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# Possible anastomoses between the long branches of the brachial plexus and their clinical significance

**Authors**: Karolina Sujka, Nicol Zielinska, Richard Shane Tubbs, Łukasz Olewnik

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REVIEW ARTICLE

# Summary of known anastomoses between the long branches of the brachial plexus and their clinical significance

Karolina Sujka et al., Brachial plexus

Karolina Sujka[1], Nicol Zielinska[1], Richard Shane Tubbs[2–4], Piotr Karauda, Łukasz Olewnik[1]

[1]*Department of Anatomical Dissection and Donation, Medical University of Lodz, Łódź, Poland*

[2]*Department of Neurosurgery, Tulane University School of Medicine, New Orleans, LA, USA*

[3]*Department of Neurosurgery and Ochsner Neuroscience Institute, Ochsner Health System, New Orleans, LA, USA*

[4]*Department of Anatomical Sciences, St. George's University, True Blue, Grenada*

Address for correspondence: Łukasz Olewnik, Department of Anatomical Dissection and Donation, Medical University of Lodz, Łódź, Poland, email: lukasz.olewnik@umed.lodz.pl

**ABSTRACT**

The brachial plexus consists of nerves that supply the upper limb and some nerves of the back, torso, and neck. It is formed by the ventral rami of C5 to T1 (in some cases, C4 or T2 also contribute). The anterior rami of the spinal nerves unite to the roots, trunks, divisions, cords, and terminal branches that innervate muscles and skin. An example is associated with terminal branches of the long nerves. Knowledge of this variation is necessary for enabling surgeons, orthopedists, and neurologists to avoid injury during surgical exploration in the arm or axilla region, and for achieving correct diagnoses, because such variability can evoke nonspecific responses. Awareness of this anastomosis is also mandatory for anesthetists performing anesthesia in the upper limb region.

The aim of this article is to describe anastomoses between long nerves from the brachial plexus and to consider their clinical significance.

**Keywords: Brachial plexus, medial brachial cutaneous nerve, medial antebrachial cutaneous nerve, median nerve, musculocutaneous nerve, radial nerve, ulnar nerve**

## INTRODUCTION

The brachial plexus is a complex structure of nerves that provide motor innervation to skeletal muscles and sensory innervation to the skin and articulations. They also affect the diameters of the blood vessels that supply the upper limb, which conduct some sympathetic fibers [Error: Reference source not found, 20]. The brachial plexus is created by the anterior rami of the spinal nerves from C5 to T1 (sometimes from C4 or T2), which unite to form roots and supply parts of the trunk: upper (C5, C6), middle (C7) and lower (C8, T1). Each of them splits into anterior and posterior divisions. After a short course, the divisions unite into cords. All posterior divisions form the posterior cord, the anterior ramus of the upper and middle trunks forms the lateral cord, and the anterior ramus of the lower trunk forms the medial cord [Error: Reference source not found, 17, 18, 20].

We can divide the brachial plexus into supraclavicular and infraclavicular parts. The supraclavicular part is located in the posterior cervical triangle. As the C5-T1 ventral rami enters between the anterior and middle scalene muscles and forms the trunks of the brachial plexus, it enters the scalenioclavicular triangle and runs along the fissure bordered by the clavicle, subclavius muscle, first rib, and scapula [Error: Reference source not found, 3, 18]. The supraclavicular part gives rise to short nerves that branch from the trunks and ventral rami and innervate mainly the superficial muscles of the back, the thoracic cavity and the shoulder [1, 2]. The infraclavicular part originates in the axilla and forms the cords of the brachial plexus that are carried along the subclavian artery and then the axillary artery; these cords are named based on their position around the latter vessel. From this part of the brachial plexus, some short nerves arise that innervate, for example, the pectoralis major and minor, the teres major and latissimus dorsi muscles. From these arise longer nerves that innervate the arm, forearm, and hand muscles. From the lateral cord, the musculocutaneous nerve (MCN) and the lateral root of the median nerve (MN) arise. From the middle cord comes the medial root of the MN and also the ulnar nerve (UN), the medial brachial cutaneous nerve (MBCN), and the medial antebrachial cutaneous nerve (MACN). From the posterior cord arises the radial nerve (RN) [6, 25].

The aim of this article is to describe the main types of anastomosis between the long nerves that originate from the brachial plexus and to consider their surgical implications. Clinicians should be aware of these variations to preclude iatrogenic injuries; and to make accurate diagnoses, because they can explain abnormal clinical symptoms [3, 6].

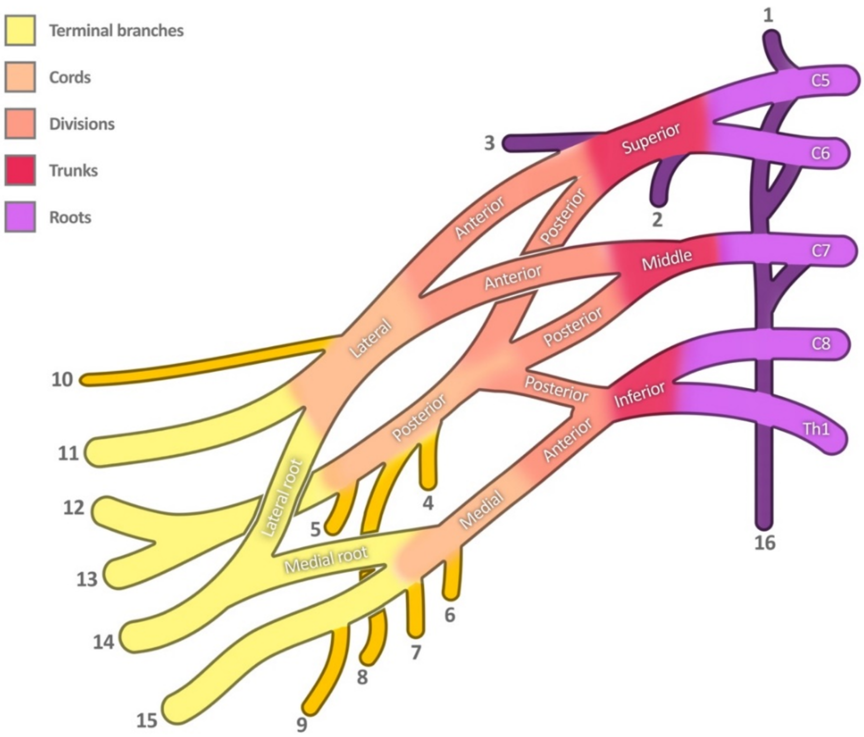


**Figure A1.** Schematic of the brachial plexus [1]

**Musculocutaneous nerve**

The MCN is a mixed nerve that supplies the flexors of the arm and the skin of the forearm. It originates in the axilla of the lateral cord of the brachial plexus; it contains nerves from C5-C7. Afterward, it runs downwards and slightly laterally and then pierces the coracobrachialis muscle. The first part of the nerve is within this muscle. After that, the MCN descends between the biceps brachii muscle and the brachialis muscle (second part). Next, it lies lateral to the bicipital groove (third part). Near the cubital fossa, it pierces the brachial fascia and extends as the lateral cutaneous nerve of the forearm (LACN). The MCN gives many branches, including those to the anterior part of the brachialis muscle, the coracobrachialis, the biceps brachii, the cubital joint and then, as its terminal branch, the LACN [Error: Reference source not found, Error: Reference source not found, 21, 27, 28].

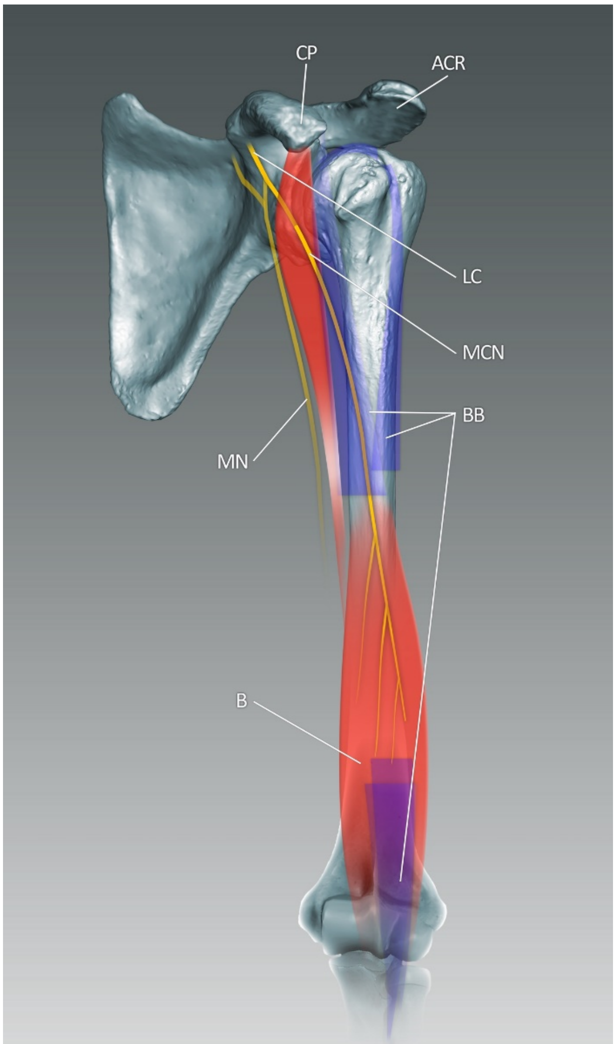


**Figure B1.** Musculocutaneous nerve [86]

The relationship between the coracobrachialis muscle and the MCN is very important. In some cases the nerve pierces the belly of muscle (type I) or courses between the heads of the muscle (type II). According to Szewczyk et al. [76] the prevalence of type I and type II is approximately 50%. The MCN anastomoses with all nearby branches of the brachial plexus

[Error: Reference source not found]. The most common communication is an anastomosis with the MN. This variation was described during the nineteenth century [3, 30] and its incidence ranges from 1.4% to 63.5% (data collected from research over the years 1985 to 2016) [16]. Fibers that create the interconnecting branch usually derive from the MCN, seldom from the MN [3, 26–29]. One widely-known classification of the relationship between these nerves was published in 1990 by Le Minor — further research was based on the Le Minor classification [3, 5, 16]. This distinguished five types of variation [3, 6, 16, 20, 22, 30]:

- Type I — the classical relationship between the MCN and MN; there is no connecting branch between these nerves
- Type II fibers deriving from the medial root of the MN pass along the MCN and then return to the MN in the middle of the arm.
- Type III — the two nerves are connected by the lateral root of the MN from which connecting fibers originate; these pass through the MCN and after a short course they form the lateral root of the MN
- Type IV — the course of the MCN begins normally and after a short distance it fuses with the lateral root of the MN; after that, all branches of the MCN come away from the lateral root of the MN
- Type V — There is no MCN and the anterior flexors of the arm are supplied by the MN; in this case the MN has three roots, two lateral and one medial.

