

Assessment of topographic brachial plexus nerves variations at the axilla using ultrasonography

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Background. The aim of this study was to describe topographic variations in the arrangement of the four main brachial plexus nerves at the junction of the axilla and the upper part of the arm.

Methods. In 153 patients undergoing upper arm surgery using axillary block, we studied nerve arrangements with a three-step approach, combining: (A) cross-sectional ultrasound imaging using a 12 MHz linear ultrasound probe; (B) distal shift of the ultrasound scanhead from the axilla to the elbow joint following the paths of individual nerves; and (C) identifying the distal motor response to electrical nerve stimulation of each nerve. These results were then converted into a 12-section pie chart with the axillary artery (AA) as the axis.

Results. The order of the nerves around the AA was median, ulnar, radial, and musculocutaneous in all cases. The most frequent arrangement was observed in 65% of the patients. Five less frequent variations were observed in 4–20% of the patients, with four other variations seen in <2% of the patients. In 78% of the cases, the four nerves were seen separately using static ultrasound imaging. The musculocutaneous nerve was close to the artery in 18% of the patients.

Conclusions. Topographic variations of the four main nerves at the axilla were found to be numerous, the most frequent arrangement being seen in less than two-thirds of the patients. Four separate nerves were seen on static ultrasound imaging at this sectional level of the axilla in only 78% of the cases.

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The brachial plexus is a complex network of nerve roots (C5–T1) that coalesce into proximal trunks, then divide into cords and distal branches, from the neck to axilla. At the junction of the axilla and upper arm, peripheral nerves arise from the brachial plexus, to supply both the sensory and the motor innervation of the upper limb. Accurate description of the brachial plexus anatomy at this site may be of importance to optimize ultrasound-guided techniques of regional anaesthesia in upper limb surgery using the axillary approach.¹

Several anatomic variations in the arrangement of nerves at the axilla based on anatomic preparations have been described previously.^{2,3} The arrangements reported

may differ from those present in living people because nerve localization could be altered by conservation or dissection techniques. Both magnetic resonance imaging and computed tomography have allowed new insights into the anatomy of the brachial plexus, but these imaging techniques can only be used with the arm alongside the body and this is not the required position for axillary block.^{4,5}

A major advance in nerve anatomy description has been made with the development of high-resolution ultrasound-imaging techniques. Ultrasound imaging of the brachial plexus has been compared with either magnetic

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resonance imaging or anatomical sections with good correlations.^{6,7} Recently, Retzl and colleagues⁸ have described the position of three of the main brachial plexus nerves using ultrasonography. Although this study improved understanding of nerve arrangements, it was limited by the small number of patients studied and the use of an intermediate resolution ultrasound scanhead. Also, the methodology did not allow confirmation of the identity of the nerves detected by ultrasound imaging and so allowed possible errors due to the presence of tissue structures that may resemble the target nerve.⁹

Recent literature has shown that a combination of high precision ultrasound imaging and electrical nerve stimulation (NS) allows for very precise location of nerve structures.¹⁰ In this study, we aimed to describe topographic variations in the arrangement of nerves at the junction of the axilla and the upper part of the arm, using both ultrasound imaging and electrical NS.

Methods

This prospective observational study took place at a single University Hospital between December 2007 and May 2008. The study was conducted according to the French bioethics law (Art. L. 1121-1 of the law no. 2004-806, August 9, 2004) and approved by the regional ethics committee. All patients gave informed consent to participate in the study, and as the study was only observational and did not modify current medical strategy, authorization was given to waive written informed consent.

Patients undergoing upper limb surgery with axillary block for either anaesthesia or postoperative analgesia were included in the study. Exclusion criteria were refusal to participate in the study, contraindication to, or refusal of regional anaesthesia. Patients in whom two or more nerves could not be found using either ultrasound imaging or electrical NS were also excluded from the analysis. The patient was placed in a supine position, and after venous access and routine monitoring, alfentanil 250–500 µg was administered i.v. The arm was abducted to 90° and externally rotated, so that the dorsum of the hand lay on a table.

