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SCIENTIFIC ARTICLE

Ultrasound anatomy of the brachial plexus nerves in the neurovascular bundle at the axilla in patients undergoing upper-extremity block anesthesia

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Abstract

Purpose Familiarity with the localization of the nerves in the neurovascular bundle that constitutes the axillary segment of the brachial plexus (BP) is important when applying ultrasound (US)-guided block anesthesia. Therefore in this study we aimed to delineate the anatomy of the median, radial, and ulnar nerves of the BP at the axilla with US and electrical stimulation.

Materials and methods The study included 60 patients who were scheduled to undergo upper-arm surgery with axillary block anesthesia. Prior to anesthesia, ulnar, radial, and median nerves were localized with US using a 12-h quadrant identification system that placed the axillary artery (AA) in the middle. The nerves were then functionally tested using a neurostimulator.

Results The radial nerve was mainly located in the 4–6 o'clock arc (posterior and posteromedial to AA) in 50 (83 %) of patients. Ulnar nerve was mainly at the 12–3 o'clock arc (anteromedial to AA) in 51 (85 %) of patients. Ulnar nerve showed a second peak at 9–10 o'clock quadrant (anterolateral to AA) in 11 % (7) of patients. Median nerve location was most common in the 12 and 9 o'clock arc (anterior and anterolateral to AA) in 53 (88 %) of the patients.

Conclusions Ultrasound is a useful tool for depicting BP anatomy in the axillary fossa prior to block anesthesia. Median, ulnar, and radial nerves form a highly consistent triangular pattern around the axillary artery that is easily recognizable with US.

Keywords Brachial plexus · Ultrasound · Electrical stimulation · Axilla block anesthesia

Introduction

The brachial plexus (BP) is a complex anatomical nerve network formed by the upper-extremity C5-T1 nerve roots in the axillary fossa and the supraclavicular region. The functional anatomy and the location of the nerves that constitute the BP and the nervous connections at the axillary region come to clinical attention especially when upper-extremity surgery and peripheral block anesthesia are concerned [1].

Most studies related to the anatomy of the BP in the axillary region are cadaveric dissection studies [2–6] or magnetic resonance (MR) examinations with a limited number of patients [7–9]. Such studies mainly provide anatomical information rather than dynamic and functional data [10]. The location of the nerves in cadaver studies may change during dissection and conservation of tissue [10, 11]. Although living subjects are studied in MR studies, a full range of motion cannot be effectively carried out due to confined space and sensitivity to motion [10].

Improvements in probe and software technology now allow us to study the fine ultrastructure of nerves by providing better resolution and high-quality images. US also has the advantage of being a mobile, safe, practical, dynamic, and a cost-effective imaging modality that is successful and accurate in delineating nerve pathology [12]. Recently, ultrasound has been utilized as a guide to perform effective

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axillary blocks [13–17]. Physicians performing the procedure need to be familiar with the ultrasound anatomy of the axillary portion of the brachial nerve plexus.

In this paper, our aim was to study the functional ultrasound anatomy of the ulnar, median and radial nerves of the BP that form the neurovascular bundle within the vascular sheath at the axilla using ultrasound and electric stimulation in patients who were scheduled to undergo upper-extremity surgery with axillary block anesthesia.

Materials and methods

This study was conducted on 60 elective patients who were scheduled to undergo upper-extremity surgery in the Orthopedics and Traumatology Department. Exclusion criteria were patients with ≥4 American Anesthesiology scores (ASA), who were less than 18 years and more than 90 years of age, who had a history of local anesthesic allergy or infection at the presumed injection site, and who were uncooperative. All the patients gave written informed consent for surgery, anesthesia, and ultrasound examinations before the procedure. The study protocol was approved by the Institutional Ethics Committee.

The imaging technique, patient position and probe placement were described in Fig. 1. All the studies were carried out with a portable ultrasound (General Electric-Vivid, Milwaukee, WI, USA) using a 5-cm, linear 8 to 13-MHz multifrequency probe, and US images were recorded. The probe was positioned so that the axillary artery (AA) was placed at the center of the image as a highly anechoic circular uncompressible structure. Short-axis images were obtained. The relative anatomy in relation to AA, including the nerves, the axillary vein (AV) were described accordingly (Fig. 2).

