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Research article

Variations in brachial plexus with respect to concomitant accompanying aberrant arm arteries

Horst Claassen[a,*], Oliver Schmitt[b], Andreas Wree[b], Marko Schulze[b]

[a] Department of Anatomy and Cell Biology, Martin-Luther-University of Halle-Wittenberg, Große Steinstraße 52, D-06097 Halle (Saale), Germany
[b] Institute of Anatomy, Rostock University Medical Center, Gertrudenstraße 9, D-18055 Rostock, Germany

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ABSTRACT

Introduction: Variations in the brachial plexus are the rule rather than the exception. This fact is of special interest for the anesthetist when planning axillary block of brachial plexus.
Material and methods: 167 cadaver arms were evaluated for variations in brachial plexus, with focus on the cords of the plexus, the loop of the median nerve, and the course of the median, musculocutaneous, ulnar, axillary and radial nerves. In addition, concomitant arterial variations were recorded.
Results: In 167 arms, variations were detected in 60 cases (36%). With 46 arms (28%) most variations concern the median nerve, followed by 13 cases (8%) which involved the musculocutaneous nerve. Ulnar, axillary and radial nerve variations were rare, amounting to 1.2% for each nerve. In median nerve conditions with a shifted loop of median nerve (12%), a hidden position of the loop or a hidden course of the beginning median nerve (8%) and a doubled loop of median nerve (17%) were observed. In musculocutaneous nerve conditions with a non-perforated coracobrachialis (1.8%), a doubled origin of the nerve (1.2%) and a giving back of branches to the median nerve (1.8%) were noted. Variations in ulnar, axillary and radial nerves concerned lower than normal diameters.
Conclusions: It must be stressed that cases which showed a hidden position or a doubled expression of the loop of the median nerve, a hidden course of its beginning and variable interconnections between musculocutaneous and median nerves are of special interest for anesthetists and surgeons. Hence, it is important to note that variations of arm arteries can be associated with brachial plexus variations. For example, a common trunk of axillary artery followed by a hidden loop and course of the median nerve may result in incomplete axillary block of brachial plexus.

1. Introduction

In textbooks of the early 19th century, variations in the brachial plexus (Meckel, 1817; von Luschka, 1865) were not described. Henle (1871) and Hoffmann (1881) were the first to report that the connections and the origins of brachial plexus branches were not developed uniformly. In the Anglo-American literature, Walsh (1877) and Kerr (1918) referred to the anatomical variation in the brachial plexus. Later on, this variability was confirmed in the textbook of Rauber and Kopsch (Kopsch, 1950). Especially the location of the loop of the median nerve is highly variable (Leonhardt in Rauber-Kopsch, 1988; Tillmann in Zilles/Tillmann, 2010). The supplies by the lateral or medial cord may be two-, three- or even fourfold (von Lanz and Wachsmuth, 1959; Leonhardt in Rauber-Kopsch, 1988; Tillmann in Zilles/Tillmann, 2010). The loop of the median nerve may lie behind the axillary artery (Gegenbaur, 1892; Gegenbaur, 1903) or may have moved to the distal upper arm (von Lanz and Wachsmuth, 1959; Leonhardt in Rauber-Kopsch, 1988; Tillmann in Zilles/Tillmann, 2010). Further on, some of the fibers of the median nerve may run for some distance in the musculocutaneous nerve and then leave it to join their proper trunk (Williams and Warwick in Gray, 1980). Besides the normal loop of the median nerve, a connection between median and musculocutaneous nerves may form an additional loop. In about 5% of cases, the median nerve's loop is absent (Leonhardt in Rauber-Kopsch, 1988; Tillmann in Zilles/Tillmann).

The next most frequent variants in the brachial plexus concern the musculocutaneous nerve. A connecting branch between median nerve and musculocutaneous nerve is observed in quite a number of cases (Kopsch in Rauber-Kopsch, 1914, 1950; Leonhardt in Rauber-Kopsch, 1988; Tillmann in Zilles/Tillmann, 2010). Instead of piercing the coracobrachialis muscle, the musculocutaneous

* Corresponding author. Fax: +49 345 557 1700.
E-mail address: horst.claassen@medizin.uni-halle.de (H. Claassen).

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nerve may pass behind this muscle to the lateral upper arm (Gegenbaur, 1892; Gegenbaur, 1903). Furthermore, this nerve may adhere for some distance to the median nerve and then pass behind the biceps instead of through the coracobrachialis muscle (Williams and Warwick in Gray, 1980). After perforation through the coracobrachialis muscle, the trunk of the musculocutaneous nerve was seen to receive fibers from the median nerve or to send fibers to it (Gegenbaur, 1892; Gegenbaur, 1903). At least, the musculocutaneous nerve may be a branch of the median nerve (Gegenbaur, 1892; Gegenbaur, 1903).

Analyses of brachial plexus seldom focussed on trunks, cords and the upper arm-route of the 5 long nerves. Therefore, we examined the variation in the 5 main brachial plexus nerves with regard to their formation at the level of the axillary artery and their course through the upper arm. In previous studies we have referred to variations of arm arteries (Claassen et al., 2006, 2010). Since we observed that a variant location of the loop of the median nerve sometimes is accompanied by an arterial variation, we additionally examined the course and the branches of arm arteries.

2. Material and methods

In the summer terms 2009 (13 arms), 2010 (32 arms), 2011 (45 arms), 2012 (31 arms) and 2014 (46 arms) the upper extremities dissected in the gross anatomy courses at the Department of Anatomy (University of Rostock) were inspected for variations in the brachial plexus and especially for the concomitant occurrence of variant arm arteries. The topography of variant plexus branches and their relation to the surrounding arteries and muscles was documented on diagrams and photographs. This study was approved by the ethics committee of the University of Rostock (A-2016-0083) and followed the guidelines of the Declaration of Helsinki.

