THERAPY

Aberrant formation and clinical picture of brachial plexus from the point of view of a neurosurgeon

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Abstract

Variations detected during surgery stimulated us to study the variations of the formation of the brachial plexus.
Methods: **We examined 110 brachial plexus in 55 adult cadavers in order to determine the incidence of neural variations.**
We observed the contribution of the C4 root and possibly Th2 root as well as various anomalies in the origination of each plexiform root and its branches from the spinal cord, and variations of the formation of the neural trunks, fascicles and peripheral branches. We examined their course, anastomosis, thickness and possible absence.
We observed the plexiform but not the spinal roots. We saw the pretruncal part of plexus including segment of spinal nerve in the sulcus spinal nerve and anterior branch of the spinal nerve. Motor innervation anomalies in relation to diagnostics are emphasized as well, apart from the anatomic variability. Attention focused on the mechanism and the morphologic reasons for particular types of injuries.
Results: **The prefixed type was present in 26 cases (47.3 %), and was postfixed in one case. We did not observe any anomaly in the formation of the plexus in 9 cases. We observed 143 anomalies in 46 cases (83.6 %). There was one anomaly present in 11 cases and in 35 two or more anomalies were noted. The anomalies were present more frequently on the left side – in 60 cases (41.2 %) and bilaterally in 48 cases (33.6 %). The anomalies were usually anatomic and in the area of the formation of the terminal branches. The least number of anomalies was present in the area of neural roots.**
Conclusion: **This study allowed us to find out and describe unusual and previously not described anatomic variations in the formation of neural roots, trunks, fascicles and terminal branches of the brachial plexus. The formation of the axillary nerve as a continuation of the posterior branch of the superior trunk was noted.** ***(Tab. 4, Fig. 8, Ref. 10.)***
Key words: brachial plexus, supraclavicular part, infraclavicular part, shoulder, variations.

The brachial plexus develops from a connection of anterior branches of the last four cervical spinal nerves (C5, C6, C7, C8) and the first thoracic nerve (Th1). These five plexiform roots are connected in order to form three plexiform trunks:

– truncus superior made up from anterior branches of C5 and C6,

– truncus medius made up from anterior branch of C7,

– truncus inferior made up from anterior branches of C8 and Th1.

Each of these trunks is divided into two branches, anterior and posterior, which then connect in order to form three plexiform fascicles:

– fasciculus lateralis made up from a connection of anterior branches of the superior and middle trunk,

– fasciculus medialis made up from the inferior trunk,

– fasciculus posterior made up from a connection of the posterior branches from the three trunks of the plexus.

The brachial plexus ensures sensitive and motoric innervation of the upper limb except of the trapezius muscle, which is the only muscle of the upper limb girdle not innervated from

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the brachial plexus. The total amount of myelin fibers in the brachial plexus in adults is between 120000 to 150000 and up to 25 % of which innervates the upper limb girdle. The fifth cervical and first thoracic nerves contain the least amount of myelin fibers – between 15000–20000. The eighth nerve is the biggest and contains around 30000 myelin fibers. The greatest amount of motoric fibers is in C5 and then in C8, the smallest amount is in C7 and Th1. The amount of sensoric fibers is greatest in C7, then in C6 and finally in C8. The basic nerves forming the plexus with the whole mass of their anterior branches are C6, C7 and C8.

Most branches of the brachial plexus come out from fascicles. Some supraclavicular branches may originate in roots or trunks. The branches from fascicles do not necessarily have to contain innervation from all roots forming the fascicle.

Our study has topographically specialized in anatomic variations of the formation of the brachial plexus from the neural roots up to the origin of the terminal branches.

We have found only rare studies concerning this problem in the literature available to us (1–7).

Material and methods

The study is concerning 50 cadavers, in which the brachial plexus was observed bilaterally. The body was in a lying position with limbs slightly pulled out. The skin incision was performed from the upper third of the lateral side of sternocleidomastoid muscle to the median third of the clavicle and from there along with the clavicle to its lateral part and through the deltoid-pectoral sulcus to the medial surface of the shoulder to its inferior third. Skin and subcutaneous tissues were moved to side. In the beginning we dealt with the supraclavicular part of the plexus.

The visualization of the spinal nerves in the intraforaminal level up to the border of dura mater was performed using a resection of the endings of the transverse processes.

When it was necessary to isolate the inferior plexus as C7 spinal root – and C7 root as the middle trunk or C8 and Th1 of the inferior trunk, we have removed the insertion of the anterior scalenus muscle up to the anterior tubercle or we have cut a part of the scalenus muscle. The origin of the long thoracic nerve was found by pulling the C6 root to the front.

