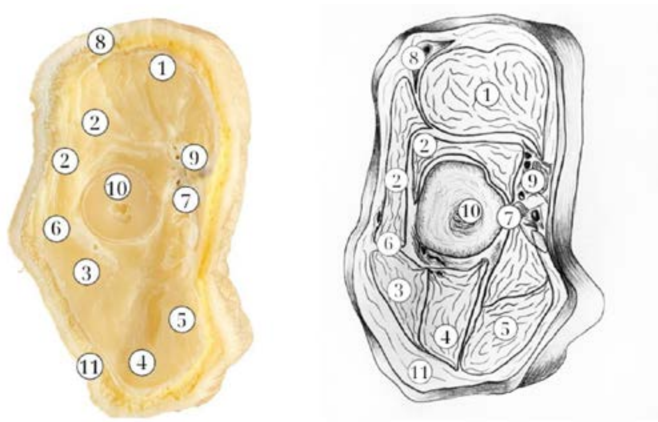

Fig. 10. Transverse section of the right brachial region at the level of the middle third in a human fetus with a crown-rump length (CRL) of 265.0 mm (A – photograph of the gross specimen; B – schematic illustration):
1 – biceps brachii muscle; 2 – brachialis muscle; 3 – lateral head of the triceps brachii muscle; 4 – medial head of the triceps brachii muscle; 5 – long head of the triceps brachii muscle; 6 – lateral intermuscular septum; 7 – medial intermuscular septum; 8 – cephalic vein; 9 – neurovascular bundle: brachial artery, median nerve, basilic vein; 10 – humerus; 11 – subcutaneous tissue.

The radial nerve remains in direct contact with the humerus. In the lower third of the arm, the median nerve assumes a medial position relative to the brachial artery. After passing through the medial intermuscular septum, the ulnar nerve enters the posterior compartment and courses toward the posterior surface of the medial epicondyle of the humerus. In this region, the radial nerve enters the anterior osteofascial compartment, where it is located between the brachialis muscle and the lateral intermuscular septum (Fig. 11).

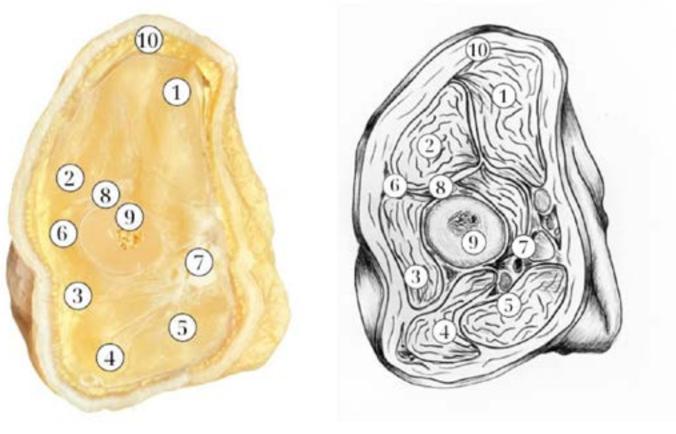

Fig. 11. Transverse section of the right brachial region at the level of the lower third in a human fetus with a crown-rump length (CRL) of 265.0 mm (A – photograph of the gross specimen; B – schematic illustration):
1 – biceps brachii muscle; 2 – brachialis muscle; 3 – lateral head of the triceps brachii muscle; 4 – medial head of the triceps brachii muscle; 5 – long head of the triceps brachii muscle; 6 – lateral intermuscular septum; 7 – medial intermuscular septum; 8 – radial nerve; 9 – humerus; 10 – subcutaneous tissue.

Throughout the fetal period, a stable topographic organization of the arm is maintained, with a clear division into anterior and posterior osteofascial compartments formed by intermuscular septa. The gradual increase in muscle volume, thickening of fasciae, and accumulation of subcutaneous adipose tissue create morphological prerequisites for the complete formation of neurovascular structures and ensure their anatomical protection and proper functioning after birth.