Function of each nerve constituting the brachial plexus around the axillary artery was identified using a 22-gauge, 5-cm, Teflon-coated neurostimulator needle (Neurostimulator, Plexygon; Vygon, UK). The neurostimulator was adjusted to 0.15-ms pulse duration, 1-mA current intensity, and 2-Hz frequency. The neurostimulator approached the nerve on the US image using the in-plane technique in which the needle entry and the route were parallel to the US probe while the axillary artery and the nerves were in phase. This method had the advantage of demonstrating the whole needle tract longitudinally as it approached the nerve while the nerves appeared as round, axial structures (Fig. 3). The neurostimulator was placed as close as possible to the nerve under US guidance but care was taken to avoid nerve puncture. If flexion appeared in the first three fingers of the

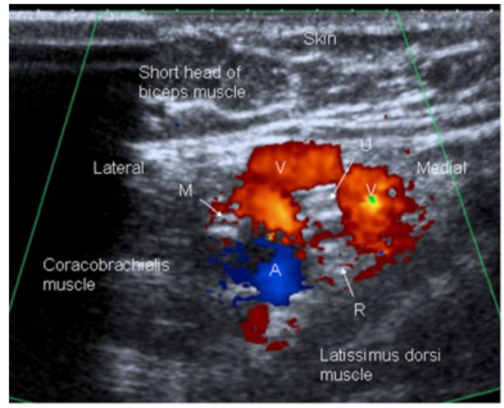

Fig. 2 On the short-axis images, the axillary artery (*AA*) [*A*] is placed at the center of the image (coded in *blue*) and appears as a highly anechoic, circular and uncompressible structure on grayscale US images. The axillary vein (*AV*) [*V*] is located medial and anterior to the AA and the deep branch of the AV is located posterior to the AA (veins are coded in *red*). The Doppler function is used to better delineate the anatomical structures and can be used to identify AA or AV when in doubt. Brachial plexus nerves (median [*M*] (10 o'clock), ulnar [*U*] (2 o'clock) and radial [*R*] (4 o'clock) are located around the AA as relatively hypo-hyperechoic, multifibered circular cord-like structures surrounded by a mild hyperechogenic epineurium. Nerves appear as round small structures

Fig. 1 All patients were placed in the supine position with the arms in 90° abduction and forearms in 90° flexion and supination at the elbow. After sterile preparation of the block anesthesia site, the skin was injected with 2 ml of prilocaine. Prior to the procedure, sterile sonic gel was applied to the axillary fossa. A probe was placed perpendicular to the skin in the axillary fossa at the intersection of the biceps brachii and pectoralis major muscles so that short-axis images could be obtained

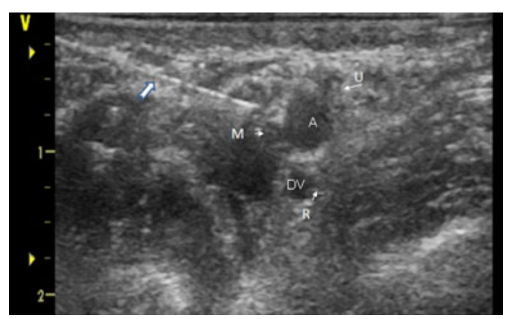

Fig. 3 Neurostimulator (*white arrow*) approaching the median nerve (*M*) (9 o'clock) on the short-axis transverse US image. The ulnar nerve (*U*) is located at 1 o'clock and the radial nerve at 6 o'clock medial to the deep axillary vein. The axillary artery is centrally located at the middle of the ulnar, median, and radial nerve. The axillary vein is compressed, which may occur during imaging with slight pressure but care is taken to avoid pressure-related changes in the localization of nerves, which may happen with moderate and severe pressure

hand, the nerve in question was labeled as the median nerve. If flexion occurred in the ring and small fingers, ulnar nerve was labeled. The same procedure was repeated for the radial nerve and extensor response in the hand and forearm after stimulation was sought.

The musculocutaneous nerve and intercostobrachial nerve were also located using ultrasound and the neurostimulator in the same manner, but because these two nerves were mostly located in the coracobrachialis muscle away from the vascular sheath and were not always detectable by US, their locations were not evaluated in the study and nerves within the vascular sheath that formed the neurovascular bundle were targeted.

Nerve localizations were coded using a 12-h quadrant technique. The image was divided into 12 quadrants similar to an hour quadrant and AA was placed in the center and each nerve was represented according to the hour segment it was located at. After identification of the nerves, axillary block using local anesthesia was carried out. Adequacy and success of the sensory and motor blocks were checked using the pinprick test and motor movements for each nerve.