After the trunks and branches were exposed, we have proceeded to the next stage. It concerned a separation of the major pectoral muscle from the clavicle in the area of 2–3 cm and then a separation of the clavicle from medial to ist lateral third. This stage exposed the clavi-pectoro-axillary aponeurosis, subclavial and minor pectoral muscle, with enabled to observe the inferior trunk and medial fascicle. In the area covered with the minor pectoral muscle were the nerves of the plexus in close contact to each other around the artery. Discission of the minor and major pectoral muscles finally enabled to observe the infraclavicular part of the brachial plexus and all pectoral nerves as well as the terminal nerves in full integrity.

We have exposed the lateral fascicle, which was fixed with fibers of connective tissue to the fascia of the subclavius muscle, using a more proximal preparation. The middle fascicle was present more inwards from the lateral and deeper. A close preparation near the middle fascicle enabled localization of the posterior fascicle. A bifurcation of the posterior fascicle to the radial and axillary nerve is in the level of the origination of the coracobrachial branches from the lateral fascicle. A deeper preparation downwards to the inferior border of the minor pectoral muscle projection enabled an exposure of the median nerve.

Working upwards, the preparation of the proximal part of the median nerve led to the lateral and medial root of bifurcation of the median nerve.

The level of the origination of the axillary nerve from the posterior fascicle was used as an orientation point.

Proximally from this level were located fascicles, distally then nerves originating from them.

The formation of fascicles took place usually not above the projection of the lower margin of the clavicle.

When anomalies were detected, we continued the preparation using a magnifying lens. Under the term root we define plexiform root not spinal root. It means pretrunkal part of plexus including segment of spinal nerve in sulcus spinalis nerve and anterior branch of the spinal nerve up to the plexiform trunk.

Results

Complicated connections between nerves were observed in the infra as well as the supraclavicular area. Variations, supra or infraclavicular, were observed more frequently on the left side.

Simultaneous contribution of the C4 and Th2 roots on the formation of the brachial plexus was not observed. The layout of the plexus was not the same on both sides. There was not accurate symmetry. The elasticity and strength of the nerve was significantly decreased in older cadavers. They were more easily damaged during preparation, they were like “gleamless”.

Variations in the level of the neural plexiform roots:

The roots C4, C5, C6 and C7 were fixed in the spinal sulcus nerve by transversal radicular ligaments to the transverse processes to the vertebrae, they were missing in C8 and Th1.

Upper cervical nerves C4, C5, C6 and in lesser rate C7 are located due to the physiologic curve of the spine more in the front in relation to the roots C8 and Th1. The roots forming the plexus were usually going through the fissure between the anterior and middle scalenus muscle.

In one case the root C5 and in one case both the C5 and C6 ran over the anterior scalenus muscle. The brachial plexus was formed only from part of the root C5 in five cases, the other part connected with root C4.

The branches to the scalenus muscles and to musculus longus coli exited from the lower parts of the anterior cervical roots as small lateral and medial branches or as branches leaving these proximal spinal nerves near their exit from the intervertebral foramens. The root Th1 did not have proximal branches. The

Tab. 1. Variations of the brachial plexus in the level of neural plexiform roots.

	SIN.	DX.	BILAT.
Roots C5 and C6 divided into anterior and posterior branch	**2**		
Root C7 is thin and does not form and anterior branch	**1**		**1**
Root C7 makes a branch to the root C8	**1**		**1**
Root C8 makes two branches to the posterior branch of the middle trunk	**1**		**1**
C8 divides into 2 branches, the anterior goes to the anterior branch of the superior trunk and the posterior connects with the root Th1			**1**
Two branches of the C8 root connect with the anterior branch of C6 root	**1**		
Branches of the C8 root connect with the lateral and posterior fascicle	**1**		
Root Th1 is broad as root C8	**2**	**1**	
Total	**9**	**1**	**4**

SIN. – left, DX. – right, Bilat – bilateral

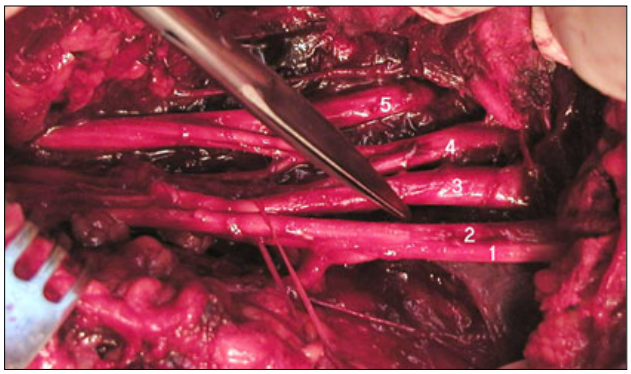

Fig. 1. Brachial plexus, left side: root C5 (1), root C6 (2), root C7 (3), root C8 (4) splits into several branches, the root Th1 (5) is thicker than the root C8.

phrenic nerve was connected by one and in two cases by more branches with the root C5.