The obtained results indicate that the topographic and anatomical organization of the human brachial region is established at early stages of intrauterine development and preserves its general spatial patterns throughout the fetal period. This finding is consistent with the observations of Tanaka et al. [1] and Hita-Contreras et al. [10], who demonstrated that the spatial arrangement of the elements of the shoulder girdle and the main muscle masses is determined already in the embryonic period and is subsequently modified only quantitatively because to tissue growth.

The study by Kawada et al. [2] emphasizes that the development of the human brachial region is adapted to obstetric constraints, leading to the early formation of a compact configuration of muscles, fasciae, and neurovascular bundles. Our data on the relative stability of spatial relationships between the brachial artery and the median, ulnar, and radial nerves at different stages of fetal development support this concept.

Particular attention should be paid to the gradual differentiation of the anterior and posterior osteofascial compartments of the arm. In fetuses at four to five months of intrauterine development, intermuscular septa are clearly identified, forming anatomical compartments that contain muscular and neurovascular structures. Further thickening of fasciae and increase in muscle mass in fetuses at 6-7 and 8 months of gestation do not alter the fundamental topography but contribute to the compaction of neurovascular bundles, which is consistent with the findings of Josemans et al. [5] obtained using MR microscopy.

Morphometric analysis of transverse sections of the brachial region, performed in 33 human fetuses with a crown-rump length (CRL) of 136.0-310.0 mm, revealed clear age-related patterns of growth and spatial reorganization of muscular-fascial and neurovascular structures. The transverse diameter of the arm significantly increased with gestational age and CRL ($r = 0.86$; $p < 0.01$).

In fetuses of four to five months of gestation, the mean transverse diameter of the arm was 18.6 ± 2.1 mm (min, 15.2 mm; max, 22.4 mm); in six to sevenmonth fetuses, 24.9 ± 2.7 mm (min, 20.8 mm; max, 29.6 mm); and in eight -month fetuses, 31.4 ± 3.2 mm (min, 26.7 mm; max, 36.9 mm). The cross-sectional area of the arm increased from 272.4 ± 41.6 mm² at four to five months to 486.7 ± 58.9 mm² at six to seven months and to 774.2 ± 96.3 mm² at eight months of gestation.

Fascial thickness increased from 0.4 ± 0.1 mm in early fetuses to 0.9 ± 0.2 mm at later stages of gestation. The distance between the brachial artery and the median nerve in the middle third of the arm decreased from 2.8 ± 0.5 mm to 1.6 ± 0.4 mm.

Variations in the anatomy of neurovascular structures were observed in 9.1% of cases, which corresponds to literature data on the frequency of fetal anatomical variability (Table).

Table

Morphometric parameters of the transverse dimensions of the brachial region in human fetuses (n = 33)

Gestational age	CRL, mm	Transverse diameter of the arm, mm	Min–max, mm	Cross-sectional area, mm²	Fascial thickness, mm
4-5 months	136-180	18.6 ± 2.1	15.2-22.4	272.4 ± 41.6	0.4 ± 0.1
6-7 months	181-250	24.9 ± 2.7	20.8-29.6	486.7 ± 58.9	0.7 ± 0.2
8 months	251-310	31.4 ± 3.2	26.7-36.9	774.2 ± 96.3	0.9 ± 0.2

Data from the multimodal atlas of human skeletal development by To et al. [4] allow the identified topographic features to be interpreted as both a morphological phenomenon and the result of complex coordination of osteogenesis, myogenesis, and neurogenesis. The findings of Koval et al. [3] on ossification of the humeral diaphysis complement the understanding of morphofunctional relationships between osseous structures and adjacent neurovascular elements.

The practical significance of the obtained data lies in their potential value for prenatal diagnostics and surgical planning. Studies by Bisht et al. [12] confirm the high diagnostic accuracy of the combined use of ultrasound, MRI, and CT in detecting congenital musculoskeletal anomalies, highlighting the importance of understanding normal fetal topography of the brachial region structures. Similarly, Farr et al. [11] emphasize the importance of anatomical prerequisites for predicting perinatal outcomes in cases of limb malformations.