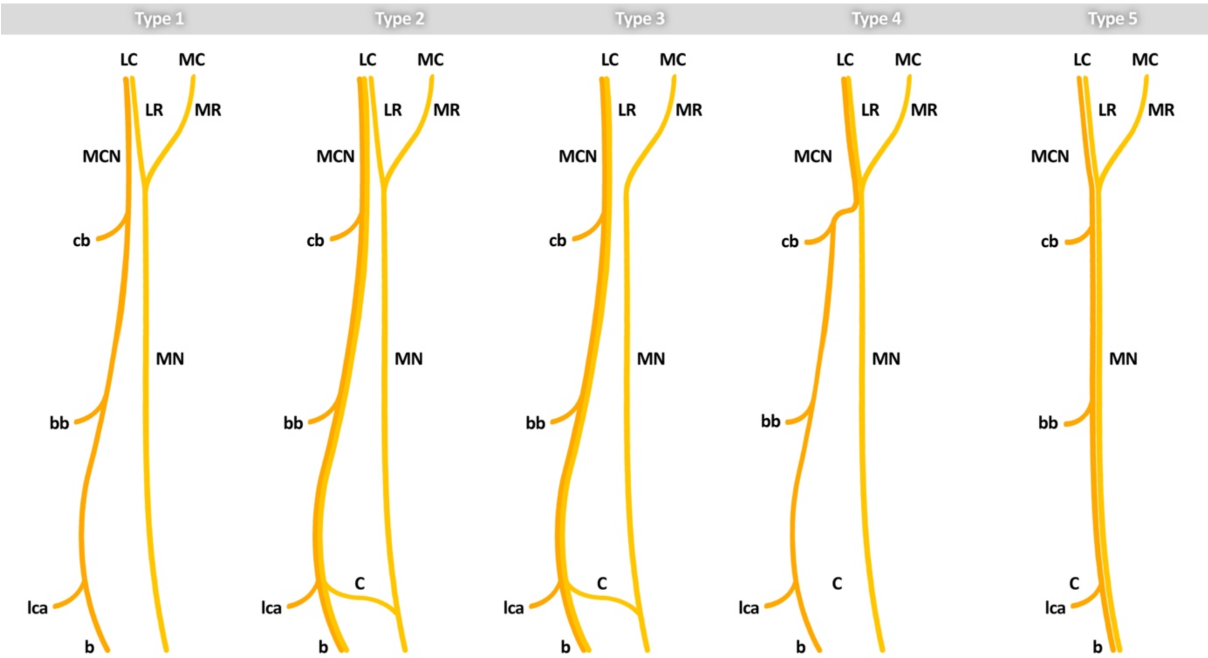


Figure B2.Type of communication between nerves [6]

MC – medial cord of brachial plexus; LC – lateral cord of brachial plexus; MR – medial root of median nerve; LR – lateral root of median nerve; cb – coracobrachial muscle branch; bb – biceps brachii muscle branch; lca – lateral cutaneous antebrachial branch; b – brachial muscle branch; C – communicating branch

Venieratos and Anagnostopoulou [8] focused on the level at which an interconnecting branch was located and classified this type of anastomosis accordingly. They distinguished three types of variation:

- Type I — The communication branch is located proximal to the point at which the MCN pierces the coracobrachialis muscle (prevalence about 41%)
- Type II — The communication is distal to the coracobrachialis muscle and lies between the biceps brachii and brachial muscles (in the highest prevalence, 45%)

- Type III — The MCN does not pierce the coracobrachialis muscle (prevalence 14%) [8].

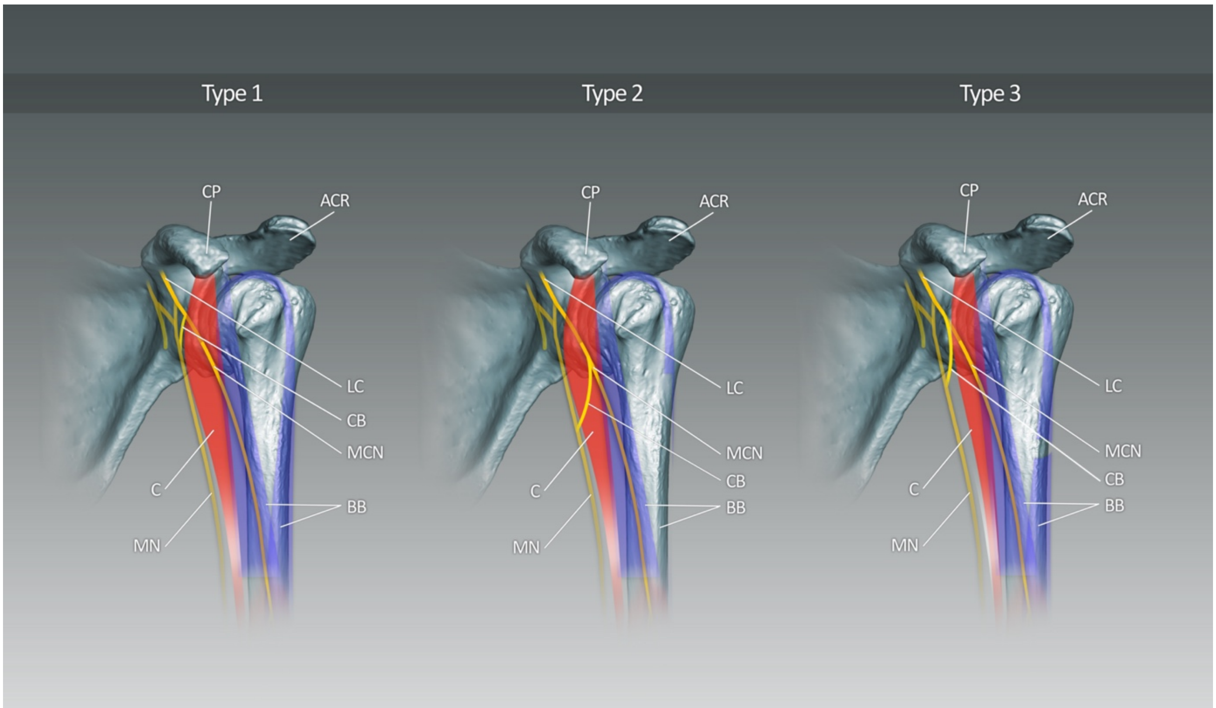


**Figure B3.** Localization of communicating branch [8]

U – ulnar nerve; C – coracobrachialis muscle; M – median nerve; CB – communicating branch; Mc – musculocutaneous nerve

Many cases have shown that this variant is usually located in the lower part of the arm [Error: Reference source not found, 8, 23, 25, 30]. Loukas and Aqueelah [82] indicated that in 45% of cases the connection between the MCN and MN began before the MCN entered the coracobrachialis muscle (type 1) [82]. Communication was distal to the point at which the MCN entered the coracobrachialis muscle in an estimated 35% of specimens (type 2) [82]. Loukas and Aqueelah [82] observed that in 9% the MCN did not pierce the coracobrachialis muscle (type 3), and 8% specimens were intermediate between types 1 and 2 [82].

If we assess the number of communication branches and the relationship between the two nerves, we can also distinguish three types. Their prevalences were studied by Choi et al. [81]:

- Pattern 1: Both nerves are completely fused, and the MN consists of three roots (this anastomosis occurred in about 19.2%) [29, 30],
- Pattern 2: There is a single interconnecting branch (the most common variation, prevalence 72.6%),
- Pattern 3: There are two supplementary branches (about 6.8% in cadaveric studies) [9, 25, 26].