The most proximal branch of the C5 root is nervus dorsalis scapulae. It was observed to originate in the lower side of root C6 in 4 cases. The long thoracic nerve was formed from contributions of C5 in all cases. In 16 cases (29 %) from C5, C6, C7 and in four cases from contributions of C4, C5 and C6. Mostly from roots C5 and C6 in 35 cases (63.4 %). The biggest trunk was always from the root C6.

We have observed variations of the formation of the neural roots 18 times in 14 cadavers, from which four were bilateral (Tab. 1) (Figs 1 and 2).

Variations in the level of the neural plexiform trunks:

We have detected several variants concerning the branches originating from the neural trunks. The subclavian nerve originated from the superior trunk on various sites following the convergence of C5 and C6. Distally along the superior trunk is the origin of angle wise running suprascapular nerve. In originated from the root C5 in three cases.

Variations in the level of neural trunks formations and their branches were observed in 25 cadavers 32 times, they were bilateral 7 times (Tab. 2).

The superior trunk was not formed in 3 cases.

The roots C5 and C6 did not connect in one case. The roots C5 and C6 divided into an anterior and posterior branch in two cases and then the anterior branches of C5, C6, C7 and the posterior branches of C5, C6, C7 connected.

The middle trunk converged in two cases and connected with the superior trunk (Fig. 3), in all cases bilaterally and in three cases with the inferior trunk. An impression developed in one case that all the branches of the middle and inferior trunk originated from this junction and the posterior fascicle did not develop. After a preparation under a magnifying lens that apart from an anterior branch to the anterior branch of the superior trunk there are 4 anterior branches to the inferior trunk. The posterior branch of the middle trunk was thinner than the anterior, it received the posterior branch from the superior and inferior trunk. The greatest quantity of anatomic variations in the supraclavicular region was observed in the level of inferior trunk formation.

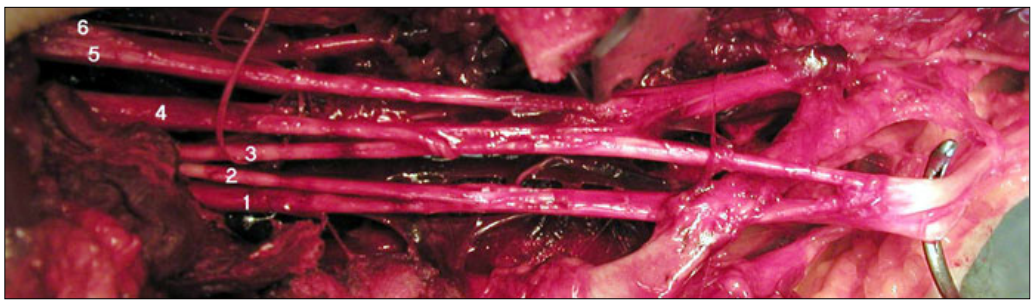

Fig. 2. Brachial plexus, left side: root Th1 (1), root C8 is splitted into two branches (2,3), root C7 (4), root C6 (5), root C5 (6). A branch of the root C8 (2) joins the root Th1 (1); another branch of the root C8 (3) joins the root Th1 over the subclavian artery.

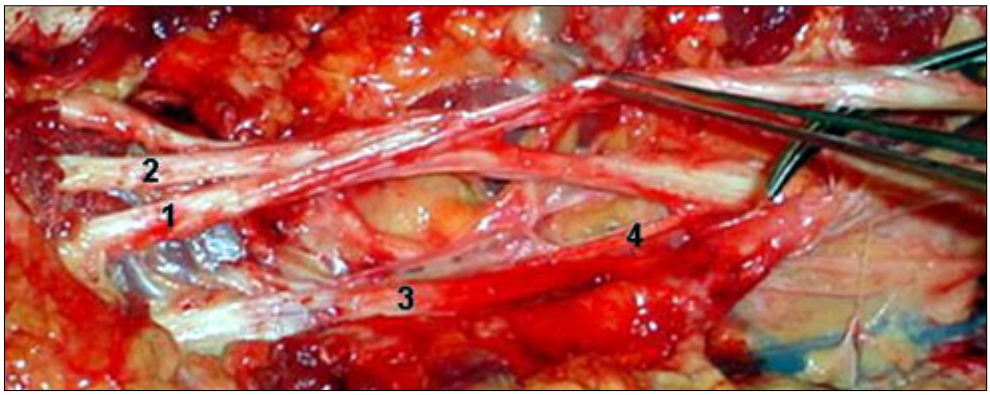

Fig. 3. Brachial plexus – convergence of the root C7 (1) with truncus superior (2), root C8 (3), root Th1 (4).

The inferior trunk did not develop in one case. The roots C8 and Th1 were parallel, Th1 was even broader. The inferior trunk didn't develop immediately in 8 cases, but after more than four centimeters of a parallel course of the roots C8 and Th1.