The study of fetal anatomy of the osseous, fascial-muscular, and neurovascular structures of the brachial region also has practical significance for postnatal clinical practice. Cunha et al. [7] demonstrated a relationship between variations in the structure of the brachial plexus in human fetuses and the risk of neonatal upper limb paralysis. Contemporary Ukrainian experience in the management of combat-related injuries of the upper extremity [14, 15] shows that understanding of the embryonic and fetal prerequisites of vascular and nerve topography may be important for reconstructive and restorative surgery, especially in complex combined injuries of the brachial region. Morphometric analysis of the transverse dimensions of the brachial region in 33 human fetuses confirmed the presence of clear age-related patterns in the growth and development of muscular-fascial and neurovascular structures, correlating with gestational age and crown-rump length (CRL) ($r = 0.86$; $p < 0.01$). The data on the increase in the transverse diameter of the arm and its cross-sectional area with fetal growth are consistent with literature reports on the progressive increase in the length of the humeral diaphysis during the second and third trimesters of pregnancy, particularly in studies of Iranian [18, 21] and Indian [19, 23-26] populations, where high correlations between bone length and gestational age were found. Three-dimensional ultrasound studies also demonstrate that the increase in humeral volume occurs in parallel with the enlargement of soft tissue transverse dimensions [20], which confirms the observed patterns of changes in cross-sectional area and fascial thickness. Furthermore, the decrease in the distance between the brachial artery and the median nerve with increasing fetal age corresponds to data on the variability and differentiated organization of neurovascular structures, observed in 9.1% of cases, consistent with reported indicators of fetal anatomical variability [24].

The results of the present study are consistent with modern morphological, imaging, and clinical data, confirming that the overall topographic organization of the human brachial region is established early and remains stable throughout intrauterine development. The identified age-related features are mainly quantitative, including an increase in muscle mass, thickening of fasciae, and accumulation of subcutaneous adipose tissue, which create anatomical prerequisites for the functional maturity of neurovascular structures after birth.

Conclusions:

1. In human fetuses at different stages of intrauterine development, a stable topographic and anatomical organization of the arm is preserved, including a clear division into anterior (flexor muscles) and posterior (extensor muscles) osteofascial compartments separated by medial and lateral intermuscular septa.
2. At early stages of development, two main muscle groups are already identified in the upper third of the arm, as well as the neurovascular bundle comprising the brachial artery, two accompanying veins, and the median nerve. The position of the median nerve changes from lateral (upper third) to anterior (middle third) and then to medial (lower third) relative to the brachial artery.
3. In the posterior osteofascial compartment, the triceps brachii muscle retains its characteristic three-headed structure (long, lateral, and medial heads), between which the radial nerve and the profunda brachii artery pass. In the distal parts of the arm, the ulnar nerve passes from the anterior compartment to the posterior one through the medial intermuscular septum.
4. The progressive increase in muscle mass, thickening of the brachial fascia, and accumulation of subcutaneous adipose tissue during the fetal period ensure improved protection and spatial stability of neurovascular structures.
5. The highest concentration of neurovascular elements is observed in the upper and middle thirds of the arm, which is important for surgical practice, traumatology, and perinatal medicine, and serves as an anatomical basis for planning surgical interventions in newborns.

Prospects for Further Research. The present study indicates the need for further investigation of the anatomical variability of organs and neurovascular structures of the forearm during the fetal period of human ontogenesis.

Contribution of co-authors to the preparation of materials for the scientific article: Tetiana V. Khmara – conceptualization, supervision, methodology, writing – review and editing; Oleksandr A. Koval – the research idea, data collection, systematization of the collected data, statistical analysis, interpretation of results, formation of conclusions, writing – original draft preparation; Tetiana V. Pankiv – data analysis, visualization, writing – original draft preparation; Ihor Yu. Oliinyk – supervision, validation, writing – review and editing; Iryna O. Tsumanets – literature review, data interpretation, manuscript editing, writing – original draft preparation. All authors participated in the preparation of the final version of the manuscript, reviewed its content and approved the submission of the article for publication.