3. Results

In summary, the present sample of 167 arms revealed variations of the brachial plexus in 60 arms (36%). Gender-specific variations were not observed. Here we firstly present a survey of the variations in the brachial plexus (Table 1). Selected, especially interesting cases are described in a second step.

3.1. Overall description of the cases

Median nerve: 167 arms were investigated and variations of the median nerve, especially concerning the loop of the median nerve, were found in 46 cases (28%). Variant locations of the loop of the median nerve were summarized in a diagram (Fig. 6). In 29 cases, the variation was on the right side and in 17 on the left side respectively. The following description comprises three categories:

In the first group the fork of the median nerve was not located at its normal place:

- in 5 cases (3%) the loop had moved slightly on axillary artery,
- in 14 cases (8.4%) the loop had moved to the beginning or to the upper third of brachial artery,
- in 1 case (0.6%) the loop had moved to the middle of brachial artery,
- in only 1 case (0.6%) the loop was missing.

In the second group we put cases where the loop of the median nerve presented a location to a distinct artery, especially a variant arm artery:

- in three cases (1.8%) the loop of the median nerve was located behind the axillary artery,
- in one case (0.6%) the loop surrounded the subscapular artery,
- in two cases (1.2%) the loop was found behind the brachial artery,
- in one case (0.6%) the loop covered the profunda brachii artery,
- in one case (0.6%) the loop covered a variant superficial ulnar artery with high origin.

The third group comprises cases with a doubled loop of the median nerve:

- one case (0.6%) with doubled loop, the first one at the normal place, the second one near to the normal place,
- one case (0.6%) with doubled loop, the first one at the normal place, the second one at the beginning of the brachial artery,
- nine cases (5.4%) with doubled loop, the first had moved somewhat distally, the second was located at the proximal third of the brachial artery,
- five cases (3%) with doubled loop, the first one at the normal place, the second one was located at the middle of the brachial artery,
- one case (0.6%) with doubled loop, the first one at the normal place, the second one was found behind the high origin of a radial artery.

Musculocutaneous nerve: 167 arms were investigated and variations of the musculocutaneous nerve, especially regarding its relation to the coracobrachialis muscle, were found in 13 cases (8%). In 5 cases the variation was located on the right side and in 8 on the left side, respectively. Our description comprises three categories:

Cases with an aberrant origin of the musculocutaneous nerve or with a non-perforation of the coracobrachialis muscle were included in the first group:

- one case (0.6%) with a high origin of the musculocutaneous nerve,
- one case (0.6%) with a low origin of the musculocutaneous nerve,
- in three cases (1.8%) the musculocutaneous nerve did not perforate the coracobrachialis muscle, but instead showed a connection to the biceps brachii muscle,
- one case (0.6%) with a thin musculocutaneous nerve,
- in one case (0.6%) a musculocutaneous nerve was missing altogether.

The second group contains cases with doubled origin of the musculocutaneous nerve:

- one case (0.6%) of doubled origin of the nerve, the first origin was found within the loop of the median nerve, the second detected within the median nerve itself at the middle of the upper forelimb,
- one case (0.6%) of doubled origin of the nerve, the first one was observed within the lateral root of the loop of the median nerve, the second one was built by the median nerve itself at its beginning.

The third group consists of cases where the musculocutaneous nerve sent branches back to the median nerve or took its origin directly from the median nerve:

- in three cases (1.8%) the musculocutaneous nerve sent branches back to the median nerve or returned with parts to it,
- in one case (0.6%) the musculocutaneous nerve took its origin directly from the median nerve in the middle of the upper forelimb.

Ulnar nerve: within 167 arms the ulnar nerve showed variations in 2 cases (1.2%). In one case, the nerve derived very late from the lateral cord or almost from the median nerve. In another case, the ulnar nerve was thinner than normally at its beginning.

Table 1
Percentage occurence of variations of the median, musculocutaneous, ulnar, axillary and radial nerves at their course through the upper arm.

Nerve	Arms	Variation	*n*	%
Median nerve	167	Loop had moved slightly on axillary artery	5	3.0
		Loop had moved to the beginning of upper third of brachial artery	14	8.4
		Loop had moved to the middle of brachial artery	1	0.6
		Loop was missing	1	0.6
		Loop was located behind the axillary artery	3	1.8
		Loop surrounded the subscapular artery	1	0.6
		Loop was found behind the brachial artery	2	1.2
		Loop covered profunda brachii artery	1	0.6
		Loop covered superficial ulnar artery with high origin	1	0.6
		Doubled loop: the first one at the normal place, the second one near to the normal place	1	0.6
		Doubled loop: the first one at the normal place, the second one at the beginning of the brachial artery	1	0.6
		Doubled loop: the first one had moved somewhat distally, the second one was located at the proximal third of the brachial artery	9	5.4
		Doubled loop: the first one at the normal place, the second one was located at the middle of the brachial artery	5	3.0
		Doubled loop: the first one at the normal place, the second one was found behind the high origin of a radial artery	1	0.6
Musculocutaneous nerve	167	High origin of the nerve	1	0.6
		Low origin of the nerve	1	0.6
		Nerve did not perforate the coracobrachialis muscle, but instead showed a connection to the biceps brachii muscle	3	1.8
		Nerve thinner than normally	1	0.6
		Nerve was missing	1	0.6
		Doubled origin of the nerve: the first one within the loop of the median nerve, the second one within the median nerve itself at the middle of the upper forelimb	1	0.6
		Doubled origin of the nerve: the first one within the lateral root of the loop of the median nerve, the second one in the median nerve itself at its beginning	1	0.6
		Nerve sent branches back to the median nerve or returned with parts to it	3	1.8
		Nerve took off directly from the median nerve in the middle of the upper forelimb	1	0.6
Ulnar nerve	167	Nerve derived very late from the lateral cord or almost from the median nerve	1	0.6
		Nerve thinner than normally at its beginning	1	0.6
Axillary nerve	167	Nerve separated from the radial nerve at a relatively high location	1	0.6
		Nerve thinner than normally at its beginning	1	0.6
Radial nerve	167	Nerve thinner than normally at its beginning	1	0.6

Axillary nerve: in a total of 167 arms, the axillary nerve showed variations in 2 cases (1.2%). In one case, the axillary nerve separated from the radial nerve at a relatively high location and for this reason took a long course until vanishing into the lateral axillary cleft. In another case, the axillary nerve was thinner than normally at its beginning.