Each trunk had usually two branches, an anterior and a posterior. The posterior branch of the superior trunk was always longer than the anterior. This was valid for the middle trunk as well except for 3 cases. The middle trunk (C7) divided to more than two branches in two cases. In such cases was one branch posterior and the rest were anterior branches. The posterior branch of the inferior trunk is significantly smaller than the others and it is variably long. It often originates in the eighth cervical root before the formation into trunks. There was no posterior branch of the inferior trunk present in one case.

Variations in the level of the neural plexiform fascicles:

We have encountered variations of the neural fascicles 26 times in 22 cadavers. They were unilateral 18 times (Tab. 3). The connection between the anterior branch of the superior trunk with the anterior branch of the middle trunk didn't develop in four cases, but once the later fascicle developed from a branch of the C8 root and once from the inferior trunk. The lateral fascicle was made up from the anterior branch of the superior trunk in two cases. In cases when the middle trunk was divided into more branches was the accessory anterior branch not connecting to the anterior branch of the superior trunk as usually, but it contributed of the formation of the medial root of bifurcation of the median nerve.

The anterior branch of the inferior trunk makes up the medial fascicle, which received a branch from the seventh cervical root in two cases.

Variations of the lateral fascicle were frequent, we have observed several combinations and in many cases multiple connections between the lateral and medial fascicle, before the origination of the median and musculocutaneous nerves. Thanks to these connections is the medial bifurcation of root of the median nerve always containing fibers from the lateral fascicle and in three cases is the ulnar nerve also receiving fibers on this level from the same fascicle.

Tab. 2. Variations of the brachial plexus in the level of plexiform trunks and their branches.

Type		SIN.	DX.	Bilat.
Truncus superior	The roots C5 and C6 divided into anterior and posterior branch	**2**		
	No connection between roots C5 and C6	**1**		
	It consisted of short 2 mm connection of C5 and C6 roots	**1**		
	The roots C5 and C6 connected in the level of the upper margin of the clavicle			**1**
Truncus medius	Connects with truncus superior			**2**
	Connects with truncus inferior	**2**	**1**	
	After making the anterior branch to the anterior branch of the truncus superior it connects with the posterior branch of the truncus superior and with the truncus inferior			**1**
Truncus inferior	No connection of the C8 and Th1 roots developed	**1**		
	As a small connection of 2 mm with a branch between C8 and Th1 roots	**1**		**1**
	Connects with two branches with the anterior and posterior branch of the truncus superior	**1**		
	The root C8 connects with the Th1 root above the subclavian artery		**1**	
	Does not make a posterior branch		**1**	
	It is made up after more than 4 cm parallel course of the C8 and Th1 roots	**2**	**4**	**2**
Total		**11**	**7**	**7**

SIN. – left, DX. – right, Bilat – bilateral

Tab. 3. Variations in the level of the plexiform fascicles.

Type		SIN.	DX.	Bilat.
Fasciculus lateralis	The anterior branches of C5, C6 and C7 connected to make up the lateral fascicle	**1**		
	The fascicle is made up from the anterior branch of the superior trunk		**1**	**1**
	It is made up from a connection of the anterior branch of the superior trunk and the anterior branch of the C8 root	**1**		
	It is made up from a connection of the anterior branch of the superior trunk with a branch from the inferior trunk		**1**	
	It is made up from a connection of the anterior branch of the superior trunk with the anterior branch of the roots C8 and C7		**1**	
	It releases a branch to the medial bifurcation of the median nerve	**2**	**2**	
	It is made up of practically the whole volume of the anterior branch of C7 and releases a branch to the ulnar nerve	**1**	**1**	
Fasciculus posterior	The posterior branches of C5, C6, C7 and the inferior trunk connected to form the posterior fascicle	**1**		
	Releases branches to the medial foot of the median nerve	**1**		
	Releases branches to the lateral foot of the median nerve	**1**		
	The posterior branch of the superior trunk is missing on its formation	**1**		
	It develops low under the clavicle projection			**1**
	The posterior fascicle is made up from the whole posterior branch of the superior trunk, which makes up 90% of its volume and a small thin posterior branch of the middle trunk		**1**	**1**
	Releases connection branches to the ulnar nerve			**1**
Fasciculus medialis	Receives the posterior branch from the superior trunk	**1**		
	It is formed from an individual branch from Th1	**1**		
Total		**11**	**7**	**4**

SIN. – left, DX. – right, Bilat – bilateral

The lateral fascicle released one or more branches to the major pectoral muscle.

The greatest variations in the nerve formation were also detected in the lateral fascicle, which continues as the musculocutaneous nerve (C5, C6, C7) after the origination of the terminal branch to the median nerve. The lateral fascicle divided as late as in the coracobrachial and in the biceps muscles in one case. The musculocutaneous nerve originated there. Then it connected with the medial bifurcation of the medial fascicle in the lower third of the arm forming the median nerve.