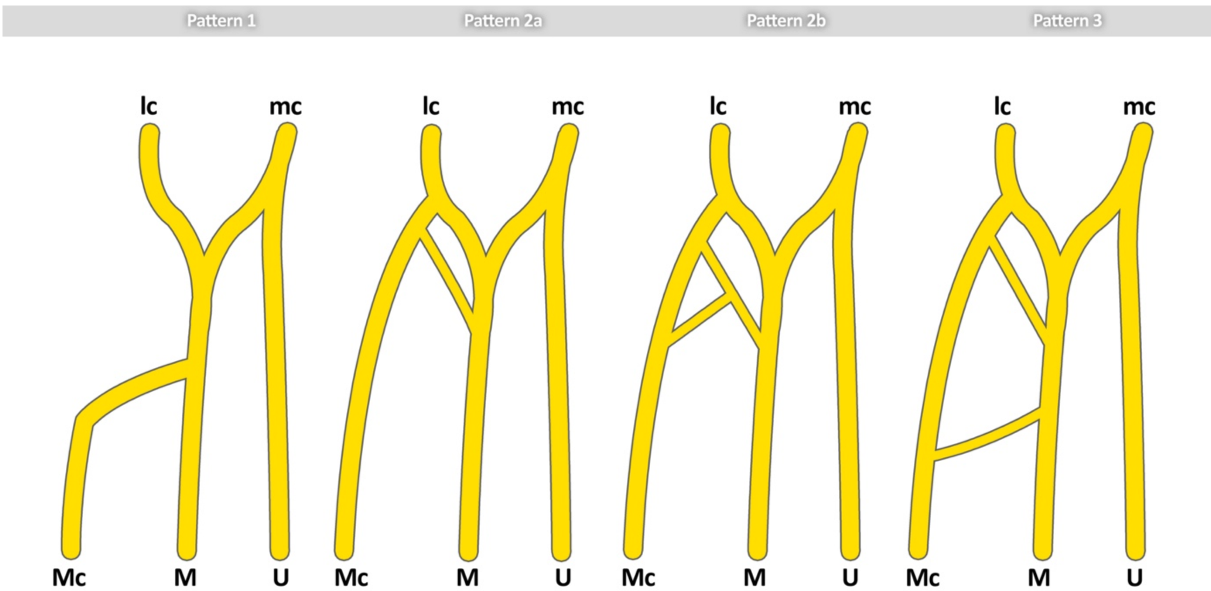


Figure B4. Types of communication between nerves according to number of branches [81]

Lc – lateral cord; Mc – medial cord; cb – coracobrachialis muscle; Mc – musculocutaneous nerve; M – median nerve; U – ulnar nerve

Marathe et al. [54] ascribed this variation to the stage in embryo development when somites migrate and form buds (anlage of the limbs). At approximately the fifth week of intrauterine life, the forelimb muscles develop from the mesenchyme of the paraxial mesoderm. The regional expression of five Hox D genes is responsible for development of the upper extremities. When the motor axons approach the base of the limb, they mix and form the brachial plexus. In the limb bud, development of the axon growth cones is regulated by expression of a chemorepellant that coordinates the characteristic fission. Tropic substances such as brain-derived neurotropic growth factor, neutrin-1, neutrin-2, and c-kit ligand allow the appropriate growth cones to be attracted or selectively maintain those that follow the correct path. Variations in nerve distribution could result from altered signaling between mesenchymal cells and neuronal growth cones, or circulating factors, during fission of the brachial plexus [54].

This variability could be clinically significant. Depending on its location, the communicating branch can compress a neighboring artery and alter blood flow through it. If it is located proximally it can compress the axillary artery, but if it is distal to the coracobrachialis muscle it can compress the brachial artery. Therefore, structures below the compression point can therefore receive a limited blood supply, which can result in palsy or mild sensory disturbance in the forearm and hand. This compression can be confirmed by precise imaging using a CT scan [6, 83].

The location of a communicating branch between the MCN and the MN is important in the diagnosis of traumatic or traction lesions in the axilla or arm. Lesions in the interconnecting nerve can lead to compound MCN and MN neuropathy. Depending on the level of injury, there may be beneficial or deleterious modifications in the movement and function. For example, if the MCN is injured near the communicating branch, unexpected weakness of the flexors in the forearm and thenar muscles can result [5, 22].

Sometimes the communicating branch from the MCN can induce redundant heads of the biceps brachii muscle. A relationship has been observed between interconnection and the high origin of the pronator teres muscle, or variability in association with the brachial and/or median artery 9, 26–29].

A lesion of the MCN (occurring during strenuous activity) and its association with an anastomosis with the MN (when some part of it passes through the coracobrachialis muscle) can cause symptoms similar to carpal tunnel syndrome, pronator teres syndrome, or anterior interosseous nerve syndrome; but such symptoms are very rare [8, 25, 27]. However, an injury involving the MN close to the communicating branch with the MCN is clinically significant: the functions of the anterior forearm and palmar muscles are preserved within the range of innervation of the median nerve [25].

Knowledge of the location of the interconnecting branch between the MCN and MN is very important in peripheral nerve surgery, especially in the diagnosis and management of nerve lesions [25].

The foregoing implies that the MCN can communicate with all neighboring nerves. Anastomoses between the UN and MACN are also known. Communication with the UN can be generated on the dorsal surface of the palm. The LACN can participate in this variation, connecting with the dorsal palmar branch of the UN. The connection with the MACN is located on the anterior surface of the forearm near the median line [Error: Reference source not found].

Anastomoses between the MCN (mainly from the LACN) and RN can also occur. This type of communication can occur in the upper and posterior part of the forearm; a branch from the RN (posterior cutaneous nerve of the forearm) combines with the terminal branch of the MCN. In the lower part of the forearm there may be an anastomosis with the superficial branch of RN [Error: Reference source not found, Error: Reference source not found, 13].

Such variations are clinically important not only during flap dissection and posttraumatic evaluation, but also during peripheral nerve repair. Some injuries may have unspecific symptoms due to intraneural communications. Communicating branches between the MCN and other nerves of the brachial plexus can change the innervated region and make the extent of injury difficult to diagnose because the symptoms can mislead [Error: Reference source not found, 3, 14].

**Median nerve**

The MN supplies some of the anterior flexors of the forearm, palmar muscles, and skin. This nerve arises from two roots; the lateral come from the lateral cord of the brachial plexus and the medial branches from the medial cord. Both roots are united in the axilla anterior to the axillary artery, at the level of the pectoralis minor muscle. Subsequently, the MN passes into the arm, runs down in the medial bicipital groove, and enters the cubital fossa with the brachial artery beneath the bicipital aponeurosis. In the upper part of the forearm it is located between the heads of the pronator teres muscle and is directed between the superficial and deep digital flexors. In the lower part of the forearm it is located between the tendons of the radial flexor of the wrist and the palmar long muscle and passes below the flexor retinaculum through the carpal canal to reach the palm. There it can divide into three terminal branches, the common palmar digital nerves [1, 2, 64].

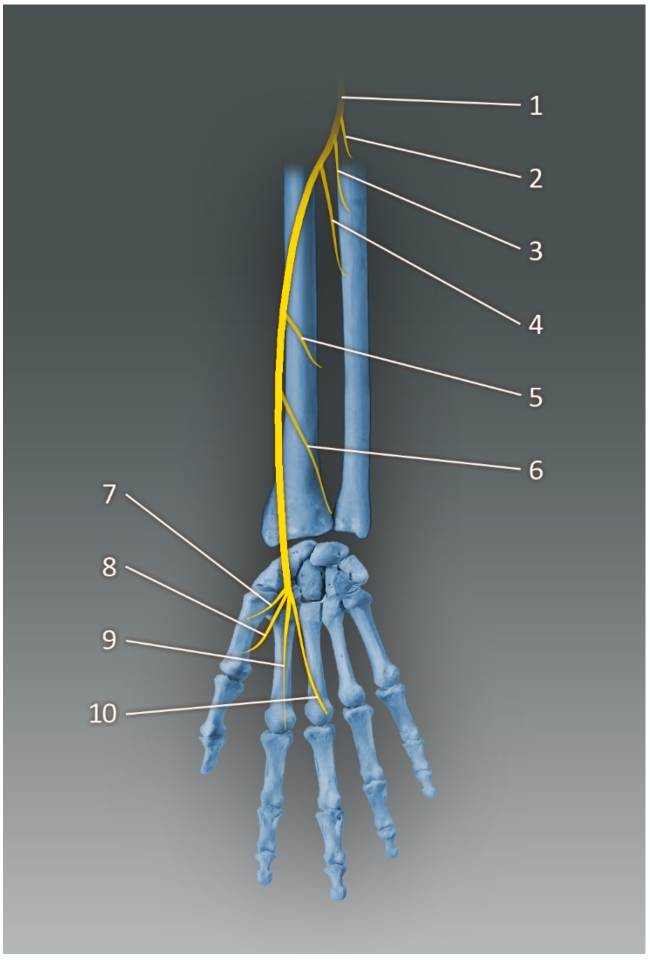


Figure C1. Median nerve [87]

All branches of the MN divide in the forearm and palm. For example, there are branches that supply the cubital joint, the forearm flexors (superficial and deep), the anterior interosseous nerve, the median palmar branch, and branches that supply the thumb muscles [1, 2].

An unusual type of connection has been discovered between the lateral and medial roots of the MN. This is a multiple variation in which the proximal lateral root gave a little branch running recurrently and medially to the axillary artery and joining the medial root [17].

The MN are clinically important. Awareness of them can lead to amendments in surgical procedures on the forearm and arm (for example, ORIF of the radius or ulnar shaft) to prevent iatrogenic injury [27, 34, 64]. Knowledge of them is also crucial to interpret electrophysiological findings [34, 64]. In carpal tunnel syndrome, the anastomosis can be associated with either aggravated or minimized symptoms [64]. The MN can communicate with the MCN (as described above), the UN, or RN [Error: Reference source not found, 15, 21].

Many anastomoses between the MN and UN can occur in the forearm or palm. Depending on the location of the interconnecting branch, four types are distinguished: Martin Gruber and Marinacci (forearm variants), Riche-Cannie and Berrettini (palmar variants) [15, 27]. A Martin-Gruber anastomosis (MGA) is located in the forearm. The communication involves a branch from the MN proximally to the UN distally [15, 64]. MGA is most often unilateral, on the right [15, 64], although Rodriguez-Niedenführ et al. [67] found this type of anastomosis mostly on the left side. MGA appears to have an autosomal dominant inheritance pattern (it has been associated with trisomy 21 during bilateral presentation) [15, 34, 66]. Srinivasan et al. [66] compared the occurrences of this anastomosis between normal and abnormal fetuses (trisomy 21) and revealed that all the fetuses with trisomy 21 had bilateral communications between the MN and UN. The connecting branch carried mainly motor fibers, rarely sensory fibers [67].