Radial nerve: in the 167 arms studied the radial nerve showed variations in 1 case (0.6%) only. In this case, the radial nerve was thinner than normally at its beginning.

3.2. Variant locations of the loop of the median nerve

Case 1: In the right arm of a 76-year-old man the loop of the median nerve covered a strong branch of the axillary artery. All axillary artery and profunda brachii artery branches derived from this common trunk (Fig. 1a,b). The axillary, subscapular, and thoracodorsal nerves took off from the lateral cord of the brachial plexus instead from the posterior one. The medial root of the median nerve, the ulnar nerve and the medial cutaneous nerve of forearm came from the posterior cord rather than from the medial one. A medial cord of the brachial plexus was absent. *Case 2*: In the right arm of a 91-year-old woman, two loops of median nerve were observed: the first one covered the axillary artery as usual, whereas the second one had moved distally to cover the brachial artery (Fig. 2a,b). The branches of the axillary artery took off as seen in the majority of cases. However, the thoracodorsal nerve took its origin from the medial cord of the brachial plexus and not from the posterior one. The lateral pectoral and the musculocutaneous nerves as well as the lateral root of the second loop of the median nerve derived from the posterior cord instead of the lateral one. A lateral cord of brachial plexus was absent.

3.3. Variations in the median and musculocutaneous nerves

Case 3: In the left arm of a 79-year-old woman, the loop of the median nerve covered the profunda brachii artery (Fig. 3a,b), with the profunda brachii artery giving off the radial and medial collateral arteries. Afterwards this artery continued as superior ulnar collateral artery. *Case 4*: In the left arm of a 85-year-old woman, both roots of the median nerve derived from the lateral cord of the brachial plexus (Fig. 4a,b). Both roots of the median nerve were covering the brachial artery and joined to build the loop of the median nerve in the proximal third of this artery. In addition, the ulnar nerve was branched off from the lateral cord of brachial plexus. On its former path to the cubital canal, the ulnar nerve crossed the brachial artery from lateral to medial in its proximal third. *Case 5*: In the arm of a 83-year-old man, a branch of the musculocutaneous nerve returned to the median nerve after it had perforated the coracobrachialis muscle (not shown). By this way a second median loop covering the brachial artery was built. A similar variation in the musculocutaneous nerve was observed in the other arm of this individual.

3.4. Loop of the median nerve covered variant branches of the axillary and brachial arteries

Case 6: In the right arm of a 94-year-old woman, the axillary artery divided into three main branches (Fig. 5a,b): the first branch continued into the brachial artery. The second one followed the

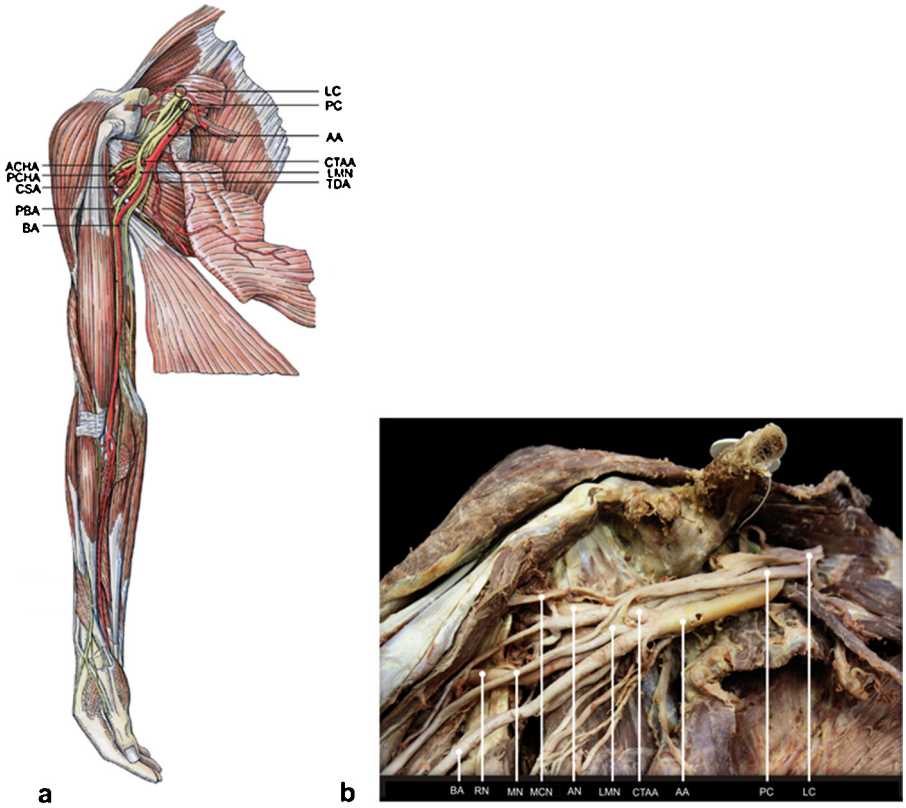

Fig. 1. Right arm of a 76-year-old male cadaver with variant location of the loop of the median nerve (case 1). (a) Diagram showing a loop of the median nerve (LMN) which covered a strong branch of the axillary artery. This strong branch was designed as a common trunk of the axillary artery (CTAA). The common trunk gave origin to circumflex scapular (CSA), thoracodorsal (TDA), anterior and posterior circumflex humeral (ACHA, PCHA) and profunda brachii (PBA) arteries. (b) The loop of the median nerve (LMN) covered the common trunk of axillary artery (CTAA). The medial cord of brachial plexus was absent. AA = axillary artery, ACHA = anterior circumflex humeral artery, AN = axillary nerve, BA = brachial artery, CTAA = common trunk of axillary artery, LC = lateral cord, LMN = loop of median nerve, MCN = musculocutaneous nerve, MN = median nerve, PBA = profunda brachii artery, PC = posterior cord, PCHA = posterior circumflex humeral artery, RN = radial nerve, TDA = thoracodorsal artery, UN = ulnar nerve.