The medial fascicle, in cases when the C7 trunk divides to more than two branches, receives fibers not only from C8, Th1 (Th2) but also from C7. It can receive the same fibers from C7 in cases when the lateral branch of the ulnar nerve is present. The typical medial fascicle didn't develop in two cases.

The medial fascicle continued as the ulnar nerve after the release of nervus cutaneus antebrachii medialis, brachii medialis and of the terminal branch to the medial head of the median nerve.

The posterior branches of all three trunks made up the posterior fascicle. The posterior fascicle was usually the thickest of the fascicles in the plexus, sometimes made up from a connection of four branches instead of three. The posterior branch of the superior trunk (C5, C6) is usually the thickest in most cases. The posterior branch of the inferior trunk (C8, Th1) is the thinnest in all cases.

There were more variations present though. It formed deeply under the clavicle in one case. The posterior branch of C7 was thin in one case and it didn't connect with the posterior branch of the superior trunk but only with a thin branch originating from it. It didn't lead to formation of the axillary nerve, nor to the nervus subscapularis and thoracodorsalis nerve. These branches originated in the posterior branch of the superior trunk, which continued as the axillary nerve into the foramen quadrilaterum.

Variations in the level of the terminal branches:

Variations in the formation of the terminal branched have occurred 68 times in 46 cadavers, out of which 50 were unilateral (Tab. 4) (Figs 4, 5, 6).

The most prevalent were anastomotic branches from all three fascicles contributing especially on the formation of the median nerve, less frequently the ulnar nerve. The terminal branches of the lateral fascicle are nervus musculocutaneous and the lateral branch to the median nerve.

There were anastomotic branches detected in the musculocutaneous nerve to the median nerve in 6 cases, out of which 4 were high in the level of the shoulder. We have observed its division before its penetration to the coracobrachial muscle in three cases. The biceps muscle was parallel in one case and it released branches to it. We have observed additional branches originating directly from the lateral fascicle to the biceps muscle and the median nerve in three cases.

It was missing eight times. Then was the lateral root of bifurcation of the median nerve thicker. There was a fusion of both nerves usually and an impression of one trunk developed,

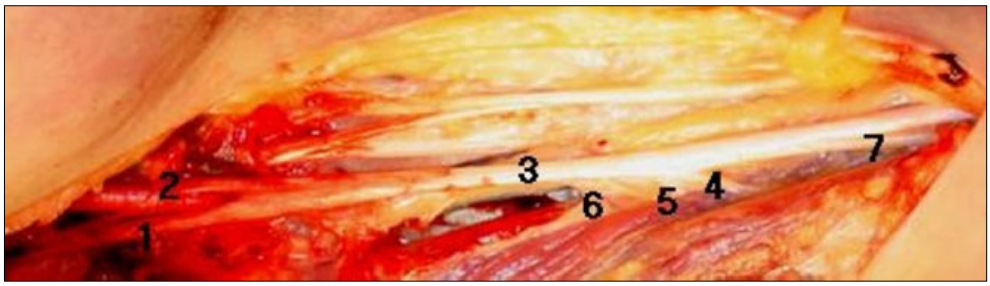

Fig. 4. Brachial plexus, right side. Lateral branch to n. medianus (1) is thicker than the median root (2), n. medianus (3) branches to m. biceps (4, 5, 6), n. musculocutaneus (7).

but a retrograde preparation revealed its origin from the apex of the median nerve bifurcation, which is forming a common trunk with it. The origin of the musculocutaneous nerve from the median nerve was occasionally (4 times) found far distally on the arm.

Lateral root of the median nerve can originate from two or three branches and in some cases it appeared as a branch of the musculocutaneous nerve.

The terminal branches of the medial fascicle are also constant, they are nervus cutaneus antebrachii medialis, nervus cutaneus brachii medialis, nervus ulnaris and medial root of bifurcation of the mediani nerve. The variations detected in nervus medianus were of anastomotic origin: 1) from the lateral fascicle and the musculocutaneous nerve as described above, 2) from the medial fascicle 11 times, twice with nervus cutaneus antebrachii medialis. Once with the ulnar nerve near its origin, 3) 6 times from the posterior fascicle.

The common trunk of the median nerve developed in 9 cases in the distal half of the shoulder.

The axillary artery was located superficially to the bifurcation of the median nerve in 5 cases, out of which once it was bilateral (Fig. 7).

We have detected four types of variations on the ulnar nerve:

1) The ulnar nerve was formed from two roots in two cases originating from the lateral and medial fascicle. They were of the same dimensions and connected to make up the ulnar nerve in the medial side of the axillary artery.

2) A branch from the posterior fascicle contributed on it in one case.