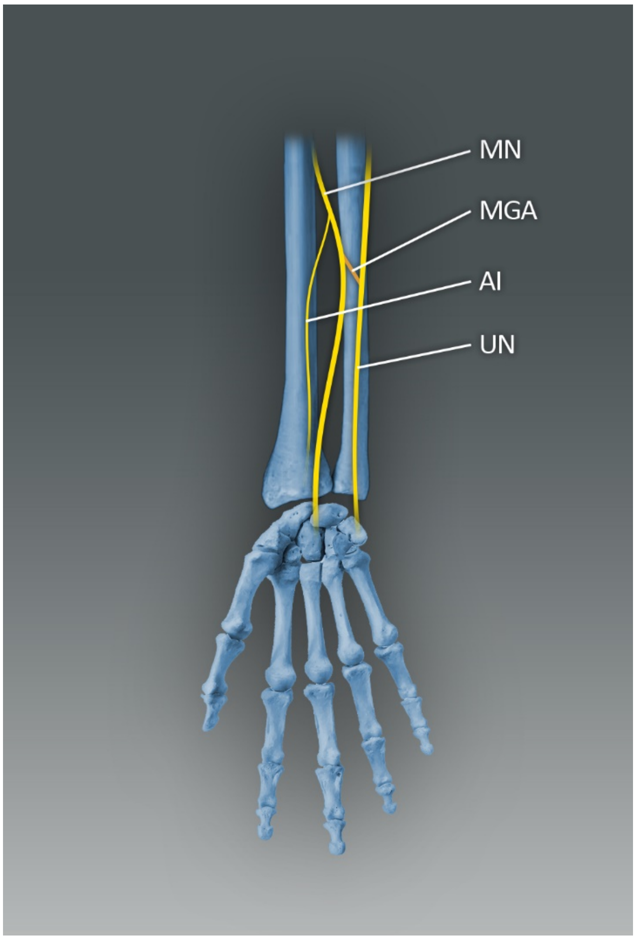


Figure C2. Martin-Gruber Anastomosis (MGA)

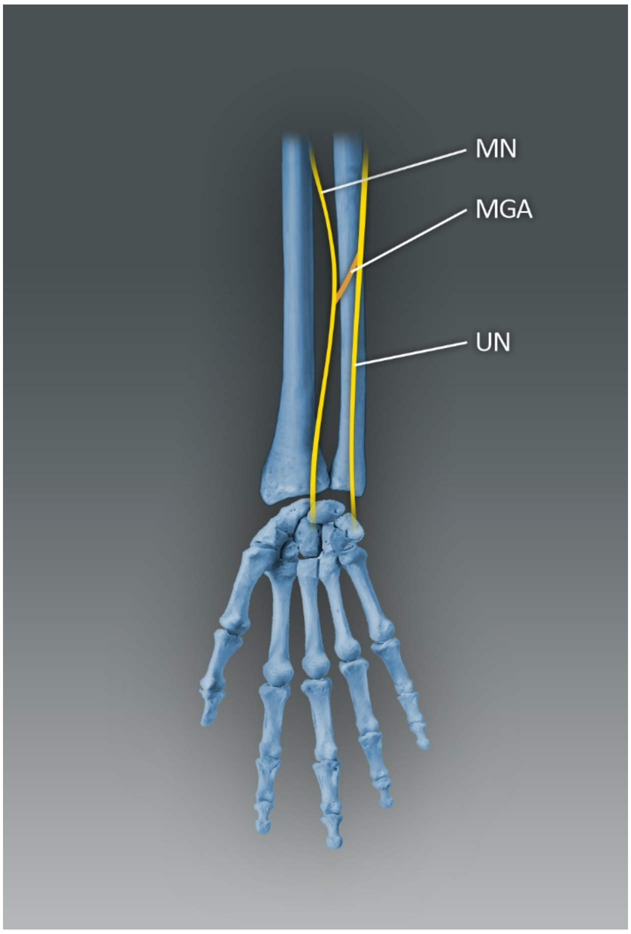


Figure C3. Marinacci Anastomosis (MA)

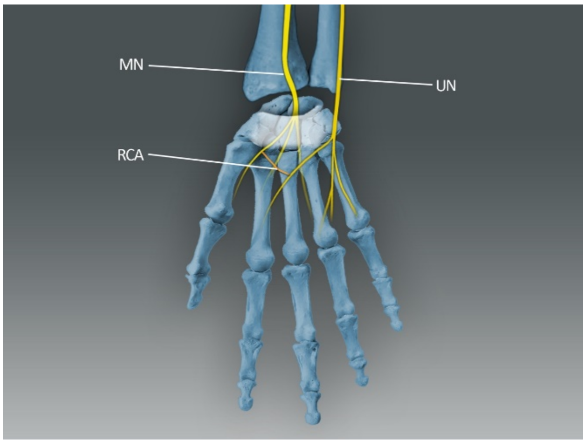


Figure C4. Riche-Cannieu Anastomosis (RCA)

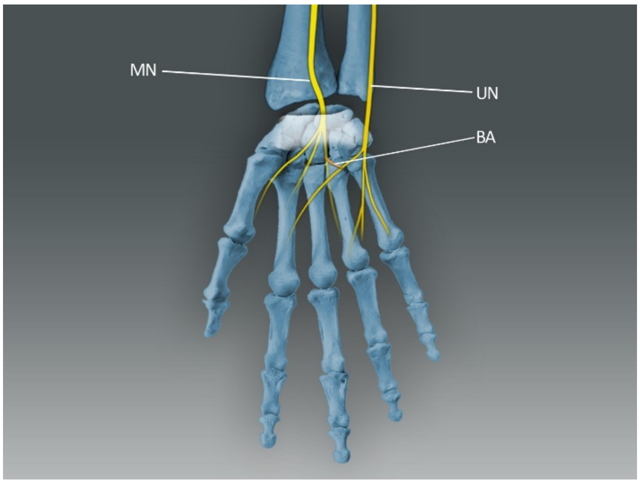


Figure C5. Berrettini Anastomosis (BA)

Cavalheiro et al. [65] classified MGAs into six types:

- Type I — described above, connection between the anterior interosseous nerve and the UN,
- Type II — double branches between the anterior interosseous nerve and the UN,
- Type III — interconnecting branches running directly from MN to UN,
- Type IV — connecting branches located between MN and an ulnar branch (toward the flexor digitorum profundus muscle of the fingers),
- Type V — intramuscular anastomosis,
- Type VI — interconnecting branch originating from branch of MN to flexor digitorum superficialis and UN [65].

Table 1. Prevalence of MGA among selected reports

| | Type I | Type II | Type III | Type IV | Type V | Type VI |
|---|---|---|---|---|---|---|
| Cavalheiro et al. [65] | 33% | 7.4% | 14.8% | 18.5% | 18.5% | 7.4% |
| Roy et al. [64] | 57.6% | – | – | – | – | – |
| Rodriguez-Niedenführ et al. [67] | – | 10.5% | 10.6% | – | – | 47.3% |
| Lee et al. [68] | – | – | – | 15% | – | – |

Table C1.

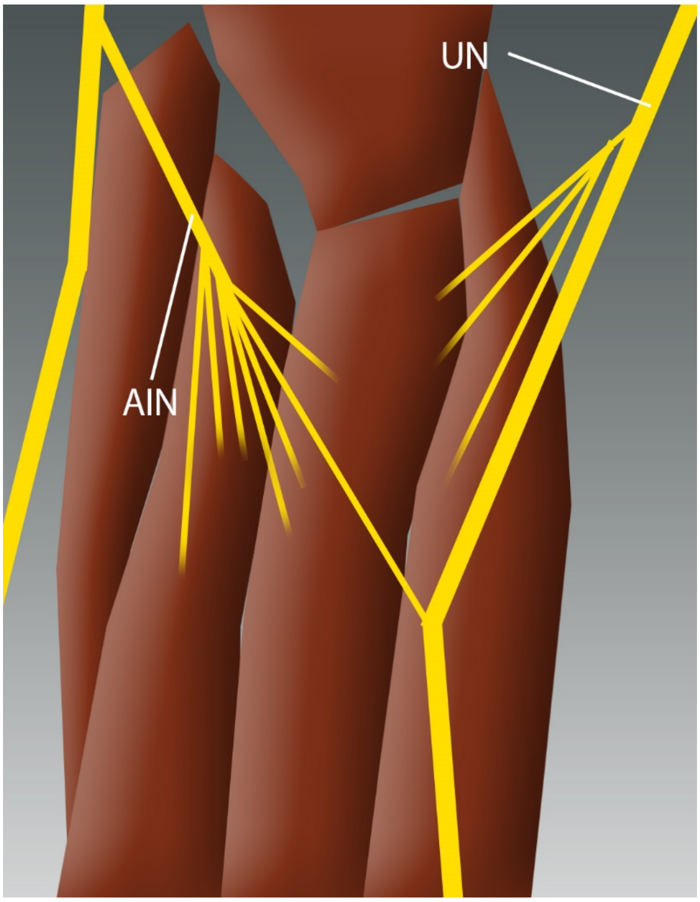


Figure C6. (Type I) [65]