path like a superior ulnar collateral artery and was covered by the loop of the median nerve. As shown in textbooks, the superior ulnar collateral artery took off from the brachial artery proximally from the middle of the upper limb and near to the origin of the profunda brachii artery. In its former course, this artery accompanied the ulnar nerve. The third branch represented a common trunk of the axillary artery which gave off the posterior circumflex humeral and circumflex scapular arteries. Furthermore, the forearm showed variations. In the cubital fossa the brachial artery divided into a radial artery and a variant superficial ulnar artery (Fig. 5c,d). The radial artery divided into a small, superficial artery running to the dorsal hand and into a quite thick artery continuing the normal course of this artery (Fig. 5c,d). In the left arm of this person a trifurcated axillary artery was missing. The loop of the median nerve covered the superior ulnar collateral artery which derived from the brachial artery (Fig. 5e). Surprisingly, the lower limb of the left arm was also characterized by a superficial ulnar artery (not shown).

4. Discussion

Past descriptions of the brachial plexus, with C5 to Th1 nerve roots to form three trunks, six divisions, three cords, and five motor/sensory branches to the upper extremities, represent oversimplifications to some degree (Orebaugh and Williams, 2009). From a clinical viewpoint, understanding the complexities of the formation and structure of the brachial plexus remains a key issue for surgical treatment and regional anesthesia (Johnson et al., 2010). According to Meier and Büttner (2004), the axillary artery is the leading structure for anesthesia of the brachial plexus. Two references elucidate the clinical impact of brachial plexus variation. Firstly, in perivascular techniques of brachial plexus block sometimes important quantities of anesthesia product are needed, surely due to variant nerve branches (Ongoiba et al., 2002). Secondly, axillary nerve block with the help of real-time ultrasound and peripheral nerve stimulator guidance revealed the following observations in a patient with wrist arthroscopy (Orebaugh and Pennington, 2006): a large structure was noted in the position typically occupied by the median nerve and contact of it with the stimulating needle produced a strong biceps contraction. It was believed that the musculocutaneous nerve was running together with the median nerve in the axilla and then became separated from it at the mid humeral level. Here we report on brachial plexus variations on the basis of 167 arms from body donors of the Rostock anatomical dissection courses.

Within 167 arms we detected variations of the brachial plexus in 60 arms (36%). For an overview of the observed variations see Table 1. A somewhat higher degree of brachial plexus variations of 53% was reported by El Falougy et al. (2013). In a study of 200 brachial plexuses from spontaneously aborted fetuses, Johnson et al. (2010) reported that 46.5% possessed the normal plexus organization, while 53.5% displayed a significant variation. The higher percentage of brachial plexus variations of these two authors may be due to population differences.

4.1. Trunks of brachial plexus

In the present series of 167 arms, almost all three trunks of brachial plexus were present. However, in a 64-year-old cadaver,