Conflict of Interest. The authors declare no conflict of interest.

Use of Artificial Intelligence. Artificial intelligence was not used in the conduct of the study or in the preparation of the manuscript.

Funding. The study did not receive any specific external funding. The work was carried out as part of the individual research activity of the authors at the Department of Anatomy, Clinical Anatomy and Operative Surgery of the Bukovinian State Medical University.

References:

1. Koval O, Khmara T, Zamorskyi I, Biryuk I, Kovalchuk P. Analiz oseredkiv skosteninnia diafiza plechovoi kistky u plodiv 20-32 tyzhni hestatsii [Analysis of foci of ossification of the diaphysis of the humerus in fetuses of 20–32 weeks of gestation]. Ukr J Perinatol Pediatr. 2024;2(98):16-22. DOI: https://doi.org/10.15574/PP.2024.98.16 (in Ukrainian)
2. To K, Fei L, Pett JP, Roberts K, Blain R, Polański K, et al. A multi-omic atlas of human embryonic skeletal development. Nature. 2024;635(8039):657-67. DOI: https://doi.org/10.1038/s41586-024-08189-z
3. Tanaka S, Sakamoto R, Kanahashi T, Yamada S, Imai H, Yoneyama A, et al. Shoulder girdle formation and positioning during embryonic and early fetal human development. PLoS One. 2020;15(9):e0238225. DOI: https://doi.org/10.1371/journal.pone.0238225
4. Kawada M, Nakatsukasa M, Nishimura T, Kaneko A, Ogihara N, Yamada S, et al. Human shoulder development is adapted to obstetrical constraints. Proc Natl Acad Sci USA. 2022;119(16):e2114935119. DOI: https://doi.org/10.1073/pnas.2114935119
5. Josemans SH, van der Post AS, Strijkers GJ, Dawood Y, van den Hoff MJB, Jens SRJ, et al. Ultra-high-field MRI of postmortem human fetal wrist joints: initial experience. Eur Radiol Exp. 2023;7(1):28. DOI: https://doi.org/10.1186/s41747-023-00341-0
6. Pušnik L, Lechner L, Serša I, Cvetko E, Haas P, Jengojan SA, et al. 3D fascicular reconstruction of median and ulnar nerve: initial experience and comparison between high-resolution ultrasound and MR microscopy. Eur Radiol Exp. 2024;8(1):100. DOI: https://doi.org/10.1186/s41747-024-00495-5
7. Cunha MRD, Dias AAM, Brito JM, Cruz CDS, Silva SK. Anatomical study of the brachial plexus in human fetuses and its relation with neonatal upper limb paralysis. Einstein (Sao Paulo). 2020;18:eAO5051. DOI: https://doi.org/10.31744/einstein_journal/2020AO5051
8. Koval OA, Khmara TV, Zamorskyi II, Ilika VV, Harvasiuk OV. Proiektsiina fetal'na anatomiia sudynno-nervovykh utvoren' perednoi plechovoi dilianky. Klinichna anatomiia ta operatyvna khirurhiia. 2023;22(2):48-55. DOI: https://doi.org/10.24061/1727-0847.22.2.2023.17

9. Koval OA, Khmara TV, Zamorskii II, Kryvchanska MI, Garvasiuk OV. Fetal anatomical variability of the ulnar and radial artery system. Neonatology, surgery and perinatal medicine. 2024;14(2):52-99. DOI: https://doi.org/10.24061/2413-4260.XIV.2.52.2024.14

10. Huang Y, Zhang L, Li X, Chen J, Wang H. Prenatal development of the human shoulder joint: anatomical and imaging correlation study. J Anat. 2023;243(5):612-23. DOI: https://doi.org/10.1111/joa.13892

11. Farr A, Wachutka E, Bettelheim D, Windsperger K, Farr S. Perinatal outcomes of infants with congenital limb malformations: an observational study from a tertiary referral center in Central Europe. BMC Pregnancy Childbirth. 2020;20(1):35. DOI: https://doi.org/10.1186/s12884-020-2720-x