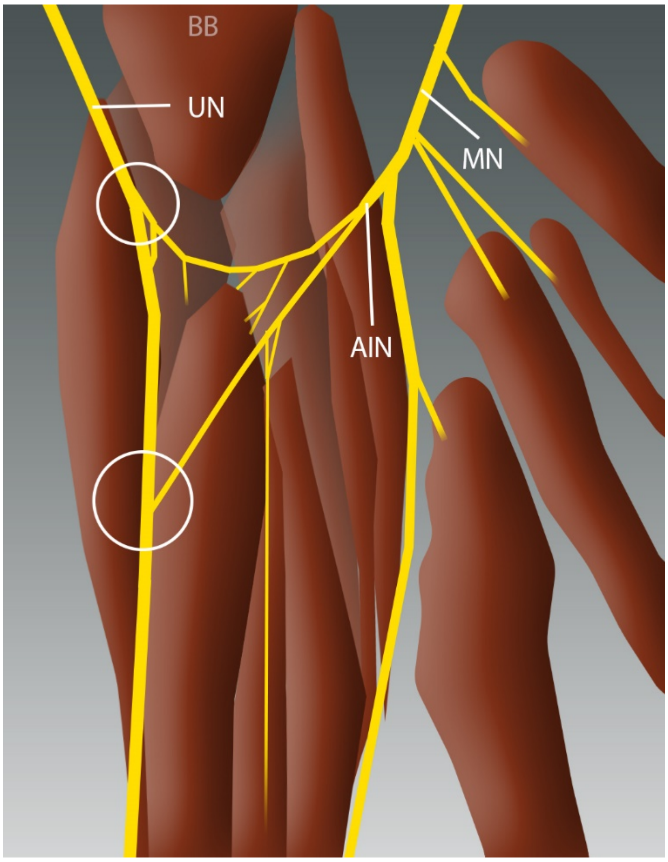

Figure C7. (Type II) [65]

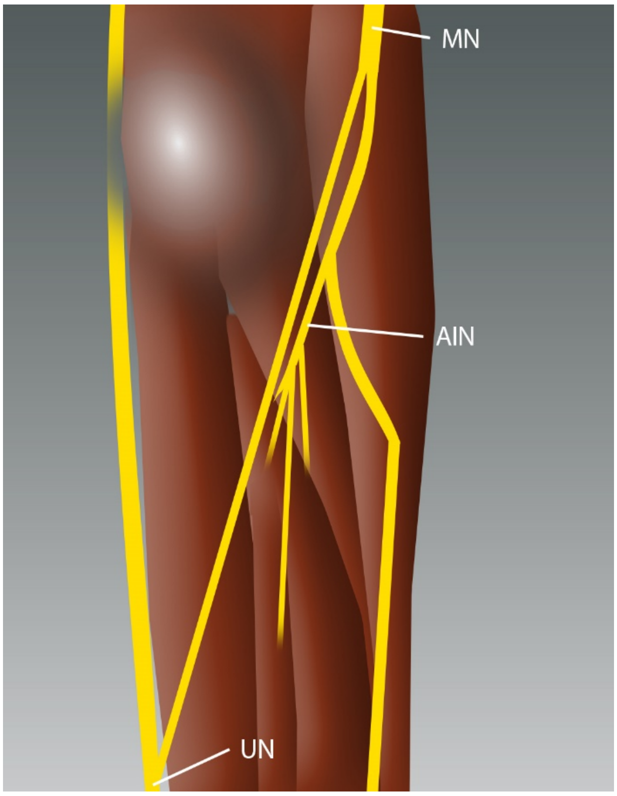

Figure C8. (Type III) [65]

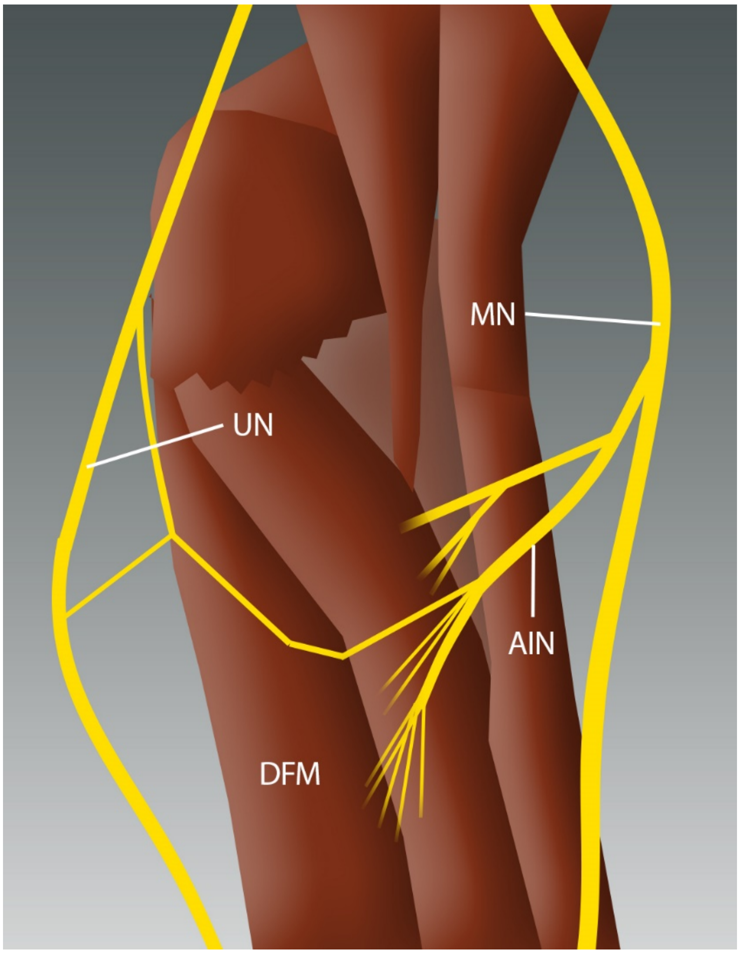

Figure C9. (Type IV) [65]

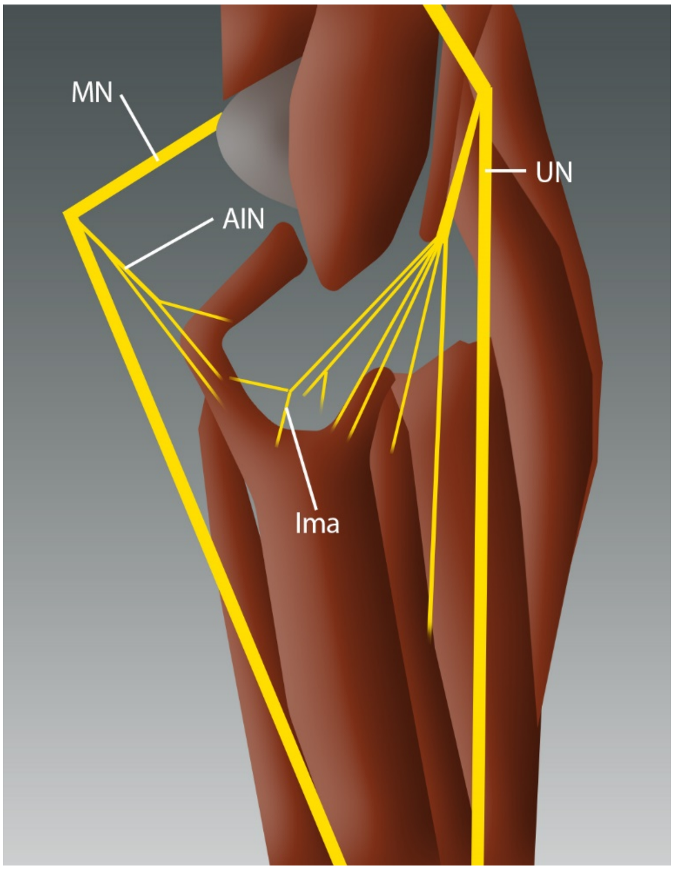


Figure C10. (Type V) [65]

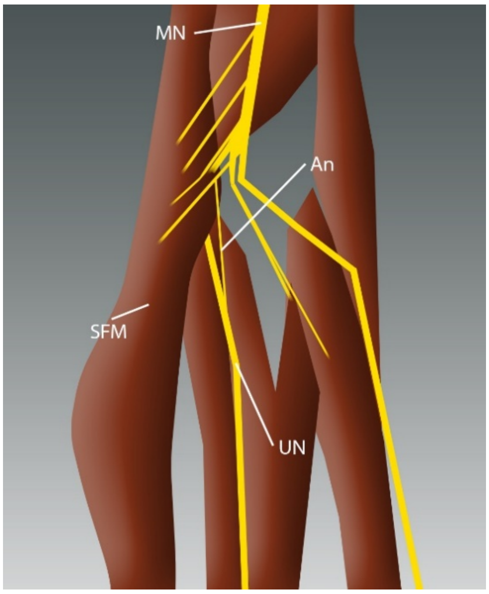


Figure C11. (Type VI) [65]

Most cases suggest that the connecting branch is located on the nearby ulnar artery. Awareness of this association could minimize iatrogenic injury (presenting, for example, as wrist drop) when the forearm bones are fractured. This type of anastomosis could cause failure to diagnose carpal tunnel syndrome, cubital tunnel syndrome and other peripheral lesions [15, 31, 36]. This anastomosis in patients with carpal tunnel syndrome (compression of the MN through the flexor retinaculum of the hand) can evince atypical electromyographic findings in the thenar muscles [31]. Some patients have carpal tunnel syndrome without compression of the MN (this can be confirmed by negative Tinel and Phalen tests), but symptoms could still occur due to UN compression in the elbow [31].