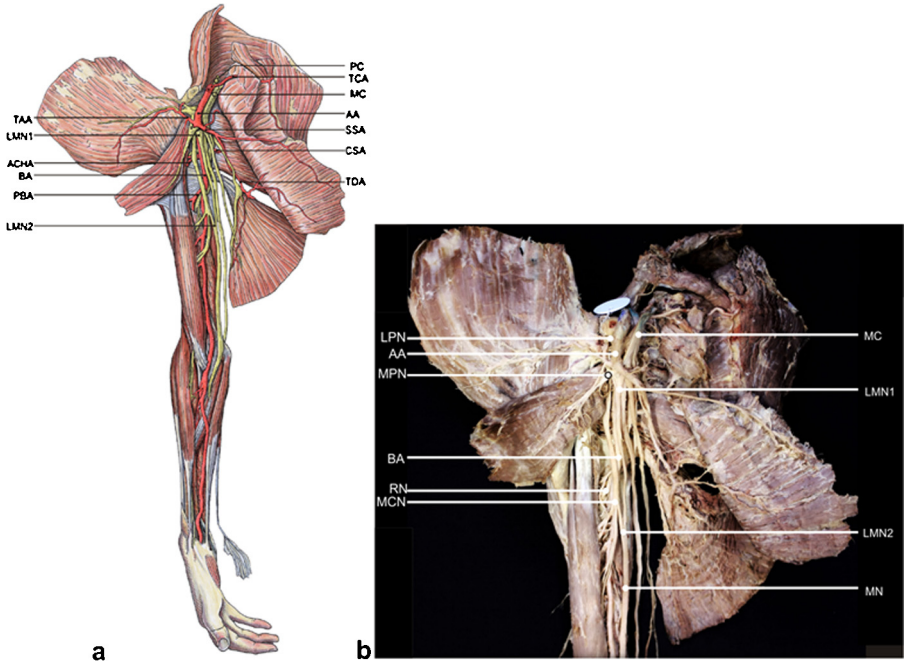

Fig. 2. Right arm of a 91-year-old female cadaver (case 2) with a doubled loop of the median nerve. (a) Diagram presenting an arm with a doubled loop of the median nerve. The first loop of the median nerve (LMN 1) covered the axillary artery (AA) while the second one (LMN2) was located distally on the brachial artery (BA). Thoracoacromial (TAA), subscapular (SSA) and circumflex humeral (ACHA) arteries derived from the axillary artery (AA). The subscapular artery (SSA) divided itself as normal into circumflex scapular (CSA) and thoracodorsal (TDA) arteries. Note that lateral cord of the brachial plexus is missing. (b) Second loop of median nerve (LMN 2) has moved distally and covers the brachial artery (BA). Lateral pectoral (LPN) and musculocutaneous (MCN) nerves and the lateral root of the second loop of median nerve took their origin from the posterior cord (PC) of brachial plexus instead of from the lateral one. AA = axillary artery, ACHA = anterior circumflex humeral artery, BA = brachial artery, CSA = circumflex scapular artery, LMN 1 or 2 = loop of median nerve 1 or 2, LPN = lateral pectoral nerve, MC = medial cord, MCN = musculocutaneous nerve, MCNF = medial cutaneous nerve of forearm, MN = median nerve, MPN = medial pectoral nerve, PC = posterior cord, PBA = profunda brachii artery, RN = radial nerve, SSA = subscapular artery, TAA = thoracoacromial artery, TCA = transverse cervical artery, TDA = thoracodorsal artery, UN = ulnar nerve.

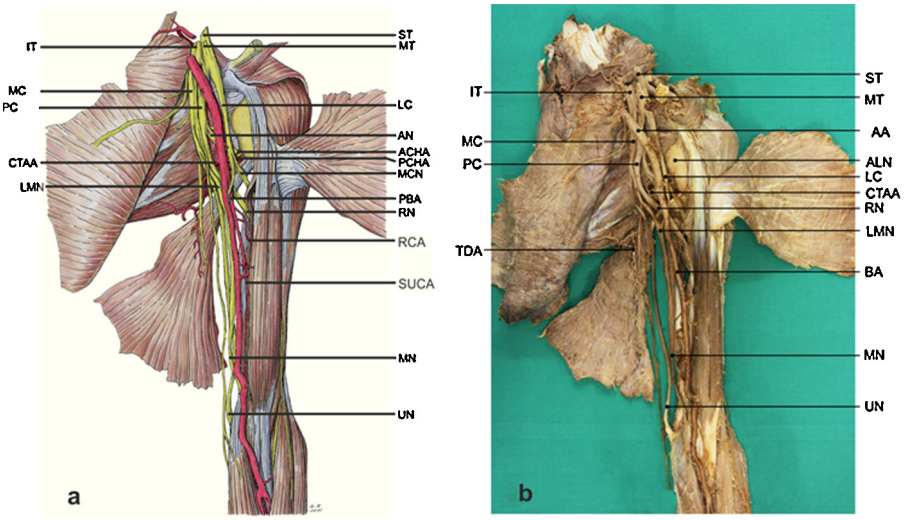

Fig. 3. Left arm of a 79-year-old female cadaver with variant location of the loop of the median nerve. (a) Diagram showing an arm with a hidden loop of the median nerve (LMN). (b) A loop of the median nerve (LMN) covered the profunda brachii artery (PBA) and therefore was hidden underneath the brachial artery (BA). The profunda brachii artery (PBA) gave off radial and medial collateral arteries and afterwards continued as superior ulnar collateral artery. AA = axillary artery, ACHA = anterior circumflex humeral artery, ALN = axillary lymphnode, AN = axillary nerve, BA = brachial artery, RCA = radial collateral artery, CTAA = common trunk of axillary artery, IT = inferior trunk, LC = lateral cord, LMN = loop of median nerve, MC = medial cord, MCN = musculocutaneous nerve, MN = median nerve, MT = middle trunk, PC = posterior cord, PBA = profunda brachii artery, PCHA = posterior circumflex humeral artery, RN = radial nerve, ST = superior trunk, SUCA = superior ulnar collateral artery, TDA = thoracodorsal artery, UN = ulnar nerve.

the brachial plexus showed two trunks superior and inferior while the middle trunk was absent (Kirazli et al., 2013). The superior trunk expressed the lateral cord forming the musculocutaneous nerve. The inferior trunk trifurcated into the radial, median and ulnar nerves, respectively. In another adult cadaver, an absent superior trunk was observed (Adam et al., 2011).

4.2. Cords of the brachial plexus

In the present series of 167 arms, we observed one case of an absent lateral cord and another case of an absent medial cord. In a series of 172 cadavers ranging from 60 to 80 years of age, Pandey and Shukla (2007) note the absence of the posterior cord in 6 cadav-