3) A thin anastomotic branch will the radial nerve contributed on its formation in two cases. It was located four centimeters under the origin of the ulnar nerve.

4) Once there was an anastomosis with nervus cutaneus antebrachii medialis.

Tab. 4. Variations of the brachial plexus in the level of the formation of the terminal branches

Type		SIN.	DX.	Bilat.
Nervus axilaris	Continuation of the posterior branch of the superior trunk	**3**		
Nervus radialis	Releases an anastomosis to the ulnar nerve	**1**	**1**	
Nervus musculocutaneous	The lateral fascicle enters the coracobrachial muscle where the musculocutaneous nerve releases and it returns then and connects with the median nerve in the lower third of the arm		**1**	
	Run together with the median nerve, it is fused with it and they separate from each other at variable level	**3**	**3**	**1**
	The musculocutaneous nerve runs along with the biceps muscle, doesn't enter but only releases branches	**1**		
	Releases anastomosis to the median nerve	**3**	**2**	**1**
Nervus medianus	The bifurcation of the median nerve is under the axillary artery		**3**	**2**
	The lateral foot from the lateral fascicle is missing on the formation of the median nerve bifurcation; it is formed from a branch from C7 instead	**1**		
	Anastomotic branches from the lateral fascicle contribute on its formation	**2**	**1**	
	Anastomotic branches from the posterior fascicle contribute on its formation	**1**	**3**	**1**
	Anastomotic branches from the medial fascicle contribute on its formation	**6**	**3**	**1**
	Formation in the lower half of the arm	**6**		**3**
Nervus ulnaris	A branch from the lateral fascicle contributes on its formation	**1**	**1**	
	A branch from the posterior fascicle contributes on its formation	**1**		
Nervus cutaneus antebrachii	Anastomosis with the ulnar nerve	**1**		
Nervus cutaneus brachii medialis	Did not develop at all	**1**	**1**	
Total		**32**	**19**	**9**

SIN. – left, DX. – right, Bilat – bilateral

Fig. 5. Branch from lateral root to median root of n. medianus (1, 2). The lateral root is not thicker, n. musculocutaneus (3) is joined with n. medianus (4).

Fig. 6. Brachial plexus n. musculocutaneus (1) is joined with n. medianus (2), lateral root of n. medianus is thicker (3).

The only anastomotic particularity in the *nervus cutaneus antebrachii medialis* was an anastomosis with the ulnar nerve.

Nervus cutaneus brachii medialis – was missing in two cases.

The terminal branches of the posterior fascicle were the most constant.

There was an anastomotic branch detected between *the radial nerve* and the ulnar nerve in two cases.

A variation of the formation of the axillary nerve was found in three cases. The *axillary nerve* was a continuation of the posterior branch of the superior trunk (Fig. 8).

The thoracodorsal nerve had a variable origination, either from the posterior fascicle or from the axillary nerve.

Clinical, motoric and innervation particularity in relation to diagnostics

It is important to understand what neural functions belong to each part of the plexus. It is also important to be aware that due to the presence of variable connections between the trunks of the plexus may the innervation of muscles change independently on the number of the root going out of the plexus. Several anomalous nerve structures are apart from atypical clinical and electromyography findings also a source of a diagnostic confusion.

In case of the prefixed type of the nerve trunk receive more fibers from neurons located more cranially. Root C4 may significantly contribute to the suprascapular nerve, but even to the axillary nerve. Radial nerve receives more fibers from C5. The same is being observed in relation to the musculocutaneous nerve and others. Injuries to superiorly located nerves or nerve trunks, such as truncus superior are associated with more extensive plegia on periphery, the same as in the postfixed type.

Injury to the C5 root may be manifested in the first case by plegia of the deltoid, biceps and brachial muscles but also by plegia of the wrist extensors, brachioradial muscle, supinator muscle and pronator teres. The same injury of the C5 root in case of caudal localization of the plexus may not manifest at all or it can lead only to a mild impairment of the function of the forearm muscles. Brachial and biceps muscles may be affected only partially.

In case of the postfixed type may the Th1 root contain several fibers normally carried in the C8 root and a contribution of the Th2 to the plexus may be greater.

The root C7 provides an extensive innervation of the upper limb and variably contributes to the formation of all nerve trunks of the upper limb. In the rare cases of its injuries we can observe rather a diffuse impairment of function, without complete anesthesia or paralysis of some significant muscle group. The eighth cervical nerve contributes to the innervation of the thumb and finger extensors. The first thoracic nerve provides almost the same and it partially contributes to the innervarion of the triceps muscle. The inferior trunk contributes on the three main nerves of the shoulder and in case of an injury each may manifest with signs of impairment. Its supply is full on the forearm, therefore the muscles of the forearm and hand innervated with the radial, ulnar and median nerves may be affected.