Marinacci anastomosis (MA) is also found in the forearm, but it is much rarer than MGA and other types of communication between MN and UN. Roy et al. [64] estimated its frequency at 0.7% and Sundaram et al. [15] found it in 4% of specimens. Hodzic et al. [70] found it in

1.67%. This variant is a reversed MGA; the MN branches distally to the UN proximally [15]. The communicating branch contains mainly motor fibers, rarely sensory, as in MGA [31, 71].

Hodzic et al. [70] observed a communicating branch of 5.2 cm behind the ulnar artery. It originated from the UN and had a transverse course. The authors located the origin of the anastomosis branch 6 cm distal to the lateral epicondyle [70]. Fellipe et al. [31] also described a 7.4 cm communicating branch that originated proximally in the UN and connected to the anterior interosseous nerve (branch of the MN) [31].

In the MA variation, MN injuries in the cubital area cannot have clinically significant effects on thenar muscle function, but injury to the UN could change the innervation of the thenar muscle (it is normally innervated by the UN) [15]. Knowledge of this anastomosis is crucial to avoid iatrogenic injury during surgical release of the flexor retinaculum [69]. If the MN is injured in the forearm, the function of the hand muscles innervated by that nerve can be preserved despite denervation of the wrist flexor muscles [31, 69].

The Riche-Cannieu Anastomosis (RCA) is present on the hand and its prevalence reaches 55.5% (according to Smith et al. [15]). Ahadi et al. [75] found RCA in 82.6% of the cases, Caetano et al. [72] in 100%. Kimura et al. [73] considered this variation of anatomical anastomosis in terms of origins; they suggested that African-American people have this anastomosis more rarely than other groups. They gave strong reasons for claiming that RCA has an autosomal dominant inheritance pattern [15, 74]. The connecting branch arises from the recurrent branch of MN [15]. The UN component originates from a deep branch (according to Ahadi et al. [75], from the ramus to the flexor pollicis brevis) [15, 72]. Awareness of this type of anastomosis is crucial for diagnosing severe carpal tunnel syndrome and preventing inappropriate surgical intervention [15, 75]. It is important to know about this variant during electromyography when the MN or UN is injured or entrapped [72].

The next type of MN-UN anastomosis is the Berrettini anastomosis (BA), which also occurs in palm [15]. Roy et al. [64] estimated the prevalence of this variation at 60.9%. Smith et al. [15] showed that it was more than 80% in several other studies. The communicating branch includes sensory fibers and is superficial in location and, therefore, vulnerable to iatrogenic injury [31, 35]. It derives from the UN (proper palmar digital branches) and goes to the third common digital nerve (branch from the MN) [15, 33, 35]. This connection could be associated with the transverse carpal ligament, which is prone to iatrogenic injury during treatment of carpal tunnel syndrome [35]. Another procedure that could involve a risk of injury is surgery to the ring finger flexor tendon, treating fasciotomy, when a Dupuytren's contracture. As with other types of anastomosis, a BA insult can cause palmar pain loss of digital sensation can be mistaken for nerve traction or scarring [33, 35].

Anastomoses between MN and RN can occur in the forearm and on the thenar and dorsal surfaces of the digits. The connection in the forearm region is formed between the anterior interosseous branch of the MN and the posterior interosseous branch of the RN. The thenar interconnecting branch can be created by the palmar branch of the MN and a superficial branch derived from the RN. There is communication on the dorsal surfaces of the first three fingers between the proper palmar digital nerves (branching from the MN) and the terminal branches of the superficial RN, the dorsal digital nerves [Error: Reference source not found, 18].

**Ulnar nerve**

The UN supplies sensory and motor fibers to the anterior part of the forearm and hand. It originates in the axilla, and then appears in the arm together with the brachial artery. It runs through the medial intermuscular groove, penetrates to the ulnar groove of the humerus, and then goes around the medial epicondyle. There it is covered only by skin and fascia. Further, the UN runs between the heads of the carpal ulnar flexor to the forearm, where it runs down close to the deep flexor of the digits and the ulnar carpal flexor. In the lower part of the forearm, it divides into the dorsal palmar and palmar branches. The palmar branch forms the terminal branch, which passes to the palm below the superficial layer of the transverse carpal ligament. Subsequently, it forms deep and superficial branches [Error: Reference source not found, 37, 40].

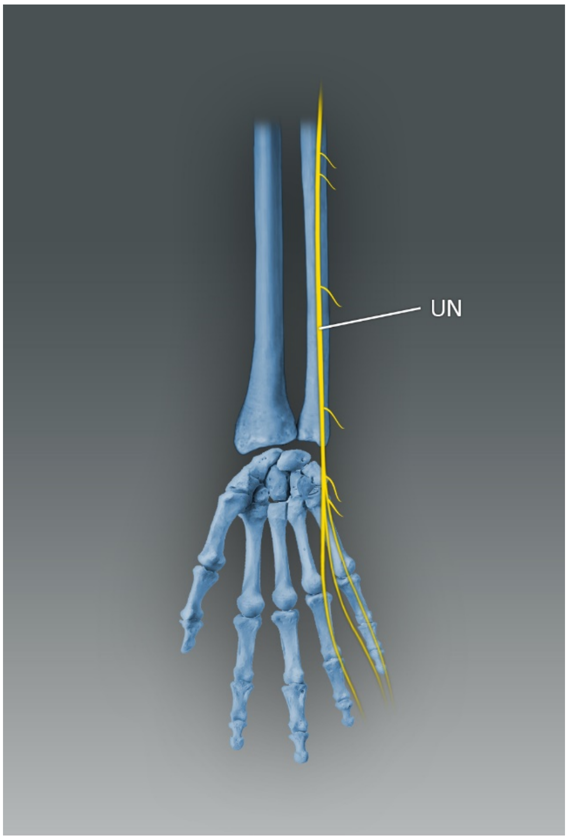


Figure D1. Ulnar nerve [88]

Like the MN, the UN gives branches mainly in the forearm, wrist and hand, such as a vascular branch to the ulnar artery and branches to the muscles, the carpal ulnar flexor and deep flexor of the digits [Error: Reference source not found, 37, 40].

The UN can create anastomoses with other long nerves derived from the brachial plexus; with the MCN and MN (described above), and also with the MACN and RN [2, 60].

Guru et al. [60] found communications between the UN and the RN and between the UN and MACN. The rare anastomosis between the UN and RN was located at the level of the humerus, where a communicating branch of 5.1 cm derived from the RN joining the UN before piercing the medial intermuscular septum. The UN is more often connected to the RN in the forearm or palm [60]. Loukas et al. [62] described the communication on the palm. Its overall prevalence was 60% and was classified into four types. Type I (59.1%) derived proximally from the RN and coursed distally to connect with the UN; in type II (19.1%) the connecting branch originated proximally from the UN and ran distally to the RN; in type III

(3.3%) the connecting branch was perpendicular between the UN and the RN; and in type IV (18.3%) there were many connecting branches between these nerves [62].

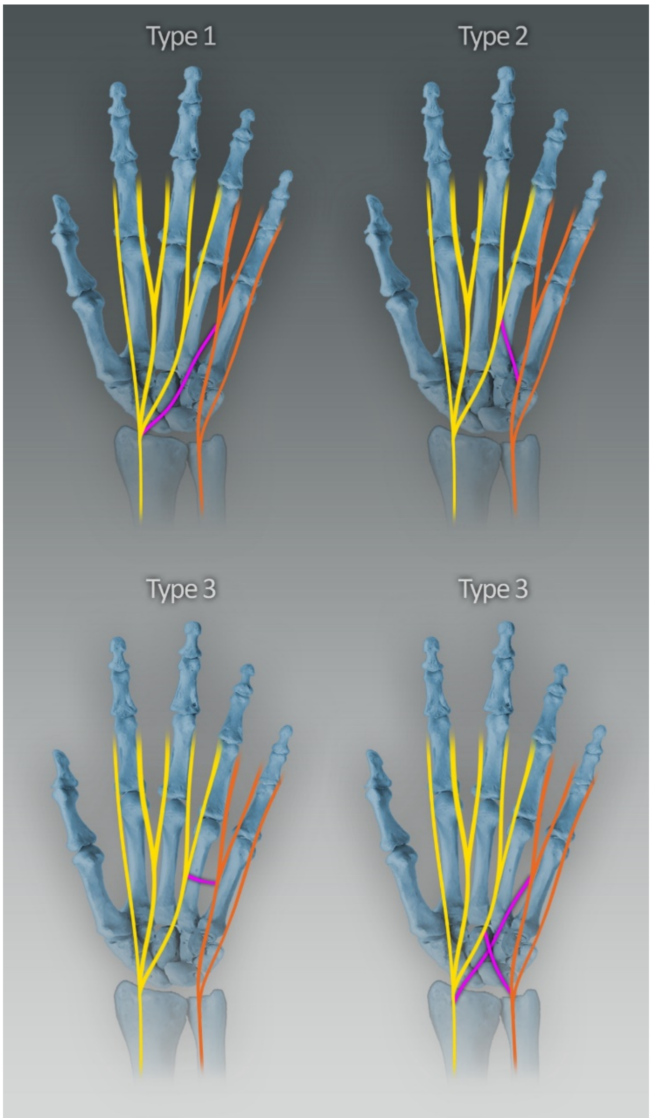


Figure D2. Types of communication according to Loukas et al. [62]

Pascual-Font et al. [84] discussed communications between the UN and the RN. During their study of embryonic and fetal upper limbs (the samples had acquired adult-like morphological features), they found a connection in all samples between a branch of the RN, specifically the ulnar collateral nerve at the level of the axilla, and the UN. The connection started in the upper third of the arms and ran downward with the UN fibers to the distal arm region, where the UN entered the medial heads of the triceps brachii [84].