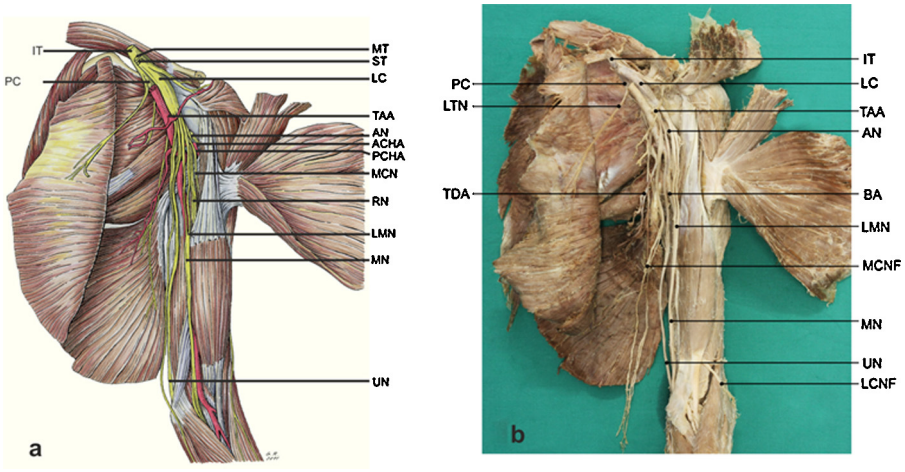

Fig. 4. Left arm of an 85-year-old female cadaver with the lateral cord giving off both roots of median nerve and ulnar nerve (case 5). (a) Diagram presenting an arm with roots of median nerve (MN) originating both from the lateral cord (LC). (b) Both roots of the median nerve (MN) covered the brachial artery (BA) and formed a loop of median nerve (LMN) in the proximal third of this artery. Since the ulnar nerve (UN) also derived from the lateral cord, it had to cross the brachial artery (BA) on its way to the cubital tunnel. AN = axillary nerve, ACHA = anterior circumflex humeral artery, IT = inferior trunk, LC = lateral cord, LCNF = lateral cutaneous nerve of forearm, LTN = long thoracic nerve, LMN = loop of median nerve, MCN = musculocutaneous nerve, MCNF = medial cutaneous nerve of forearm, MN = median nerve, MT = middle trunk, PC = posterior cord, PCHA = posterior circumflex humeral artery, RN = radial nerve, ST = superior trunk, TAA = thoracoacromial artery, TDA = thoracodorsal artery, UN = ulnar nerve.

ers (3.5%). The brachial plexus is very rarely formed by a single cord instead of three cords. This constellation was seen in 4 of 90 brachial plexuses (4.4%) dissected by Aggarwal et al. (2012).

4.3. Median nerve

The highest percentage of variation concerned the median nerve (Table 1). Within 167 arms this nerve was variant in 46 cases (28%). In 8 cases (4.8%), the loop of the median nerve had a hidden position in relation to the axillary artery (Fig. 6). In detail, the loop can be located behind the axillary or brachial artery, it can cover profunda brachii artery and seldom may be located on an ulnar or radial artery with high origin in the upper forelimb.

Miller (1939) noted variations in the relationship of the brachial plexus to the axillary artery, and to the brachial artery more distally in 8% of 480 dissections. Budhiraja et al. (2012) found an unusual low formation of the median nerve in front of the brachial artery in 18.4% of 174 upper limbs of formalin-preserved cadavers. Butz et al. (2014) reported a case which may explain the observation of a distally moved loop of the median nerve: in this case, the lateral cord of the brachial plexus passed through the coracobrachialis muscle prior to its bifurcation into the musculocutaneous nerve and the lateral root of the median nerve.

Uysal et al. (2003) examined variations in the brachial plexus of 200 human fetuses. The authors observed that roots of the median nerve joining in the distal part of the arm occurred in 8.5%. By contrast, Yang et al. (2009) found an aberrant arrangement of the axillary artery with the brachial plexus in 12 of 607 arms (2%) only. In any case, it must be kept in mind that positional variation of the axillary artery may increase the risk of incomplete axillary block and the incidence of brachial plexus injury after canulation (Yang et al., 2009). In addition, this condition may be connected with difficulties to repair acute traumatic injuries of the axillary artery and brachial plexus.

The cords of the brachial plexus forming the median nerve are a matter of variation too. In our present analysis, in one case the medial cord was absent (Fig. 1) and in another case the lateral cord was missing (Fig. 2). The lateral cord of the median nerve might also cross the axillary artery anteriorly and meet the medial cord in such a way that the median nerve lies medial to the axillary artery (Singhal et al., 2007). In the rare case of an adult cadaver, the median nerve was formed from the lateral cord only (Patil et al., 2012). Furthermore, a case where the median nerve was formed from a single root originating from the lateral cord while the medial cord was absent was reported (Aggarwal et al., 2010). In this case, the second part of axillary artery was found lying inferomedial to the cords of brachial plexus and further distally. Satyanarayana et al. (2009) reported a case where all three cords of brachial plexus were observed to be lateral to the axillary artery.

Double loops of the median nerve are a further significant variation (Fig. 6). Such a constellation was observed in 17 of 167 arms (10.2%). There are some reports in the literature that deal with a second loop of the median nerve: in a 45-year-old male cadaver, the medial root of the median nerve received a supplementary branch from the lateral cord of brachial plexus (Bala et al., 2014). Radunovic et al. (2013) observed a communicating branch of the musculocutaneous nerve to the median nerve which was given at the lower edge of the pectoralis major muscle. Furthermore, the musculocutaneous nerve might join to the median nerve at mid-humeral level (Mehta et al., 2009). Finally, Bhat et al. (2009) reported a case where the lateral root of the median nerve had two parts.

Last but not least, the course of the median nerve distal to the loop of median nerve can be variant. In a 85-year-old female, the median nerve changed its course from lateral to medial by crossing the brachial artery (Fig. 4). In our sample, the median nerve attended a position behind the brachial artery in 1.2% of the cases. The ultrasonic position of brachial plexus long nerves was studied in 69 healthy volunteers, consisting of 31 males and 38 females (Retzl et al., 2001). The median nerve was found in anterior medial position in 30% and in posterior medial position in 26%.