Ultrasound imaging was done using a high-resolution monofrequency 12 MHz 4 cm width linear ultrasound probe (Logiq-e, GE healthcare, Milwaukee, WI, USA). Ultrasound images were recorded to allow subsequent analysis. The ultrasound scanhead was placed perpendicular to the skin of the axilla, at the intersection of the pectoralis major muscle with the biceps brachii (Fig. 1). The probe was applied, with light pressure, just enough to collapse the main veins surrounding the axillary artery (AA), without changing anatomic structures (Fig. 2). The ultrasound beam was set perpendicular to the brachial plexus nerves and the AA, so that they appeared in short axis as round or oval structures on the ultrasound scan. The radial,



Fig 1 Typical picture showing level of analysis of the brachial plexus, at the junction of the axilla and upper part of the arm.

ulnar, median, and musculocutaneous nerves were then located in a three-step approach, consisting in:

- Step A: possible nerve structures were identified on the cross-section ultrasound image by the visualization of round, slightly hypoechoic structures with either punctuate internal patterns or characteristic internal hyper-echoic bands shaped like a bunch of grapes;¹¹
- Step B: the ultrasound probe was then moved slowly down from the axilla to the elbow joint following the possible path of a single nerve and then back to the axilla, as described by Retzl and colleagues;⁸
- Step C: finally, nerves were definitely identified and located at the same sectional level as Step A, using NS (Fig. 1). A 22 G, 50 mm insulated, short bevel needle (Stimuplex A50, B-Braun, Melsungen, Germany) was advanced in line with, and on the same plane as, the ultrasound beam. The needle was connected to a nerve stimulator (HNS 12, B-Braun) delivering a square current of 0.5–0.8 mA, 1 Hz frequency, 0.1 ms impulse width. A typical distal muscular response was elicited for each nerve.¹²

After locating each nerve, blockade was performed using in-plane technique by slowly injecting local anaesthetic solution (either mepivacaine 1% or ropivacaine 0.475%) around the nerve, according to the most recent

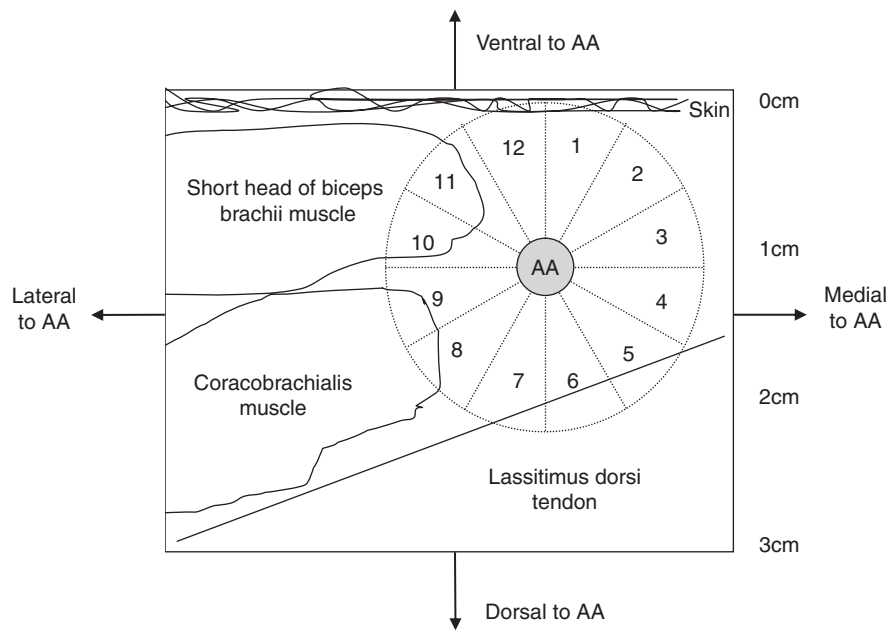


Fig 2 Schematic representation of a cross-section ultrasound scan at Step A of the procedure (see text for explanations). The nerve positions are shown as a 12-section pie chart radiating out from the central axis of the AA.

guidelines from the French Society of Anaesthesia and Intensive Care (available from <http://sfar.org/t/spip.php?article184>).¹³ Nerve blocks were performed in the same order: radial, ulnar, median, and musculocutaneous, using 7, 6, 7, and 6 ml of anaesthetic solution, respectively. Needle position was adjusted to provide circumferential spread of local anaesthetic around each nerve.