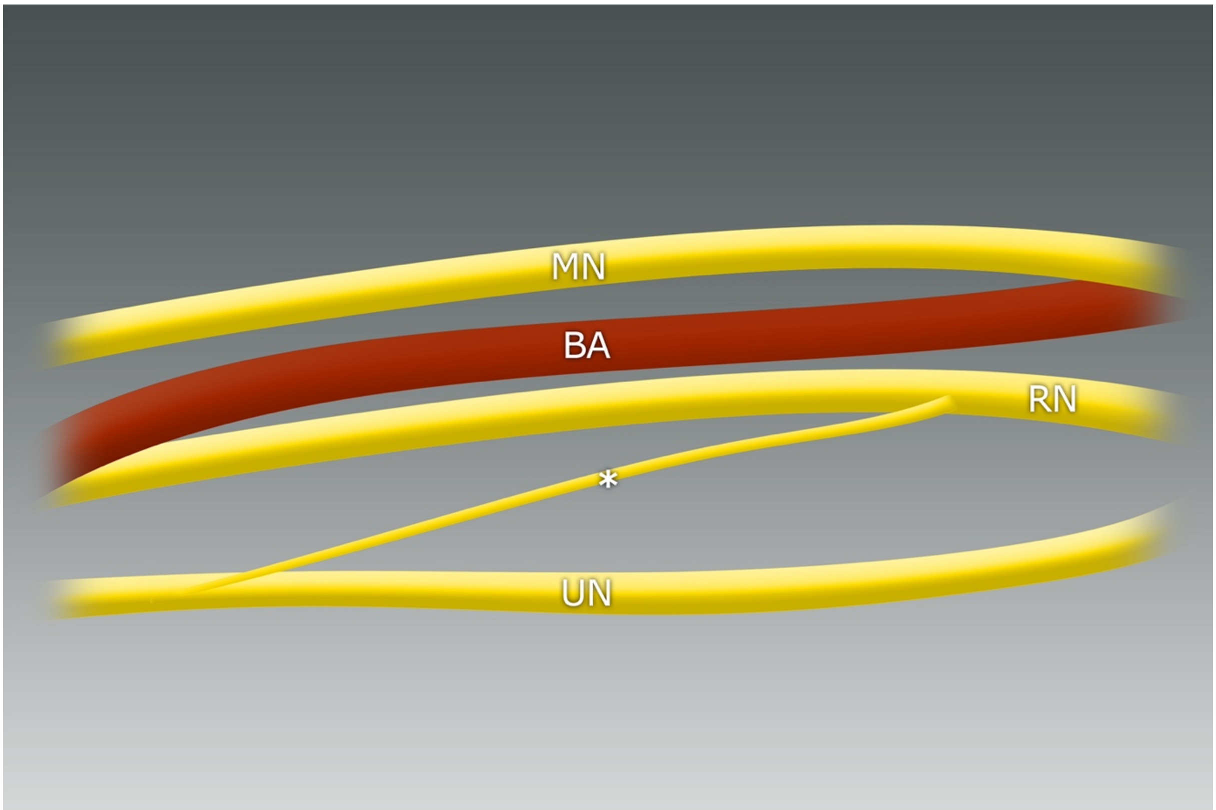

Figure D3. Communication between RN and UN [84]

r – radial nerve; u – ulnar nerve; bb – biceps brachii muscle; m – median nerve; ba – brachial artery; v - vein

An anastomosis between these nerves can contribute to the difficulty of treating complex regional pain syndrome [60–62]. The connecting branches can increase the risk of injury during peripheral nerve surgery, manifested by ulnar neuropathies, weakness and sensory loss [60]. In some cases, this variant can entail extended sensory loss from the lesion, but in a sporadic situation, communication can provide a collateral supply and prevent sensory loss [62]. However, knowledge of the anastomosis could be useful in explaining some symptoms, for example distal UN entrapment syndrome [62]. In some cases, the connecting branch may be useful for digital nerve grafting because it provides the donor nerve to maximize sensitivity [62, 63].

**Medial brachial cutaneous nerve and medial antebrachial cutaneous nerve**

The MBCN provides sensory innervation to the medial cutaneous region of the arm. It usually originates from the medial cord and is the most medial cord of the brachial plexus. It descends the arm and courses with the basilic vein. It terminates in the distal third of the medial arm [38, 49]. Distal to its origin, it communicates with the ulnar branch of the MACN [49]. Gupta et al. [17] studied this communication; 2.9 cm from its origin, the MACN gave a connecting twig running downward and laterally for 2.4 cm, to join the MBCN 4.7 cm distal to its origin [17].

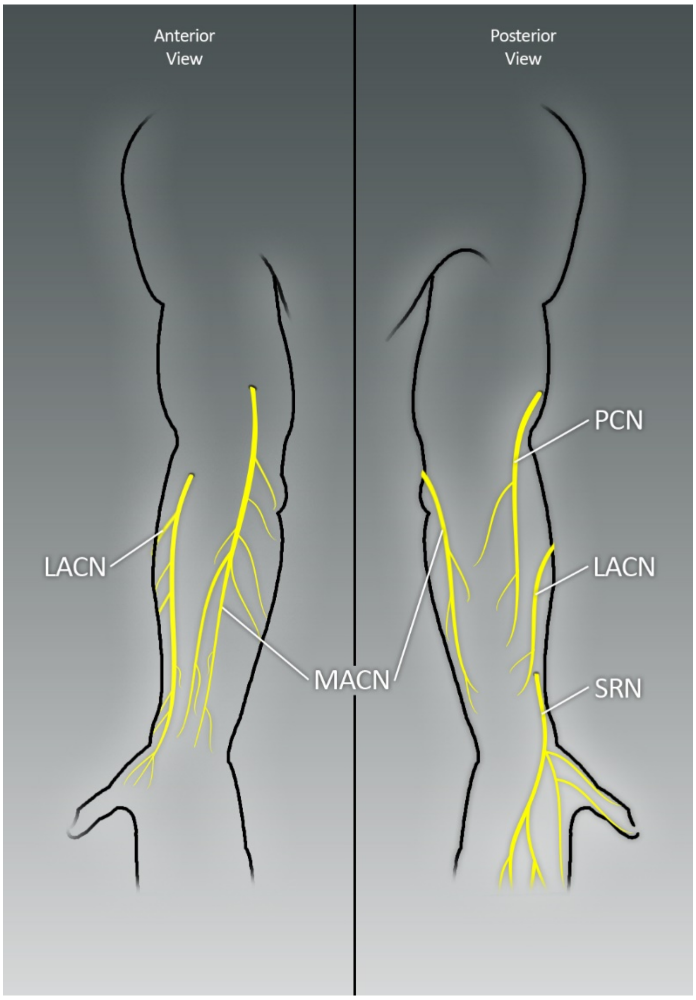


Figure E1. View of cutaneous nerve [89]

During brachioplasty involving an incision from the axilla to the medial epicondyle, a complication can be injury to the MBCN; and, when the two nerves are connected, to the MACN [49]. This can affect pain and pressure sensations in the arm and cause pressure ulcers over the elbow [49].

The MACN also derives from the medial cord of the brachial plexus. Above the medial epicondyle, it pierces the brachial fascia and commonly emerges in two branches, anterior and posterior (before entering the forearm), which run downward to the wrist. The larger, anterior branch of the MACN courses anteromedially in the forearm. After curving round to the back of the forearm it runs along the medial border to the wrist. It supplies part of the sensory innervation of the forearm and skin over the olecranon [2, 52–54].

A known anastomosis between the MACN and another nerve is communication between the MACN and RN [54, 55]. Marathe et al. [54] found a communicating nerve arising from the MACN and crossing the third part of the axillary artery on the medial side of this vessel. Running further down, backwards and laterally, it finally joined to the RN [54]. Bonczar et al. [56] also found a variant between these two nerves in all specimens. They revealed 1–5 communicating branches that crossed the distal cutting line between the posterior interosseous nerve (continuation from the deep branch of the RN) and the MACN. There was one communicating branch in 6.7% (running centrally or subtly radially); two branches that were ends of the posterior interosseous nerve (PIN) trunk in approximately 26.6%; and 3–5 communicating branches in 66.7% derived from the main trunk or its larger branches [56].

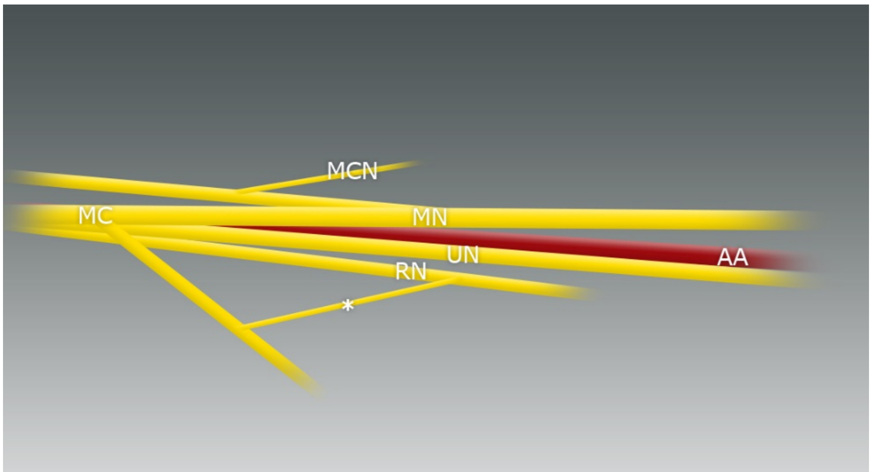


Figure E2. (*communicating branch) [54]. Communication between MACN and RN

AA – axillary artery; BBr – biceps brachii; CBr – coracobrachialis muscle; LD – latissimus dorsi muscle; MC – medial cord; MCN – musculocutaneous nerve; MN – median nerve; RN – radial nerve; SC – subscapularis muscle; UN – ulnar nerve; 1- medial antebrachial cutaneous nerve; 2 – nerve to latissimus dorsi muscle; 3 – lower scapular nerve; 5 – subscapularis region

Masear et al. [57] found communications between MACN with UN in 6% of specimens. Connections between the MACN and the palmar or dorsal cutaneous branches or the cutaneous branch of the UN are known [58]. Ballard et al. [59] found that the posterior branch of the MACN was connected to the palmar cutaneous branch of the UN. Guru et al. [60] found that the MACN gave off a connecting branch (3.2 cm) on its medial course and went medially to join the UN [60].