Results

A total of 60 patients were included in the study (26 females and 34 males). The mean age of the patients was 41.06 (range, 18–89 years), the mean weight was 76.3 kg (range, 48–110 kg) and mean height was 171 cm (range, 155–185 cm). The mean arm circumference was 31.6 cm (range, 24–60 cm). The right arm was studied in 34 patients and the left arm in 26 patients.

Topographic anatomies of the nerves were recorded using the 12-h quadrant technique in relation to AA, which was placed in the center. Locations of the nerves in accordance to hour segments were displayed in Table 1. Graphic schematizations of the nerve locations according to hour quadrants were presented in Figure 11. Nerves showed a consistent localization in 81 % of (49) the patients (Fig. 4). All nerves were juxtaposed in a clockwise manner; as ulnar, radial, and then median nerve. Nerves were seen as separate structures in all cases. The presence of septa within the perivascular sheath was encountered in one patient and presence of accessory axillary artery was noted in another patient. In this patient, the location of the ulnar nerve shifted posteromedially and the median nerve shifted posterolaterally (Fig. 5). In all patients, complete and uncomplicated block was achieved.

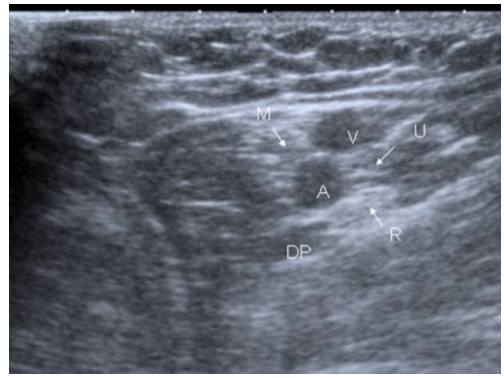

Fig. 4 The nerves are typically arranged around axillary artery (*A*) in a consistent “classical” anatomical pattern, which is depicted as the ulnar nerve (*U*) at 1-2 o’clock position, radial nerve (*R*) at 5-6 o’clock position, and median nerve at the 11-10 o’clock position. Axillary vein (*V*) and deep axillary vein (*DP*) can be seen here as well

The radial nerve was commonly located at the 4–7 o’clock arc (posterior, posteromedial, and posterolateral) in 95 % (57) of the patients. The radial nerve was most frequently located at the 6 o’clock position (posterior) in 51 % (31) of patients and 5 o’clock position (posteromedial) in 28 % (17) of patients. Typical location of radial nerve in between the 6–4 o’clock arc (posterior and posteromedial to AA) was observed in 50 (83 %) of the patients.

In 51 (%85) patients, the ulnar nerve was localized at the 12–3 o’clock arc (anteromedial) position with regards to axillary artery. A second common localization for the ulnar nerve was at the 9–10 o’clock position (anterolateral) in seven patients (11 %) (Fig. 8a, b, c). The ulnar nerve was most commonly located at 2 o’clock position in 51 % of the patients and the 3 o’clock position in 18 % of the patients.

In 58 of the patients (95 %), the median nerve was located at the 1–9 o’clock position (anterior, anteromedial, and anterolateral). The typical location for the median nerve, which was between 12 and 9 o’clock segments, was detected (anterolateral to AA) in 53 (88 %) of the patients. The median nerve was most commonly located at the 12 o’clock position (anterior) in 41 % of patients and at 11 o’clock (anteromedial) position in 26 % of the patients.

Table 1 Distribution of ulnar, median, and radial nerves according to 12-h quadrants

Nerve	1	2	3	4	5	6	7	8	9	10	11	12	Total
Ulnar	4	31	11	1	–	1	–	–	5	2	–	5	60
Median	5	–	1	–	–	–	1	–	8	4	16	25	60
Radial	–	–	1	2	17	31	7	–	2	–	–	–	60
Total	9	31	13	3	17	32	8	–	15	6	16	30	

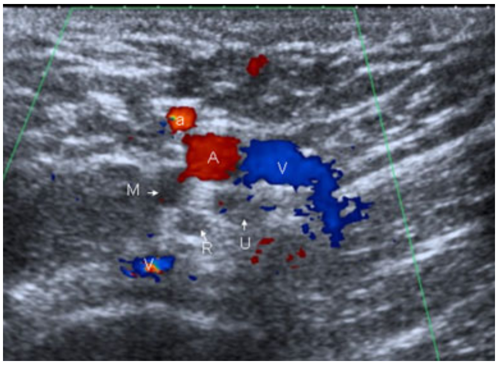

Fig. 5 An accessory axillary artery (**a**) is detected on color Doppler imaging lateral to the axillary artery (*A*) coded in *red*. The axillary vein (*V*) was medial to the artery coded in *blue*. Duplication of the axillary artery caused a posteromedial shift in the position of the ulnar (*U*) and posterolateral shift in the position of median (*M*) nerve. The artery lies anterior to the median nerve. This posterior variant displacement is encountered in 1–5 % of patients