Analysis of the cross-section ultrasound image recorded at Step A allowed nerve positioning in relation to the AA using a technique modified from Retzl and colleagues.⁸ The nerve positions were recorded on a 12-section pie-chart (numbered from 1 to 12, starting at 12 o'clock) with the AA as the central axis. The section in which each nerve was located was plotted on the pie-chart on transparent film. The distance between the musculocutaneous nerve and the AA was then measured.

Statistical analysis

Data were analysed using Statview 5 software (SAS Institute Inc., Cary, NC, USA).

Results

We included 153 patients, with a median age of 44 (range 14–88) yr and BMI of 24.4 (SD 4.2) kg m⁻². Eleven patients had a BMI >30 kg m⁻². The sex ratio M/F (%) was 53/47, and 57% of the procedures were done on the right side. The radial, ulnar, median, and musculocutaneous nerves were correctly located using the three-step technique in all cases, except for the radial nerve in one

patient. No patient was excluded from the analysis. Nerves were located at a depth <3 cm under the skin in all patients.

The distribution of nerve positioning is shown in the 12 sections radiating from the AA on the pie-chart in Figure 3. In all cases, the four nerves were found in the same clockwise order (median, ulnar, radial, and musculocutaneous) around the AA. The most common position (89%) of the radial nerve was in sections 4–6, at the dorsal (posterior) and medial side of AA. The ulnar nerve was located in sections 2 and 3, medially to the AA in 85%. The median nerve was most often found (81%) in sections 11 and 12, located at the ventral (anterior) and lateral side of the AA. The musculocutaneous nerve was nearly equally distributed in sections 8 and 9 on the lateral side of the AA in 90%.

Ten different arrangements of the four nerves were observed: the most frequent organization, shown in Figure 4, was observed in 64.7% of the patients. Five less frequent nerve arrangements, observed in 4–13% of the cases are depicted in Figure 5A–E. Finally, other variations, shown in Figure 5F–I, were observed in <2% of the patients.

We observed in 31 cases (20%) that two or more nerves clearly different by their motor response to electrical NS could not be differentiated on ultrasound image. In these cases where nerves were in close relationship, during local anaesthetic injection, the two nerves could either be separated by local anaesthetic spread (26 cases) or not (five cases) (Table 1).

Mean distance between AA and musculocutaneous nerve was 1.03 (0.54) cm. The distance between AA and