12. Bisht RU, Belthur MV, Singleton IM, Goncalves LF. Accuracy of Multimodality Fetal Imaging (US, MRI, and CT) for Congenital Musculoskeletal Anomalies. Children. 2023;10(6):1015. DOI: https://doi.org/10.3390/children10061015

13. Patel N, Singh R, Mehta V, Arora J. Advanced imaging of fetal limb development: correlation of ultrasound and MRI findings with anatomical sections. Prenat Diagn. 2023;43(9):1152-61. DOI: https://doi.org/10.1002/pd.6345

14. Lysak A, Gaiovych V, Strafun S, Shypunov V. Ukrainian Orthopedic Trauma Experience in Managing Wartime Injuries of the Upper Extremity. Hand Clin. 2025;41(3):373-85. DOI: https://doi.org/10.1016/j.hcl.2025.03.012

15. Strafun SS, Gaiovych VV, Strafun OS, Bogdan SV, Kravchenko DD. Peculiarities of shoulder joint arthroplasty after war injuries. Pain, Joints, Spine. 2025;15(1):1–5. DOI: https://doi.org/10.22141/pjs.15.1.2025.448

16. Prasanna LC, Managuli V, Bhat KMR. Histological observations of the developing human fetal humerus at different trimesters of pregnancy. Int J Anat Res. 2024;12(2):8917–23. DOI: https://doi.org/10.16965/ijar.2024.115

17. Duymuş AC, Bozbay N, Orgul G. Fetal humerus length nomogram in gestational weeks 19–24: clinical significance and ethnical differences. ACH Med J. 2024;3(4):131-6. DOI: https://doi.org/0.5505/achmedj.2024.96967

18. Arrillaga B, Miguel-Pérez M, Möller I, Rodríguez-Niedenführ M, Sañudo JR. Human shoulder anatomy: new ultrasound, anatomical, and microscopic perspectives. Anat Sci Int. 2024;99(3):290-304. DOI: https://doi.org/10.1007/s12565-024-00775-5

19. Arduç A, van Dijk S J B, Ten Cate, FJ, van Doesburg M H M, Linskens I H, van Leeuwen E, et al. Phenotype-to-Genotype Description of Prenatal Suspected and Postnatal Discovered Upper Limb Anomalies: A Retrospective Cohort Study. Prenat. Diagn. 2025; 45(1): 3–14. DOI: https://doi.org/10.1002/pd.6714

20. Dawood Y, Strijkers GJ, Limpens J, Oostra R J, & de Bakker B S. Novel imaging techniques to study postmortem human fetal anatomy: a systematic review on microfocus-CT and ultra-high-field MRI. Eur. Radiol. 2020; 30(4): 2280–2292. DOI: https://doi.org/10.1007/s00330-019-06543-8

21. Krzyżanowski A, Kwiatek M, Gęca T, Stupak A, & Kwaśniewska A. Modern Ultrasonography of the Umbilical Cord: Prenatal Diagnosis of Umbilical Cord Abnormalities and Assessement of Fetal Wellbeing. Med Sci Monit: international medical journal of experimental and clinical research. 2019; 25: 3170–3180. DOI: https://doi.org/10.12659/MSM.913762

22. Kaur M, Sharma R, Kapoor K, Kaur , & Arora KS. Fetal Humeral Diaphyseal Length in the Second Trimester - A Radiographic Observational Study among Indian Population. J. Pharm. Bioallied Sci. 2023; 15(Suppl 2): 1239–43. DOI: https://doi.org/10.4103/jpbs.jpbs_147_23

23. Singh A, Anand AK, Ranjan M. Fetal humerus length as a Gestational Age parameter – A nomogram for local Indian population. J Neonatal Surg. 2025;14(8S):840-5. DOI: https://doi.org/10.63682/jns.v14i8S.3420