The posterior fascicle supplies mainly the extensor muscles, the medial and lateral mainly the flexor muscles. The medial fascicle contributes on the inervation of the proper hand muscles innervated from the median nerve. The lateral fascicle contrib-

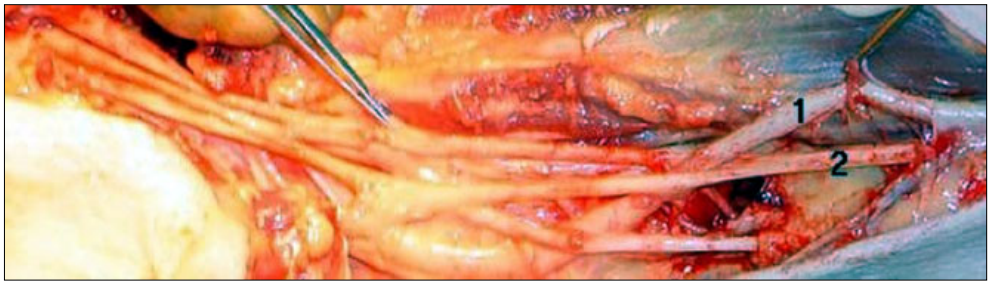

Fig. 7. The axillary artery (1) is located over the bifurcation of n. medianus (2).

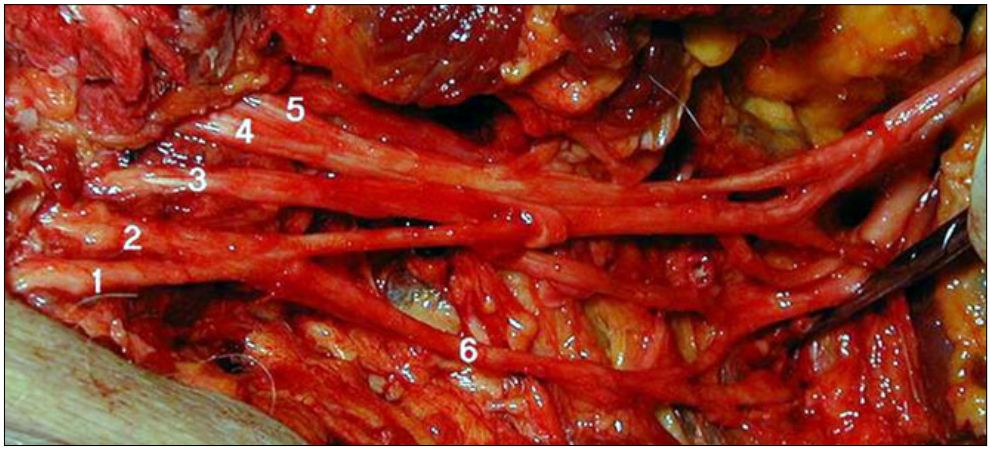

Fig. 8. Brachial plexus, right side. Root C5 (1), root C6 (2), root C7 (3), root C8 (4), root Th1 (5), nervus axillaris (6) – extension of the posterior branch of truncus superior.

utes on the innervation of the sensoric component of the median nerve. Presence of the Horner syndrome indicates avulsion of the C8 and Th1 spinal roots.

Three branches of the nerve roots seem to be clinically important. Nervus thoracicus longus and nervus dorsalis scapulae – if the function of the muscles supplied by these nerves is impaired, it signifies a proximal injury of the plexiform roots or an avulsion from the spinal cord. On the other hand, if muscles innervated by these nerves work well, even if no other muscle is functional, there is a presumption that the proximal nerve roots are preserved and they can be identified and used for a reconstruction surgery of the brachial plexus.

The radicular supply of the major pectoral muscle (C5–Th1) is a reduced picture of the condition of the whole brachial plexus. The clavicular part is supplied from C5 and C6, the sternal part from C7 and the abdominal part from C8–Th1 by means of the pectoral nerves, what clinically corresponds with the upper, middle and lower type of lesion of the brachial plexus. It can be of some importance in the localization of the lesion on the level of the fascicles.

Mechanisms and morphological reasons of some types of injuries

The root is most vulnerable in the site of its origination from the spinal cord. The motoric roots contain less radicular fibers and they are thinner than the sensitive roots. They are therefore pulled out more frequently. The sheaths of the spinal nerves are firmly connected with the dural bag and the traction forces are therefore transferred on its infundibular concavity into the intervertebral foramens, where the C8 and Th1 roots are freely movable. In comparison with the spinal nerves C5, C6 and C7 that are located in the sulcus spinalis nerve where they are firmly fixed with strong fibrous connective tissue and thereby protected. They are arranged the way to be less vulnerable during traction forces compared with the roots C8 and Th1, which are not fixed. The upper roots are therefore affected more distally during traction – more on the periphery. If an avulsion is to occur, the fixation of these roots has to be broken as well or a transverse vertebral process have to be fractured. A presence of avulsion fractures on this level is strongly suspicious for an avulsion of the nerve roots from the spinal cord.