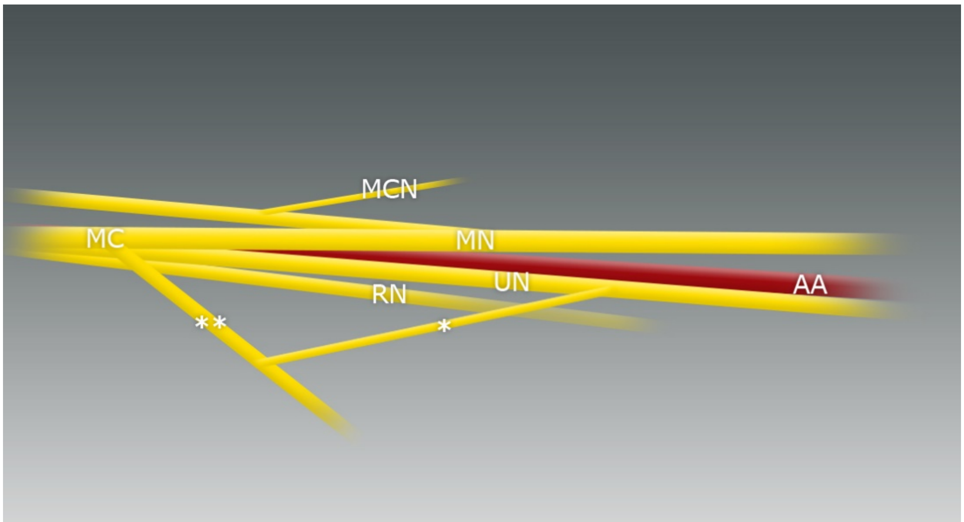


Figure E3. Communication between MACN and UN [60]

Knowledge of where such variants can be located helps in the management of various traumas to the shoulder joint and arm and helps surgeons to avoid iatrogenic injury during repair [54, 56]. Communication between the MACN and UN can increase the risk of injury during the release of the UN at the elbow for treating cubital tunnel syndrome. Complications of this MACN injury include hyperesthesia, hyperalgesia and painful neuroma [59].

**Radial nerve**

This nerve is the largest branch of the brachial plexus. It arises from the posterior cord, and during its course it provides motor branches to the posterior parts of the arm and forearm muscles. The RN also gives sensory branches to the posterior, lower lateral part of the arm, the posterior part of the forearm and dorsal part of the hand. Its terminal branches are the superficial and deep terminal rami, which separate from the main nerve at the lateral epicondyle level [1, 2, 47, 54].

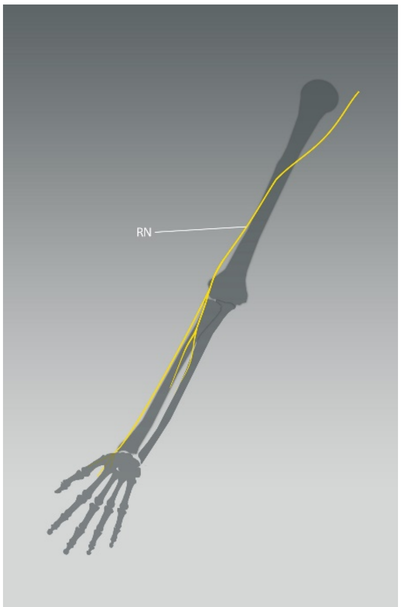


Figure F1. Radial nerve [90]

In some cases, there is a communicating branch between the RN (specifically from the superficial branch) and the lateral cutaneous nerve of the forearm (LACN — terminal branch of the MCN). That terminal branch of the RN commonly innervates two thirds of the dorsal palm and dorsal sides of 2.5 digits [43, 47]. The SBRN, after curving around the wrist under the tendon of the brachioradialis muscle and above the radial styloid process, splits into two or three sensory rami to the digits and the dorsal aspect of the palm. Normally, after it divides, the SBRN gives off three branches: SR1, which innervates two thirds of the dorsal part of the hand; SR2 to the dorsal aspect of the thumb and the index finger; and SR3 to the lateral part of the dorsal region of the thumb [43, 47]. A ramus can connect with the lateral cutaneous nerve of the forearm (LACN), which is close to the SBRN [41, 52]. Georgiev et al. [41] found that after curving around the wrist the SBRN divided into four or five digital branches. The first of these, which innervated the thenar eminence and the lateral part of the thumb, can connect with the LACN [41].

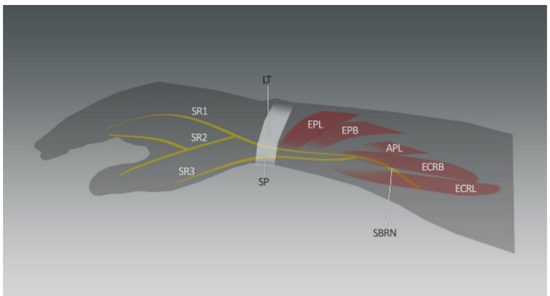

Figure F2. Scheme of the common branching SBRN [43]

SP – styloid process of radius; LT – Lister's tubercle; EPL – extensor pollicis longus; EPB – extensor pollicis brevis; APL – abductor pollicis longus; ECRB – extensor carpi radialis brevis tendon; ECRL – extensor carpi radialis longus tendon; BR – brachioradialis muscle; SBRN – superficial branch of radial nerve; SR1,SR2,SR3 – branches of SBRN

Ikiz et al. [43] found this connecting branch while researching anatomical variants of the SBRN. About 20.83% of their specimens had this variation. Fukumoto et al. [44] and Omokawa et al. [46] found that about 30% had communication between the SBRN and LACN. Huanmanop et al. [47] quoted about 43% for this variation. Park et al. [45] found it in 75%.

Fukumoto et al. [44] found that in 95% of cases the branch led to the first metacarpal space. Ikiz et al. [43] found it was located a mean of 2.6 cm from the styloid process of the radius and started between the bases of the first and second metacarpals. Park et al. [45] did not pinpoint the location of interconnection, but noted the bifurcation of the SBRN into medial and lateral branches; the lateral branch, located close to the abductor pollicis longus, connected with the LACN. Huanmanop et al. [47] noted that the connecting branch mainly involved SR3 (85.3%) [47].

Despite the SBRN, the posterior antebrachial cutaneous nerve (PACN), the branch that derives from the RN and provides sensory innervation to the skin of the posterior part of the forearm, can connect with LACN [50, 51]. Chodewaratham et al. [50] found this communication in about 8.9%, the communicating branches being either proximal or distal to the interepicondylar line. Li et al. [51] also noted this connection. However, they pointed out the division of the LACN into posterior and anterior branches and revealed that the posterior branch communicated with the branches of the posterior antebrachial nerve, located between the upper and middle thirds and between the middle and lower thirds of the posterolateral forearm [51].

This variation is significant during the treatment of distal radius fractures when external fixation pins are applied [43]. Knowledge of the connection between PACN and LACN is crucial to avoid injury during surgery at the elbow and during selection and matching of materials for sensory reconstruction in transplant cases [50, 51]. Irritation or injury to these sensory branches can cause paresthesia in the lateral part of the thenar eminence and the radial and dorsal part of the thumb. Furthermore, during surgery for de Quervain's disease, communication could be vulnerable to injury because it is near the first dorsal compartment [43, 47]. The course of the SBRN branches should be considered during regional anesthesia. If there is a communicating branch between the SBRN and LACN, it can cause problems in the treatment of neuromas on the dorsal side of the hand [43, 44, 47]. It is important to consider this connection during nerve conduction studies because stimulation and the associated response may appear unspecific [45, 50]. Tryfonidis et al. [48] compared the appearance of this connection with Wartenberg's syndrome and noted that it could contribute to the minimal region of sensory loss [48].

## CONCLUSIONS

Awareness of anastomoses between the terminal branches of the brachial plexus is clinically important because it can prevent nerve injury or upper limb palsy. Different morphological possibilities must be considered to ensure successful surgical treatment and accelerate recuperation. To identify the variation pre-operatively, the surgeon should perform an electroneuromyography examination, although changes recorded in this examination will not always be confirmed by clinical evidence. Therefore, it is necessary to conduct the dissection during surgery with extreme care.

In some cases, this continuity does not contribute to paralysis of a corresponding group of muscles or sensory loss because nerve impulses are transferred through the communicating branch. Anastomosis could make peripheral nerve examination difficult because it can cause an unspecific response. Furthermore, knowing where this anastomosis is located is useful for nerve grafting and for neurophysiological examinations to diagnose peripheral nerve neuropathy.

## Article information and declarations

### Availability of data and materials

Please contact authors for data requests (Łukasz Olewnik PhD - email address: lukasz.olewnik@umed.lodz.pl).

**Author contributions**

Karolina Sujka — project development, data collection and management, data analysis and manuscript writing.

Nicol Zielinska — data analysis and manuscript editing.

Richard Shane Tubbs — data analysis and manuscript editing.

Łukasz Olewnik — data collection, data analysis and manuscript editing.

All authors have read and approved the manuscript.

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