Discussion

US-guided axillary blocks are gaining wide popularity because success rates are higher and complications are less when compared to conventional axillary block techniques [17]. US guidance helps better localization of the nerves, avoids hemorrhages related to AA or AV puncture, and prevents neural injury from direct intraneural injections. Also with US, how local anesthetic agent diffuses around nerves and the perivascular sheath can be tracked so that better control over anesthesia and local anesthetic dose can be achieved. There are prerequisites to achieve these goals such as familiarity with the accurate and dynamic US anatomy of the nerves and arteries of the axillary fossa and also dexterity regarding alignment of the needle and the US probe for safe and specific needle advancement.

Major motor and sensory nerves innervating the upper extremity are closely packed around the AA (neurovascular bundle) often in a consistent fashion at the axillary fossa. This particular segment is called the third portion of the AA. Anatomic and functional studies including the current study suggest the presence of a multicompartmental, variably incomplete, perivascular connective sheath (vascular sheath) surrounding the neurovascular bundle in an inconsistent fashion [7, 18, 19]. This favorable location and presence of a perivascular sheath allow the physicians to achieve complete upper-extremity block at a single location [14]. In all patients except one, total anesthesia of the ulnar, radial, and median nerves were achieved by a single intra-sheath injection and in that one patient local anesthetic appeared compartmentalized and block was incomplete until needle was used to puncture and inject through the septa within the sheath.

When imaging the third axillary part of the brachial plexus, short-axis images are most useful and the landmark structure is AA. Arterial variations are reported to occur in 8 % and venous anomalies in 21 % of the patients at the axilla [1, 2, 5]. AA coursing superficially to the median nerve [2, 10], division of median nerve or cord by branches of the artery, changes in the structure of plexus by aberrant artery or branch are some of the most significant variations [1, 2, 10]. Presence of an accessory axillary artery was noted in only one patient in our study, which caused posteromedial shift in the location of the ulnar nerve and posterolateral shift in the location of the median nerve (Fig. 5). The prevalence of this nerve arrangement pattern was observed in approximately 5 % of the patients in the study by Cristophe et al. [10].

The results of this study were mostly consistent with the results from other studies reported in the literature [3, 10, 11, 20–25]. The peripheral nerves that form the BP at the third portion of AA are located around the AA in a typical triangular terminal nerve position [10, 11, 20, 25], which is also described as the “classical anatomy” (ulnar at 1–2, radial at 5–6, and median at 11–10 o’clock) [10, 11, 25] (Fig. 4). Posterior cord of BP forms the radial nerve (C5–8), which runs behind the AA in a posterolateral or posteromedial fashion. Ulnar nerve which is formed by the medial cord (C8-T1) of the BP is located internally therefore anteromedial to AA. The Median nerve which has dual innervation both form the medial (C8-T1) and the lateral cords (C5–7) course anterolaterally or anteromedially to the AA [3, 10, 20, 24].

This triangular presentation (Fig. 4) was 78 % in the study by Patridge et al. [6], which included 18 cadavers

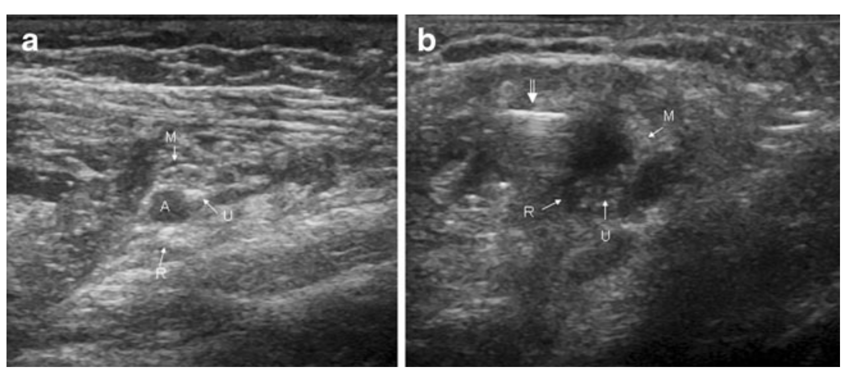

Fig. 6 a, b Variant anteromedial localizations of median nerve are also observed in this study, such as in Fig. 6a, where the median nerve (*M*) shifts to the 1 o’clock position and in Fig. 6b where it shifts to the 3 o’clock position. *A* axillary artery, *U* ulnar nerve, *R* radial nerve. At Fig. 6b, needle is shown with an arrow approaching the nerves