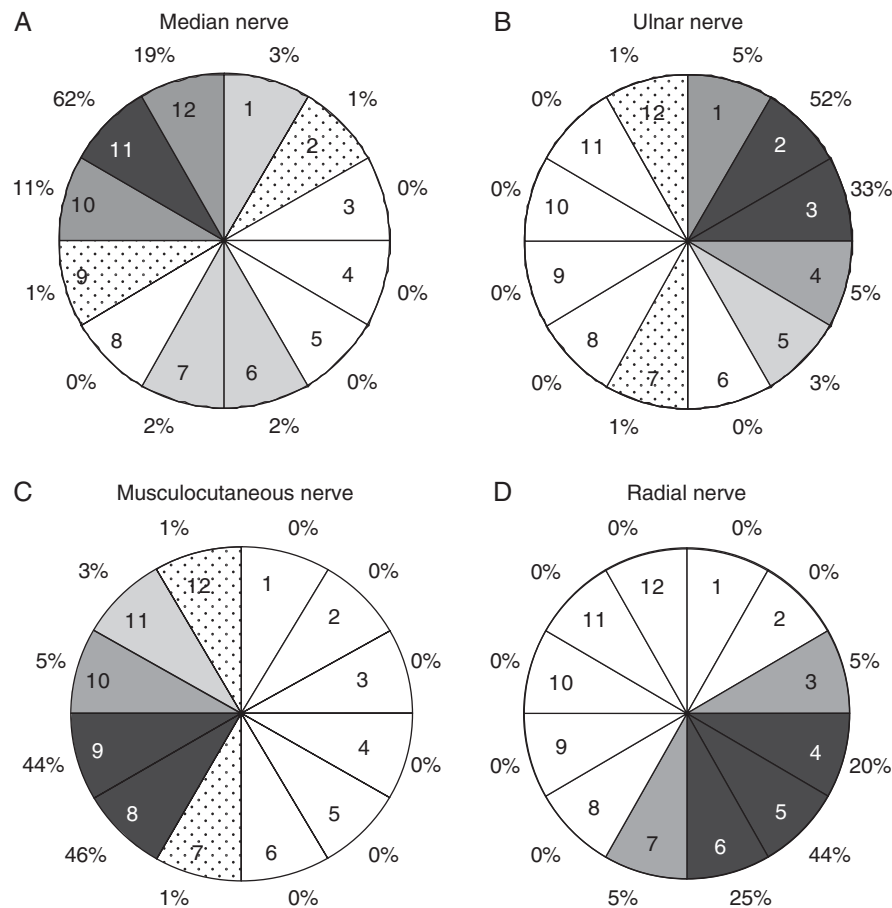


Fig 3 Section distribution (in %) of the median (A), ulnar (B), musculocutaneous (C), and radial (D) nerves at the junction of the axilla and upper arm. The cross-section ultrasound image was subdivided into 12 pie-chart sections (numbered from 1 to 12, starting at 12 o'clock) with the AA as the axis. The colour of each sector varies from white to grey, according to the percentage of distribution.

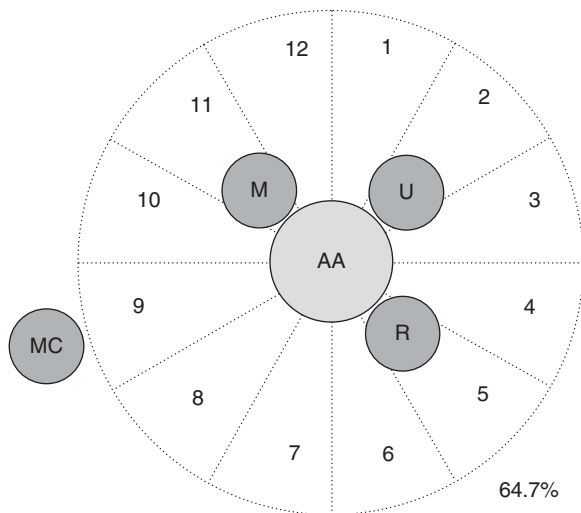


Fig 4 Schematic drawings of the most common arrangement of the four main brachial plexus nerves (R, radial nerve; U, ulnar nerve; M, median nerve; MC, musculocutaneous nerve) around the AA. Frequency of this topographic pattern is given in percentage.

musculocutaneous nerve was 0.5 cm or less in 18.2% of the cases.

An accessory AA, defined as a second artery, running parallel to the AA from the axilla to the elbow was observed in four of the seven patients with the nerve arrangement described in Figure 5D (2.6% of all cases).¹⁴

Discussion

In this study, we combined ultrasound imaging and motor response to electrical NS in 153 patients, to describe the most frequent topographic variations of the four main nerves issuing from the brachial plexus at the junction of the axilla and upper arm. Our results showed that the description corresponding to the most frequent configurations seen during cadaver dissections and described in anatomy textbooks was only observed in 65% of the cases. Partridge and colleagues² studied 36 dissections from 18 cadavers, and described a main configuration of nerve locations similar to our findings in 78% of the cases. The authors called this organization 'normal' anatomy, and