24. Dawood Y, Strijkers GJ, Limpens J, Oostra R J, & de Bakker BS. Novel imaging techniques to study postmortem human fetal anatomy: a systematic review on microfocus-CT and ultra-high-field MRI. Eur. Radiol. 2020; 30(4): 2280–92. DOI: https://doi.org/10.1007/s00330-019-06543-8

25. Sewify A, Steffens M, Perrier N, Antico M, Lavaill M, Edwards C et al. Comprehensive reconstruction of the musculoskeletal anatomy in the shoulder using a hybrid 3D ultrasound mosaicking workflow: A pilot study. PloS one. 2026; 21(6), e0347231. DOI: https://doi.org/10.1371/journal.pone.0347231

26. Hassan MG. Humeral length versus femur length for estimating fetal age in the third trimester using ultrasound among Saudi fetuses. J Med Ultrasound. 2022;31(2):133-6. DOI: https://doi.org/10.4103/jmu.jmu_26_22

ТОПОГРАФІЧНА АНАТОМІЯ ПОПЕРЕЧНИХ ПЕРЕТИНІВ ПЛЕЧА У ПЛОДІВ ЛЮДИНИ

Т. В. Хмара, О. А. Коваль, Т. В. Паньків, І. Ю. Олійник, І. О. Цуманець[1]

Буковинський державний медичний університет
(м. Чернівці, Україна);
Волинський національний університет імені Лесі Українки[1]
(м. Луцьк, Україна)

Резюме.

У статті наведено результати дослідження топографо-анатомічних особливостей поперечних перетинів плечової ділянки у плодів людини в різні терміни внутрішньоутробного розвитку. Встановлено закономірності формування просторових взаємовідношень м’язів, фасцій, судин і нервів, а також їх вікові морфометричні зміни.

Мета роботи. Встановити синтопію м’язів, судин і нервів плечової ділянки у плодів людини та систематизувати дані щодо фетальної анатомії структур верхньої кінцівки.

Матеріал і методи. Проведено дослідження 33 плодів людини з тім’яно-куприковою довжиною 136,0-310,0 мм із використанням методу топографо-анатомічних зрізів. Дослідження схвалено комісією з біоетики Буковинського державного медичного університету (протокол № 3 від 20 листопада 2025 року); під час його проведення порушень етичних або правових норм не виявлено. Статистичний аналіз проведено із застосуванням стандартних методів варіаційної статистики. Кількісні дані подано у вигляді середнього значення та стандартного відхилення. Оцінку відмінностей і взаємозв’язків між показниками здійснювали з використанням відповідних статистичних методів. Рівень статистичної значущості приймали на рівні $p < 0,05$. Дослідження проводилися в рамках виконання науково-дослідної роботи на тему: «Морфо-функціональні особливості розвитку органів та систем у межах топографо-анатомічних ділянок в онтогенезі людини» (номер державної реєстрації 0125U002137, терміни виконання – 01.01.2025-31.12.2029 рр.).

Результати. Встановлено, що топографічна організація плечової ділянки формується на ранніх етапах внутрішньоутробного розвитку і зберігає стабільність упродовж плодового періоду. Виявлено чіткий поділ на передню (згиначі) та задню (розгиначі) кістково-фасціальні піхви, сформовані міжм'язовими перегородками. Визначено закономірні зміни топографії серединного нерва від латерального до медіального положення щодо плечової артерії. Встановлено достовірне збільшення поперечного діаметра плеча та площі його перерізу зі зростанням гестаційного віку ($r = 0{,}86$; $p < 0{,}01$), а також зменшення відстані між плечовою артерією та серединним нервом. Варіантна анатомія судинно-нервових утворень виявлена у 9,1% випадків.

Висновки. Отримані дані мають важливе значення для пренатальної діагностики, неонатальної хірургії та травматології, а також можуть бути використані у навчальному процесі.

Ключові слова: плечова ділянка; поперечні зрізи; судинно-нервові утворення; морфометричні параметри; плечове сплетення; розвиток скелета людини; пренатальна діагностика.