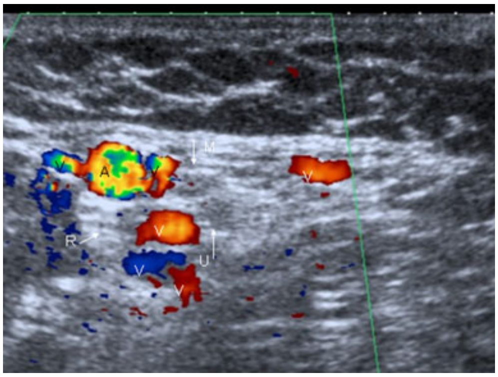

Fig. 7 Posterior shift of ulnar nerve (*U*) and median nerve (*M*). There are multiple axillary veins (*V*) and a single axillary artery (*A*). The ulnar nerve has shifted to 4 o'clock position and median nerve to 3 o'clock position somehow posteriorly. *R* radial nerve

and 65 % in the study by Cristophe et al., which included 153 patients [10]. This pattern was encountered in approximately 81 % of our patients. Radial artery position was somehow more posterior (6 o'clock) in our study than posteromedial (5 o'clock) as compared to Cristophe et al. [10] and Retzl et al. [11], more in accordance with Coceiçao et al. [25]. Median nerve was also more anterior (11–12 o'clock) than anteromedial (10 o'clock) as compared to Cristophe et al. [10], more consistent with the study of Retzl et al. [11] and Conceiçao et al. [25].

Variant anteromedial (six patients) and posterolateral localizations (one patient) of median nerve were also noted (Fig. 5 and Fig. 6a, b). The position of the median nerve was quite variable in other studies as well [10, 11, 25]. In the study by Retzl et al., in 56 % of patients, anteromedial (26 %), and anterolateral (30 %) positions for median nerve were described [11]. This was 55 and 28 %, respectively in the study by Conceiçao et al. [25]. Posterior localization of the median nerve was randomly seen, with 4 % in the study by Cristophe et al. [10], 14.4 % in the study by Retzl et al. [11], and only in 3 % in the current study (Figs. 5, 7, and 9c).

Anteromedial location of the ulnar nerve was detected in 59 % of patients in the study by Retzl et al. [11]. This was 85 % in our study, higher than reported by Retzl et al. [11] and the same as Cristophe et al. [10]. A variant anterolateral localization of ulnar nerve was also detected in 11 % (two in 10 o'clock and five in 9 o'clock position) of our patients, which had not been encountered this frequent before (Fig. 8a, b, c). The same position was described in the study by Retzl in 4.3 % [11]. This position was not reported for the ulnar nerve in the study by Cristophe et al. [10] and Conceiçao et al. [25]. Posterior medial shift of the ulnar nerve can also be depicted (Figs. 6b, 7).

Radial nerve positions were most constant in our study; in 95 % of the patients it was posterior, posteromedial, or posterolateral, and never shifted anterior to AA. Medial to posteromedial location was described for radial nerve in 65 % of patients in the study by Retzl et al. [11] and in 85 % of patients in the study by Cristophe et al. [10]. This was 80 % in our study and highest (93 %) in the study by Conceiçao et al. [25]. Anterior position of the radial nerve had been observed in other studies [10, 11] but never in ours, and in the study by Conceiçao et al. [25], but radial nerve has shifted to 9 and 3 o'clock positions in some of our patients (Fig. 9a, b, c).