4.4. Musculocutaneous nerve

The next most frequent brachial plexus variation concerned the musculocutaneous nerve (Table 1). Ferner (1938) reported about variations of the musculocutaneous nerve which in quite a number were accompanied by a third head of the biceps brachii muscle (Ferner, 1938). In a total of 167 arms this nerve was variant in 13 cases (8%). Three most frequent conditions were observed: 1. the nerve did not perforate the coracobrachialis muscle (1.8%), 2. the nerve had a doubled origin (1.2%), and 3. the nerve gave back branches to the median nerve (1.8%). In Nepalese cadavers, a variation in course, branching pattern and termination of musculocutaneous nerve was observed in 6.25% (Bhattarai and

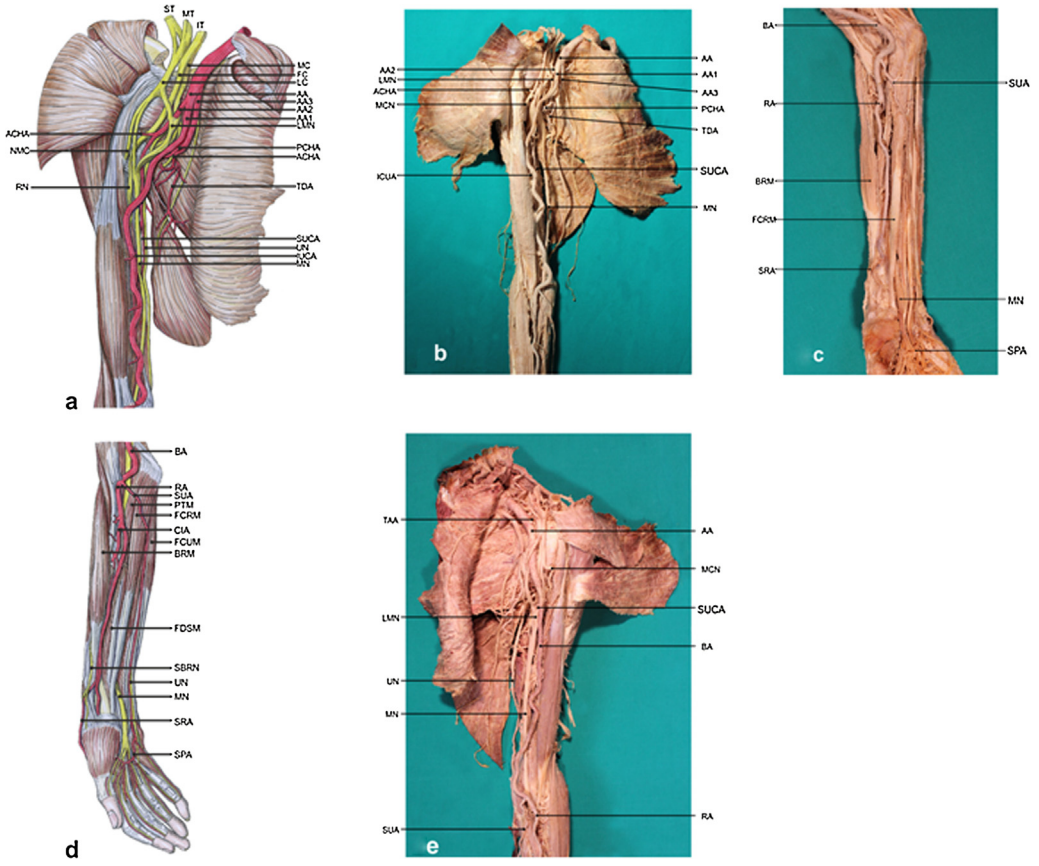

Fig. 5. Right (a–d) and left (e) arms of a 94-year-old female cadaver with variant locations of the loop of median nerve combined with variations of forearm arteries (case 6). (a) Diagram demonstrating an arm with a trifurcated axillary artery (AA, AA1–AA3). The second main branch (AA2) was covered by the loop of median nerve (LMN) and continued its course like a superior ulnar collateral artery (SUCA). (b) Loop of median nerve (LMN) covered the second main branch (AA2) of the axillary artery (AA). The first branch (AA1) continued the course of the axillary artery and became the brachial artery (BA) at the lower rim of the pectoralis major muscle. The second main branch (AA2) behaved like a superior ulnar collateral artery (SUCA) accompanying the ulnar nerve (UN). The third main branch (AA3) can be assigned as common trunk of axillary artery (AA) and gave off posterior circumflex humeral and circumflex scapular arteries. (c) Diagram of the right forearm showing that the brachial artery (BA) divided itself into a variant superficial ulnar artery (SUA) and a radial artery (RA). However, in the distal third of the forearm, the radial artery (RA) again divided into a thick branch similar to the normal radial artery and a thin branch, assigned as superficial radial artery (SRA), taking its course to the dorsal hand. (d) In the right forearm, the superficial ulnar artery (SUA) crossed the flexor digitorum superficialis muscle. The radial artery (RA) followed the brachioradialis muscle (BRM) and gave off the superficial radial artery (SRA) to the dorsal hand (e) In the left arm of this individual a trifurcation of the axillary artery (AA) was absent. However, as in the right side, a loop of the median nerve (LMN) covered the superior ulnar collateral artery (SUCA) which here took a quite normal origin from the brachial artery (BA). AA = axillary artery, AA1–AA3 = main branches 1–3 of the trifurcated axillary artery, ACHA = anterior circumflex humeral artery, AN = axillary nerve, BA = brachial artery, BRM = brachioradialis muscle, CIA = common interosseous artery, FCRM = flexor carpi radialis muscle, FCUM = flexor carpi ulnaris muscle, FDSM = flexor digitorum superficialis muscle, IT = inferior trunk, IUCA = inferior ulnar collateral artery, LC = lateral cord, LMN = loop of median nerve, MC = medial cord, MCN = musculocutaneous nerve, MN = median nerve, MT = middle trunk, PC = posterior cord, PCHA = posterior circumflex humeral artery, PTM = pronator teres muscle, RA = radial artery, RN = radial nerve, SBRN = superficial branch of radial nerve, SUCA = superior ulnar collateral artery, SPA superficial palmar arch, SRA = superficial radial artery, ST = superior trunk, SUA = superficial ulnar artery, TAA = thoracoacromial artery, TDA = thoracodorsal artery, UN = ulnar nerve.