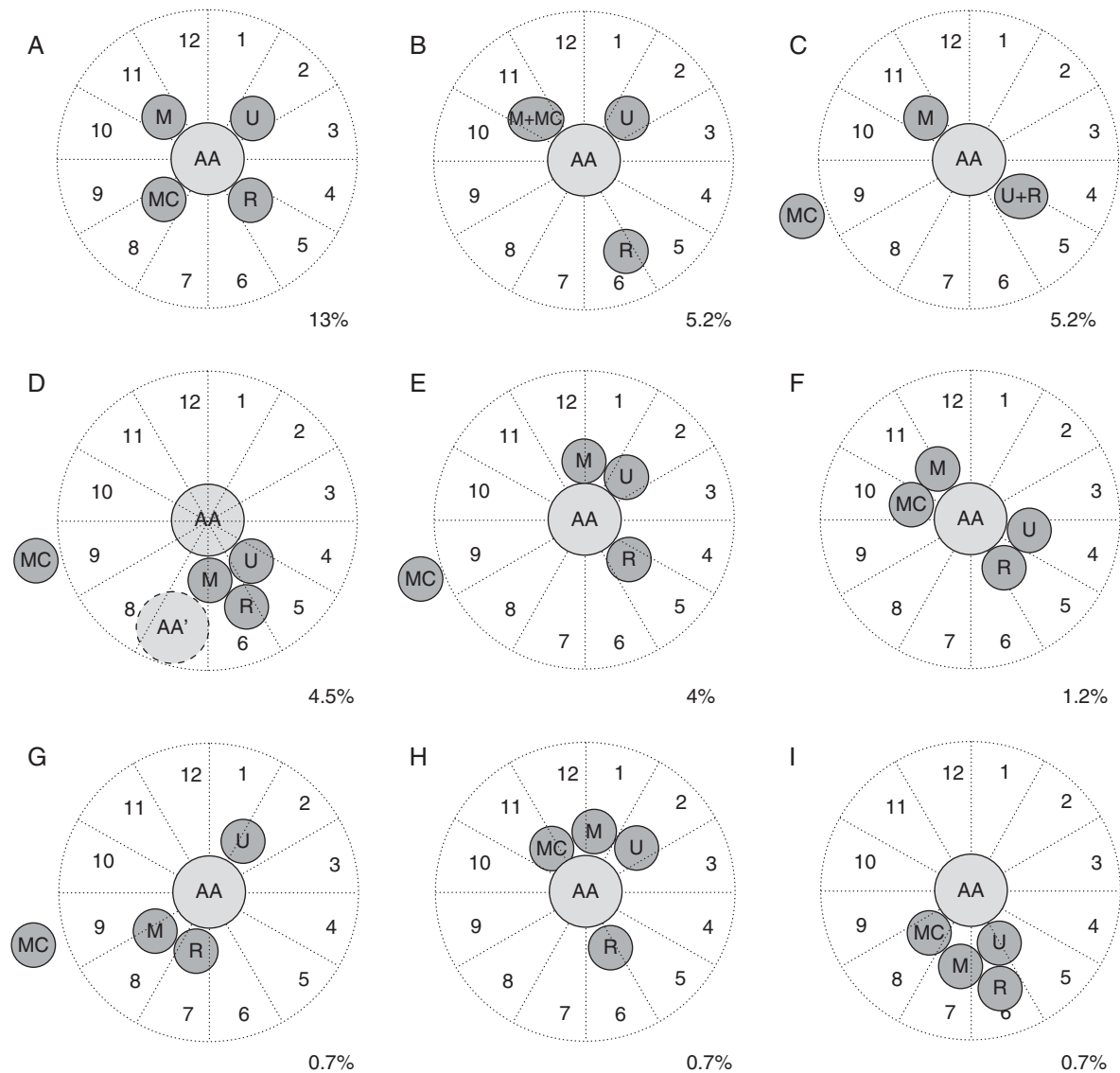


Fig 5 (A–I) Schematic drawings of less common arrangements of the four main brachial plexus nerves (R, radial nerve; U, ulnar nerve; M, median nerve; MC, musculocutaneous nerve) around the AA. An accessory AA, defined as a second artery running parallel to the AA, was observed in four of the seven patients with the nerves arrangement shown in Figure 5b. Frequency of each topographic variation is given in percentage.