Even in case of an avulsion of C5, C6, C7 and C8 may the injured patient be able to perform movements in the shoulder.

The motility can be caused by the function of the XI. cranial nerve and the cervical plexus.

The biceps brachii muscle may, even in complete types of plexus injury with avulsion of the roots, restore its function in some cases. The roots C3, C4 and the phrenic nerve contribute on the innervation (8).

Discussion

The variations of the formation of the brachial plexus are of a clinical and surgical importance. Knowledge of its anatomical

variations may contribute on the explanation of inconceivable clinical pictures. It is supposed that the variations of the formation of the brachial plexus are caused by a deviation of the normal development. Some anatomical peculiarities are important especially for surgeons engaged in the reconstruction of plexus injuries.

It is important to be aware of these variations but also of their relation to the great vessels, because the topographic relations of fascicles and arteries may be various and they can lead to problems during an urgent surgery (1, 6). There was not always the same type of variation in case of bilateral variations.

The main supraclavicular variations described in literature concerned the contrubution of C4 or Th2 (9, 10). We haven't encountered any study in literature available to us concerning the variations of the formation of the neural roots, trunks and fascicles.

We have only detected the actual origination of the terminal branches of the plexus in 6 cases after a preparation of the variation of the trunk and fascicle formation.

Attention deserves sparse connective tissue foming sleeves, often multiplayer, which was greatest in the level of the trunk branching and fascicle formation, especially medial. Less of this tissue was present in the area of terminal branches formation. Its function is probably to prevent a damage of nerves among each other or by arteries or bone structures in these sites during movements with the upper limb. We have detected fibrotic changes in this tissue in several cases. The greatest fibrotic changes were in individuals heavily physically working, former sportsmen and in cases of postcaval catheters.

Our results concerning the variations of the formation of the terminal branches of the brachial plexus often corresponded with previously described findings (2–7).

The described variations of the *musculocutaneous* nerve concern *ist origination.* It can originate on the apex of the median nerve bifurcation, from the apex of the bifurcation between the median and ulnar nerve or finally from the median nerve (2, 3, 6, 9, 10).
– *its course* – it doesn't go over the coracobrachial muscle, it goes before it (2, 4),
– *its division* – the terminal branches may originate from the nerve before its penetration to the coracobrachial muscle or it can penetrate to other shoulder muscle (5, 6),
– *full fusion* of the musculocutaneous and median nerves (3, 9, 10),
– *ist anastomosis* – with median nerve, but also with the nervus cutaneus antebrachii medialis, ulnar nerve or radial nerve (2, 5, 6).

Described variations of the *median nerve:*
– *its origination* – fusion of two roots, more or less distal, sometimes in the lower third of the shoulder, which provides an image of two median nerves in the upper and middle part of the shoulder. A supplementary branch forming the third medial trunk of the median nerve (2, 4, 6).
– *its course* – various relations to the axillary artery and brachial artery (1, 5, 6),
– *ist anastomosis* – with musculocutaneous nerve (2, 5, 6).

Variations of the *ulnar nerve* concerned:
– *its origination* – it can receive the lateral trunk or it can develop from a common trunk with the median and musculocutaneous nerves under the bifurcation of the median nerve (6),
– *its anastomosis* – with musculocutaneous, median, ulnar and cutaneus antebrachii medialis nerves (2, 6).

Described variations of the *axillary nerve* concerned:
– *its origination* – it can detach from the posterior fascicle, at the back from the radial nerve or rarely laterally (6). We have detected three, up till now not described variations of the axillary nerve, as a continuation of the posterior branch of the superior trunk.
– *its course* – its course over the subscapular muscle was described, while it goes generally under this muscle (6).

The described variations of the *radial nerve* concerned its origination: from two roots formed variably from the posterior branches of the trunks (6).

Variations of the *cutaneus brachii medialis nerve* concerned:
– *its origination* – from the inferior or superior trunk, or from the first thoracic nerve (6),
– *its anastomosis* – there are described anastomosis with nervus cutaneus antebrachii medialis with the radial, axillary and finally the first thoracic nerves (6).

Described variations of the *cutaneus antebrachii medialis nerve* concerned:
– *its origination* – from the posterior fascicle, from inferior trunk or from a common trunk with the medial pectoral nerve of with nervus cutaneus brachii medialis (6),
– *its anastomosis* – with nervus cutaneus brachii medialis, musculocutaneous, ulnar, median, axillary and radial nerves (6).

The anatomical arrangement of the brachial plexus is complicated. It is necessary to be aware of the individual variations in the development of the clinical syndromes, diagnosis and surgical treatment, because it can prevent findings during surgery.

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