Poudel, 2009). An interesting case, partly resembling the conditions of our third group, was reported by Öztürk et al. (2010). Here, the first branch of the musculocutaneous nerve ended in the coracobrachialis muscle and the second one continued as lateral cutaneous nerve of forearm. The third one also pierced the coracobrachialis muscle and then communicated with the median nerve.

It is rather common for the musculocutaneous nerve to be absent and the flexor muscles to be innervated by the median nerve (Aydin et al., 2006; Fregnani et al., 2008; Uzel et al., 2011; Kaur et al., 2014). It is also possible that branches from the lateral cord innervated the coracobrachialis muscle while the biceps brachii and brachialis muscles were supplied by the median nerve (Gümüsburun and Adigüzel, 2000).

4.5. Ulnar, axillary and radial nerves

Our sample contained less frequent variations of ulnar (1.2%) and axillary (1.2%) nerves. However, during the dissection of 42 cadavers a variation of the ulnar nerve which was directly originating from the posterior trunk was found (Goncalves et al., 2002). Moreover, within 100 brachial plexuses, one case with a variant axillary nerve which began as the continuance of the posterior branch of the upper trunk was reported (Matejcik, 2005). Very seldom variations concerned the radial nerve (0.6%). Finally, also variations of the posterior aspect of the brachial plexus are known. From this point of view, subscapular nerves were the most variant structure (Ballesteros and Ramirez, 2007).

5. Conclusions

Since the axillary artery is a landmark for anesthesia of the brachial plexus, variations of the cords of brachial plexus with concomitant arterial variations are of particular interest (Table 1). An important finding is the hidden loop of the median nerve which was identified behind the axillary or brachial artery, and has covered a common trunk of the axillary artery or profunda brachii artery and seldom may be located at a high origin of a superficial ulnar artery

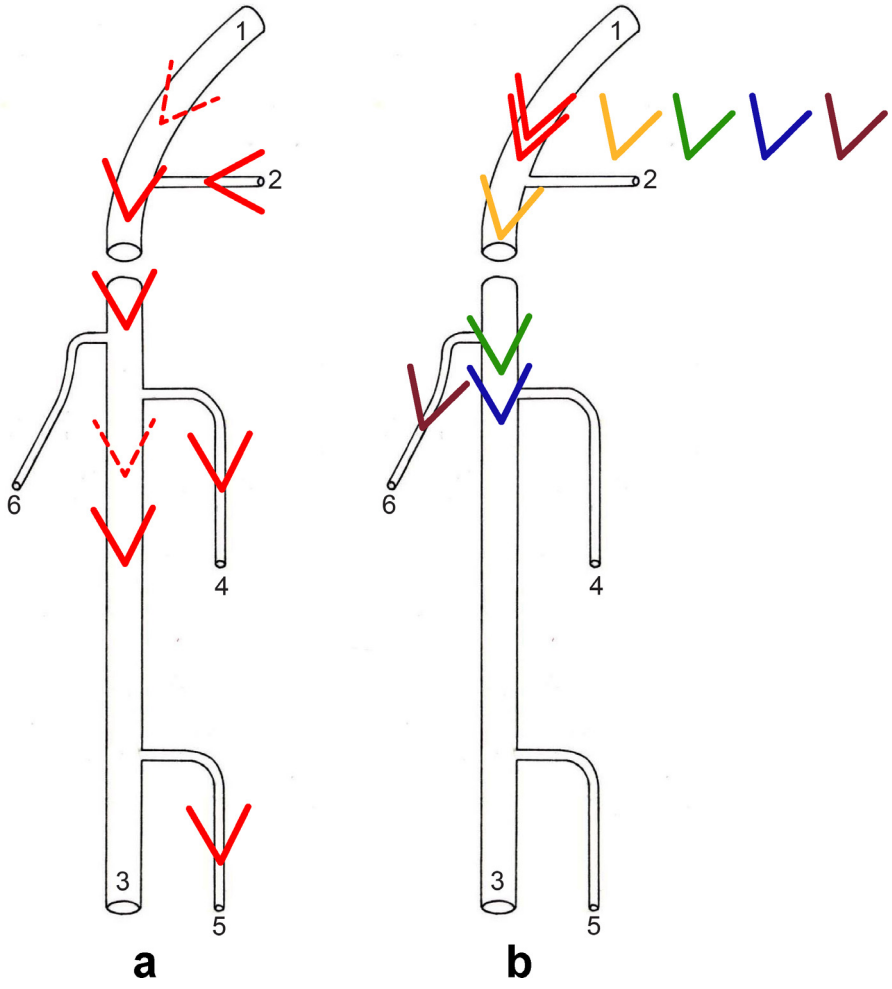

Fig. 6. Diagram showing the variant locations of the loop of the median nerve. (a) Variant locations of a single loop of the median nerve. Note that the loop of the median nerve can assume a hidden position (dotted line) behind the axillary or brachial artery. This arrangement may result in incomplete axillary block of brachial plexus. (b) Variant locations of a doubled loop of the median nerve. In most cases, the first loop of the median nerve was located at the normal place while the second one has moved distally. 1 = axillary artery, 2 = subscapular artery, 3 = brachial artery, 4 = profunda brachii artery, 5 = superior ulnar collateral artery, 6 = radial artery with high origin.

(Fig. 6). In previous works we have referred to both, to the common trunk of the axillary artery as well as to the superficial ulnar artery (Claassen et al., 2006, 2010). In only 0.6% of cases was the loop of median nerve missing. In surgical interventions involving the upper forelimb, attention should be paid to the chance of a doubled median loop and the possible interconnections between median and musculocutaneous nerves. A total axillary block of brachial plexus may also be hampered by a musculocutaneous nerve of deep origin or a missing musculocutaneous nerve. Variations in ulnar, axillary and radial nerves are infrequent and sometimes involve a reduced diameter of these nerves in comparison to normal.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.aanat.2016.07.007.

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