Table 1 Characteristics of the 31 cases of nerve structures, seen in close relationship on ultrasound imaging and differentiated by their typical motor response to electrical NS and the effect of the local anaesthetic injection. Results are given as number (%) of cases on 153 studies

Nerves	Total	Effect of local anaesthetic injection	
		Separation of nerves	No separation
Median+musculocutaneous nerves	8 (5.2%)	4 (2.6%)	4 (2.6%)
Ulnar+radial nerves	8 (5.2%)	7 (4.5%)	1 (0.6%)
Median+ulnar nerves	6 (4%)	6 (4%)	0
Median+ulnar+radial nerves	7 (4.5%)	7 (4.5%)	0
Other patterns	5 (3.3%)	5 (3.3%)	0

also described three typical variations, observed in 22% of the cases. However, description from anatomic dissection may differ from *in vivo* studies, because of variations in preparation technique, changes in volume of vessels close to the nerve structures, or fat removal during dissection. Furthermore, the position of the arm in anatomic preparations may be different from that used during nerve block. The small number of cases studied in most dissection series precludes identification of infrequent topographic variations.

Our results were in accordance with those reported by Retzl and colleagues⁸ who have previously shown certain variations in nerve arrangement in the distal part of the axilla and upper arm in 69 healthy volunteers using ultrasound imaging. They reported a larger variation of

position of the median and radial nerves to the AA than we did. This may be related to nerves sliding one over each other when light to moderate pressure was applied with the probe on the skin. In order to reduce this phenomenon, we were careful to exert a pressure just sufficient to collapse the veins around the AA and the same investigator (F.B.) was present during all procedures to minimize the interindividual variability reported with ultrasound imaging. Retzl and colleagues⁸ used in 2001 an 8 MHz ultrasound probe, the resolution of which is significantly lower than that of modern 12 MHz probes. As a consequence, they could not locate the musculocutaneous nerve, whose variations are particularly frequent at this level. We found it valuable to confirm the identity of each nerve seen on ultrasound imaging by motor response to NS. This reduced the margin of error caused by structures seen on ultrasound imaging that may be difficult to distinguish from nerve structures, particularly when two or three nerves were very close from each other. The final nerve position was plotted from ultrasound images obtained at Step A, before NS and injection as local anaesthetic alters regional anatomy.

Precise data on these variations are important for anaesthesiologists as ultrasound-guided nerve blocks at this level have become more popular for upper arm surgery over the past few years. The different arrangements that we observed may correspond to either true anatomic variations such as those described by Choi and colleagues¹⁵ in anatomic preparation or more probably to topographic variations at the level of division of the cords into nerves at the distal part of the axilla. Whatever the mechanism in the nerve arrangement variations, the main clinical implication for anaesthesiologists who perform ultrasound imaging at this sectional level of the axilla is that they will see four separate nerves in 78% of the cases only. This implies that additional techniques, including distal nerve tracking, are valuable for correct identification of the single nerves and safe performance of the block.

In this study, we confirm that all nerves were located at this sectional level at <3 cm under the skin in all patients, even in the 11 patients with a BMI >30 kg m⁻². It should be noted that, despite the frequent variations, the four nerves were always found in the same clockwise order (median, ulnar, radial, and musculocutaneous) around the AA.

We found a distance between the musculocutaneous nerve and the AA <0.5 cm in more than 18% of the patients. This may explain in part why the musculocutaneous nerve has been shown to be anaesthetized simultaneously with the other nerves, even when it was not specifically identified. We also found in eight cases (5.2%) that it was not possible to differentiate the musculocutaneous and the median nerves on ultrasound image. Local anaesthetic injection did not separate the nerve structure in half of the cases suggesting either a true anastomosis or a non-divided cord at the study level. This is in accordance

with the results of Choi and colleagues¹⁵ who found this variation in 3–5%.

We found 11 different nerve arrangements in our series of 153 patients, but we acknowledge that the number of patients included did not allow for all possible topographic nerve variations.

In conclusion, this study described different topographic variations of the four main nerves issuing from the brachial plexus at the junction of the axilla and the upper part of the arm. The most frequent arrangement is observed in less than two-thirds of the patients, and four separate nerves will be seen on static ultrasound imaging at this sectional level of the axilla in only 78% of the patients. The knowledge of these variations emphasizes the value of additional technique, including distal ultrasound tracking for precise localization of nerves at the axilla.

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