Peripheral nerves have mild echogenic echostructure in accordance with their fascicular nature and appear as striated circular structures in short-axis images due to the hyperechogenic

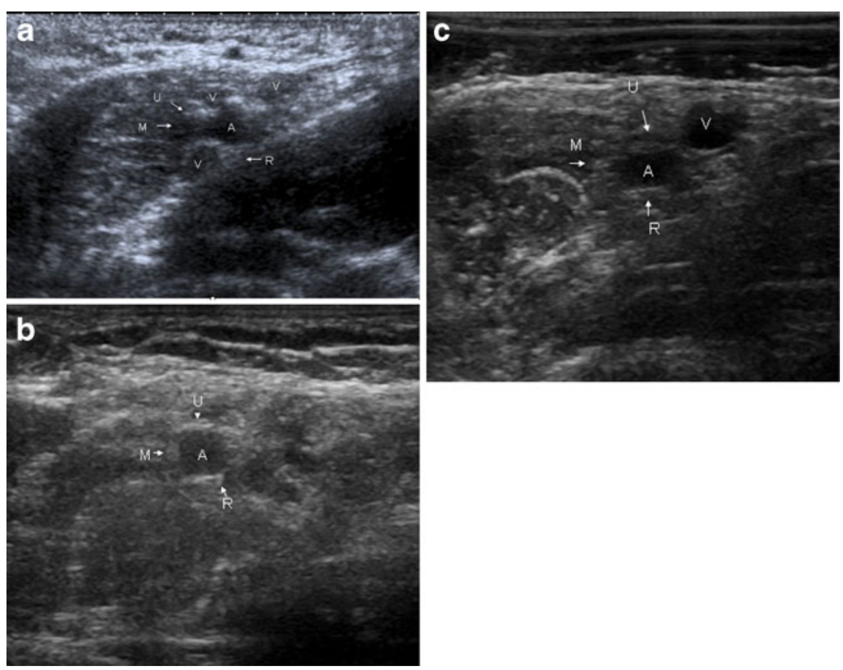

Fig. 8 **a**, **b**, **c** The ulnar nerve is commonly located at 12-3 o'clock arc (anteromedial) position. Seldomly, the ulnar nerve (*U*) may shift anteromedially to the 9 o'clock (Fig. 8a) and 10 o'clock (Fig. 8b) and 11-12 o'clock positions (Fig. 8c). *A* axillary artery, *M* median nerve, *R* radial nerve

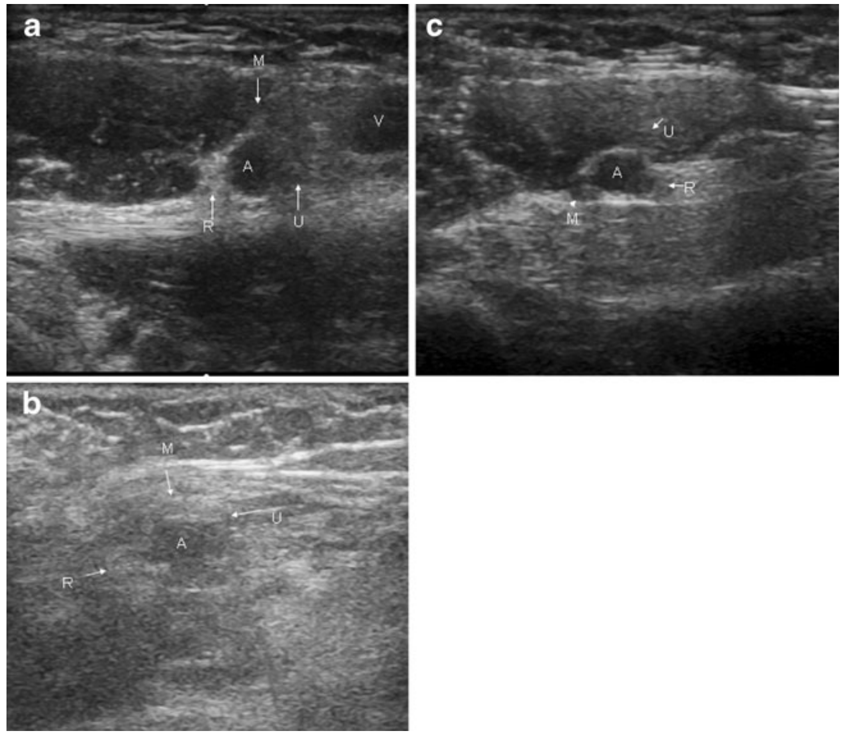

Fig. 9 **a**, **b**, **c** The radial nerve (R) remained somewhat posterior to AA at all times in the study, however, atypical 9 o'clock (Fig. 9a, b) and 3 o'clock positions (Fig. 9c) are observed. *A* axillary artery, *U* ulnar nerve, *M* median nerve

epineurium surrounding the hypoechogenic fascicules [11, 12, 20]. High-resolution imaging with high-frequency probes (7–14 MHz) is recommended for better depiction of nerve structures. Higher frequencies trade off depth to better axial resolution of superficial structures [12]. Common artifacts are "side lobe artifacts", which may cause a false appearance of the needle tip inside the AA [26] and anisotropy that may cause the nerve to appear hypoechoic due to oblique beam angles [20]. Peripheral nerves may resemble tendons in short-axis images but their echogenities and sizes differ [20]. Compression should be avoided during US imaging because the location of the nerves may change [10, 11] and air bubbles in the local anesthetic may cause reverberation artefacts. No such artefacts or false identification of another structure as a nerve occurred in our study but we observed that compression displaces the nerves significantly around the AA.