Contact information:
Tatiana V. Khmara – MD, professor, professor of the Department of Human Anatomy named after MG Turkevich of the Bukovinian State Medical University (Chernivtsi, Ukraine).
e-mail: khmara.tv.6@gmail.com
ORCID ID: https://orcid.org/0000-0001-8023-5181
Researcher ID: https://researchid.com/C-9964-2017
Scopus Author ID: 57209663496

Oleksandr A. Koval – PhD (Medicine), Assistant at the Department of Disaster Medicine and Military Medicine, Bukovinian State Medical University (Chernivtsi, Ukraine).
e-mail: koval190488@gmail.com,
ORCID ID: https://orcid.org/0000-0002-9434-8213
Researcher ID: ABZ-1757-2022
Scopus Author ID: 58038661100

Tetiana V. Pankiv – PhD (Medicine), assistant of the Department of Pathological Anatomy of the Bukovinian State Medical University (Chernivtsi, Ukraine).
e-mail: komar.tetiana.ls14@bsmu.edu.ua
ORCID ID: https://orcid.org/ 0000-0003-0947-6729
Researcher ID: https://researchid.com/komartetiana
Scopus Author ID: 58100789200

Ihor Yu. Oliinyk – MD, Professor, Professor of the Department of Pathological Anatomy, Bukovinian State Medical University (Chernivtsi, Ukraine).
e-mail: olijnyk.igor@bsmu.edu.ua
ORCID ID: https://orcid.org/0000-0002-6221-8078
Researcher ID: https://www.webofscience.com/wos/author/record/ABA-5062-2020
Scopus Author ID: 57192587959

Iryna O. Tsumanets – PhD, Associate Professor in the Department of Obstetrics, Gynaecology, Paediatrics and Paediatric Surgery, Lesya Ukrainka Volyn National University (Lutsk, Ukraine).
e-mail: iratsumanets@gmail.com
ORCID ID: https://orcid.org/0009-0001-2308-0184
Researcher ID: https://www.researchid.co/rid149660

Контактна інформація:
Хмара Тетяна Володимирівна – д.мед.н., професорка, професорка закладу вищої освіти кафедри анатомії людини імені М. Г. Туркевича Буковинського державного медичного університету (м. Чернівці, Україна).
e-mail: khmara.tv.6@gmail.com
ORCID ID: https://orcid.org/0000-0001-8023-5181
Researcher ID: https://researchid.com/C-9964-2017
Scopus Author ID: 57209663496

Коваль Олександр Анатолійович – к.мед.н., асистент кафедри медицини катастроф та військової медицини Буковинського державного медичного університету (м. Чернівці, Україна).
e-mail: koval190488@gmail.com
ORCID ID: https://orcid.org/0000-0002-9434-8213
Researcher ID: ABZ-1757-2022
Scopus Author ID: 58038661100

Паньків Тетяна Василівна – д-р філософії (PhD), асистентка кафедри патологічної анатомії Буковинського державного медичного університету (м. Чернівці, Україна).
e-mail: komar.tetiana.ls14@bsmu.edu.ua
ORCID ID: https://orcid.org/ 0000-0003-0947-6729
Researcher ID: https://researchid.com/komartetiana
Scopus Author ID: 6507286431

Олійник Ігор Юрійович – д.мед.н., професор, професор закладу вищої освіти кафедри патологічної анатомії Буковинського державного медичного університету (м. Чернівці, Україна).
e-mail: olijnyk.igor@bsmu.edu.ua
ORCID ID: https://orcid.org/0000-0002-6221-8078
Researcher ID: https://www.webofscience.com/wos/author/record/ABA-5062-2020
Scopus Author ID: 57192587959

Цуманець Ірина Олегівна – д-р філософії (PhD), доцент закладу вищої освіти кафедри акушерства, гінекології, педіатрії та дитячої хірургії Волинського національного університету імені Лесі Українки (м. Луцьк, Україна)
e-mail: iratsumanets@gmail.com
ORCID ID: https://orcid.org/0009-0001-2308-0184
Researcher ID: https://www.researchid.co/rid149660

Received: April 04, 2026
Accepted: May 28, 2026
Published: June 29, 2026