Approximately 53 % of variations are reported for the brachial plexus in cadaver studies [1, 4], but somehow in the axillary region, the common triple appearance of the BP nerves remain constant within a vascular sheath and they do not branch in the axilla. Radial nerve may give branches to the dorsal musculature of arm and forearm in the axilla, but this is clinically insignificant in terms of anesthesia [1]. The location and juxtaposition of the nerves are quite

Fig. 10 Ulnar nerve (*U*) is located far away from the axillary artery, beyond the median nerve (*M*). The radial nerve is at the 5 o'clock position. *Arrows* indicate the neurostimulator needle

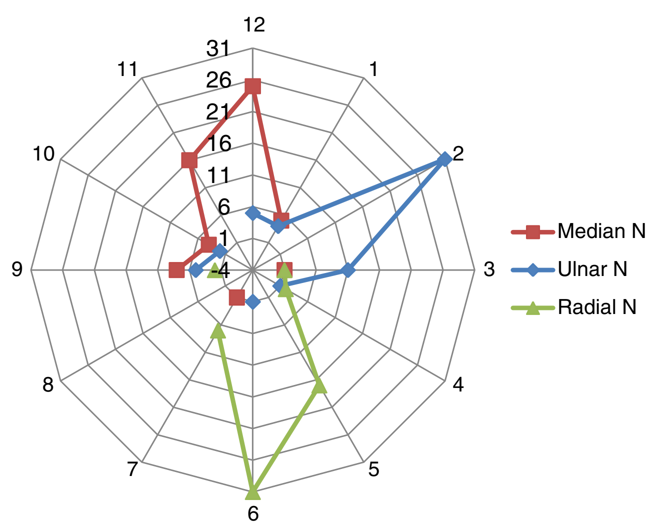

Fig. 11 Topographic localization of ulnar, median, and radial nerves around the axillary artery

predictable and often depicted as separate structures. Even when they are in close proximity, they move away from each other when local anesthetic agent is administered and appear as if floating. In case of a variant anatomy, nerves can also be identified solely with ultrasound if traced down the arm and imaged at distal landmark points (Fig. 10). Also, studies regard US as an accurate tool in depicting BP anatomy [27]. All of these findings in combination suggest that nerve specification using only US without a neurostimulator can be made at this specific axillary region if one is familiar with the BP anatomy (Fig. 11).

In conclusion, US is useful in depicting the locations of ulnar, radial, and median nerves around AA at the axillary fossa and the "common appearance" was observed in 81 % of patients.

Conflict of interests The authors declare no conflicts of interest.

References

1. Orebaugh SL, Williams BA. Brachial plexus anatomy: normal and variant. The Scientific World Journal. 2009;9:300–12.
2. Miller RA. Observations upon the arrangement of the axillary artery and brachial plexus. Am J Anat. 1939;64:143–63.
3. van Geffen GJ, Moayeri N, Bruhn J, Scheffer GJ, Chan VW, Groen GJ. Correlation between ultrasound imaging, cross-sectional anatomy and histology of the brachial plexus. Reg Anesth Pain Med. 2009;34:490–7.
4. Uysal LL, Seker M, Karabulut AK, Buyukmumcu M, Ziylan T. Brachial plexus variations in human fetuses. Neurosurgery. 2003;53:676–84.
5. Kutinyanawala MA, Stotter A, Windle R. Anatomical variants during axillary dissection. Br J Surg. 1998;85:393–4.
6. Partridge BL, Katz J, Benirschke K. Functional anatomy of the brachial plexus sheath: implications for anesthesia. Anesthesiology. 1987;66:743–7.
7. Klaastad O, Smedby O, Thompson GE, Tillung T, Hol PK, Rotnes JS, et al. Distribution of local anesthetic in axillary brachial plexus block: a clinical and magnetic resonance imaging study. Anesthesiology. 2002;96:1315–24.
8. Gerevini S, Mandelli C, Cadioli M, Scotti G. Diagnostic value and surgical implications of the magnetic resonance imaging in the management of adult patients with brachial plexus pathologies. Surg Radiol Anat. 2008;30:91–101.
9. Hergan K, Morrigl B, Kathrein A, Buchberger W, Judmaier W, Peer S, et al. MR and CT anatomy of the axilla. Acta Radiol. 1997;38:198–205.
10. Cristophe JL, Berthier F, Boillot A, Tatu L, Viennet A, Boichut N, et al. Assessment of topographic brachial plexus nerve variations at the axilla using ultrasonography. Br J Anaesth. 2009;103:606–12.
11. Retzl G, Kapral S, Greher M, Mauritz W. Ultrasonographic findings of the axillary part of the brachial plexus. Anesth Analg. 2001;92:1271–5.
12. Kermarrec E, Demondion X, Khalil C, Le Thuc V, Boutry N, Cotten A. Ultrasound and magnetic resonance imaging of the peripheral nerves: current techniques, promising directions and open issues. Semin Musculoskelet Radiol. 2010;14:463–72.
13. Chan VW, Peng PW, Kaszas Z, Middleton WJ, Muni R, Anastakis DG, et al. A comparative study of general anesthesia, intravenous regional anesthesia, and axillary block for outpatient hand surgery: clinical outcome and cost analysis. Anesth Analg. 2001;93:1181–4.
14. Liu FC, Liou JT, Tasi YF, Li AH, Day YY, Lui PW. Efficacy of ultrasound-guided axillary brachial plexus block: a comparative study with nerve stimulator-guided method. Chang Gung Med J. 2005;28:396–402.
15. Casati A, Danelli G, Baciarello M, Corradi M, Leone S, Di Cianni S, et al. A prospective, randomized comparison between ultrasound and nerve stimulation guidance for multiple injection axillary brachial plexus block. Anesthesiology. 2007;106:992–6.
16. Lo N, Brull R, Perlas A, Chan VW, McCartney CJ, Sacco R, et al. Evolution of ultrasound-guided axillary brachial plexus blockade: analysis of 662 blocks. Can J Anesth. 2008;55:408–13.
17. Abrahams MS, Aziz MF, Fu RF, Horn JL. Ultrasound guidance compared with electrical neurostimulation for peripheral nerve block: a systematic review and meta-analysis of randomized controlled trials. Br J Anaesth. 2009;102:408–17.
18. Cornish PB. "The sheath" vs "the axillary tunnel": a conflict of states and understanding. Reg Anesth Pain Med. 2009;34:297–80.
19. Thompson RE, Rorie DK. Functional anatomy of the brachial plexus sheaths. Anesthesiology. 1983;59:117–22.
20. Bargalló X, Carrera A, Sala-Blanch X, Santamaria G, Morro R, Llusa M, et al. Ultrasound-anatomic correlation of the peripheral nerves of the upper limb. Surg Radiol Anat. 2010;32:305–14.
21. Chan VW, Perlas A, McCartney CJ, Brull R, Xu D, Abbas S. Ultrasound guidance improves success rate of axillary brachial plexus block. Can J Anaesth. 2007;54:176–82.
22. Delaunay L, Jochum D. Anatomy of the brachial plexus. In: Chelly JE, editor. Peripheral nerve blocks: a color atlas. 2nd ed. Philadelphia: Lippincott Williams and Wilkins; 2004. pp 28–38.
23. Hadzic A, Vloka JD. Peripheral nerve blocks. McGraw-Hill, New York: Principles and Practice; 2004.
24. Martinoli C, Gandolfo N, Perez MM, Klauser A, Palmieri F, Padua L, et al. Brachial plexus and nerves about the shoulder. Semin Musculoskelet Radiol. 2010;14:523–46.
25. Conceiçao DB, Helayel PE, Carvalho FAE, Wollmeister J, Oliveira Filho GR. Ultrasound images of the brachial plexus in the axillary region. Rev Bras Anesthesiol. 2007;57:684–9.
26. Koyyalamudi V, Laduzenski S, Boezaart AP. Illusory intravascular needle placement an unusual ultrasound artefact. Reg Anesth Pain Med. 2010;35:319–20.
27. Yang WT, Chui PT, Metreweli C. Anatomy of the normal brachial plexus revealed by sonography and the role of sonographic guidance in anesthesia of the brachial plexus. AJR. 1998;171:1631–6.