Ultrasound-guided axillary brachial plexus block.
Part 1 — basic sonoanatomy

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Abstract

Axillary brachial plexus block is one of the most popular and widely used approaches for brachial plexus blocks. Its main advantages are its versatility and high safety. Brachial block facilitates analgesia for the distal arm, elbow, forearm and hand. Numerous upper limb procedures, particularly orthopedic ones, can be carried out under axillary block. Axillary block is well suited for the ultrasound-guided technique. Because the brachial plexus in the axillary region is located superficially, the nerves, block needle, and local anesthetic spread are all relatively easy to visualize. A high-frequency linear probe can be used during block procedure, so the quality and resolution of the ultrasound images are excellent. An important feature of the axillary approach is its high level of safety. In the axillary area, there are no anatomical structures other than vessels, to which damage during block placement could pose a risk for the patient. For this reason, axillary block is one of the techniques that are recommended for learning ultrasound-guided regional anesthesia. This paper summarizes anatomical fundamentals and provides basic sonoanatomic knowledge that is essential for successful ultrasound-guided axillary block.

Key words: regional anesthesia, peripheral nerve block, brachial plexus; regional anesthesia, peripheral nerve block, axillary block; ultrasound, sonoanatomy

Axillary brachial plexus block was first described by Hirschela in 1911 [3]. This technique, which was modified by Pitkin in 1920, differs from the currently used approach. It involves needle puncture from the axillary side and deep insertion to the level of the first rib, with the subsequent administration of a local anesthetic agent, similar to a supraclavicular block. Using this technique results in the upper blockade of the brachial plexus. In 1921, Reding described anesthesia of the terminal branches of the brachial plexus in the lower part of axilla, which is currently performed [4]. Parasthesia appearance was a confirmation of the appropriate placement of needle in relation to nerve structures. Until the
end of the 1950s, parasthesia was the most frequently used way of localization during brachial plexus block. In 1958, Burnham proposed using a novel, perivascular technique of axillary brachial plexus block. This approach was based on the administration of anesthetics in two sites within the neurovascular bundle: above and below the axillary artery. In this technique, the primary way to assess location of brachial plexus was via pulsation of axillary artery. The sign confirming the appropriate placement of needle’s end was a “click” that accompanied the puncture of the fascial layer and indicated that needle had been inserted in the brachial plexus covering; parasthesia appearance was not needed [5]. In 1961, De Jong highlighted the significance of the volume of local anesthetic for its ability to effective block using perivascular technique. Based on post-mortem examinations, he concluded that the brachial plexus covering consists of a closed sac with a diameter of 2–3 cm in adults and approximately 1 cm in children. De Jong noted that local anesthetics injected into the neurovascular bundle evenly spread along the nerves, in both the proximal and distal directions, and that the sac prevents its leakage. Additionally, he assumed that effective brachial plexus block requires moving the anesthetic agent of approximately 3 cm proximally and approximately 3 cm distally from the injection site, e.g., liquor fulfillment of cylinder with a diameter of 3 cm and a height of 6 cm. Doing so will give a volume of 42 cm³ (cubic-centimeter), which, according to the above-mentioned concept, constitutes the optimal volume of an anesthetic agent to obtain an efficient brachial plexus block in adults [6]. Alon Winnie supported the idea of a “volumetric” brachial plexus block. This method was a relatively simple way to achieve effective anesthesia by using a single anesthetic injection and popular [4, 6].

The introduction of a electrical nerve stimulation technique into clinical practice in the mid-1980s gave new possibilities for localizing nerve structures and enabled the precise identification of particular nerves; additionally, it opened the way to using both multistimulation and multi-injection techniques. Compared with the traditional technique, this approach enables the significant reduction of anesthetic volume and better efficacy of achieved plexus block [7, 8].

In 1994, Dupre described the approach that was widely known thereafter under the English name midhumeral and is based on the blocking of single, more distal branches of the brachial plexus instead of those branches that exist within the proximal 1/3 of the brachial length [9].

The introduction of ultrasonography to practical regional anesthesia opened new possibilities for the blockade of the brachial plexus. This method enabled clinicians to perform anesthesia under direct visual inspection, which subsequently improves the control of block, increases its efficacy and patient comfort and makes anesthetic dose reduction possible [10–12].

ANATOMY OF THE BRACHIAL PLEXUS

The brachial plexus is formed by the spinal nerves from C5 to T1. It can be divided into the supraclavicular part, which is placed within the lateral cervical triangle, and the subclavian part, which is located within the axilla. Spinal nerves, which form the roots of the brachial plexus, leave the spinal canal and run along the slits of scalene muscles of the neck. Two superior and two inferior roots merge to form three trunks (superior: junction of C5-C6, middle: extension of C7, inferior: junction of C8-T1). The trunks of the brachial plexus run between the scalene muscle in lateral-inferior direction, toward middle part of clavicle. In the distal part of the scalene muscle slit near the first rib, the brachial plexus is approached by the subclavian artery. The brachial plexus goes into the axilla between the first rib and the clavicle. At this level, each of the trunks splits into two divisions (anterior and posterior) (zone of brachial plexus’ splitting), which, distal to the clavicle, re-group to become the cords of the brachial plexus. The posterior cord is formed from the three posterior divisions of the trunks, the lateral cord is formed from the anterior divisions of the superior and middle trunks, and the medial cord is simply a continuation of the anterior division of the inferior trunk. Within the splitting zone and directly under clavicle, the brachial plexus lies lateral to the subclavian artery, and further along the course, the cords run around the artery and are finally placed on three sides of the axillary artery. The names reflect their location in relation to artery at the level of axillary apex, with the limb adducted to the trunk. With the patient lying supine with an abducted limb, the medial cord is placed below an artery, the lateral cord above an artery and the lateral cord to the back and below an artery. In the distal part of the axilla, the brachial plexus cords split in terminal branches to become nerves: musculocutaneous, median, radial, ulnar, median cutaneous nerve of the arm and medial cutaneous nerve of the forearm [13–15].

SONOANATOMY OF THE BRACHIAL PLEXUS

In the axillary region, the brachial plexus is located superficially, even in obese patients. In the majority of patients, the nerves run at a depth of 1-3 cm. The linear transducer is optimal for plexus visualization. Useful frequencies range from 10–13 MHz. Use of the automatic mode of ultrasound image optimization is recommended for nerve block (presets). In some patients, particularly those with well-developed muscles, use of musculoskeletal preset could improve the quality of imaging. In the majority of patients, adjusting the visualization depth to 3 cm is sufficient. The focus level should be set at the depth reflecting axillary artery loca-
tion. Using the visualization option in crossed ultrasounds increases image readability and can decrease the noise level. It is worth checking the quality of the image with the option of harmonic imagination, which commonly enables further improvements to image readability [16].

To visualize the brachial plexus on the level of the axilla, the arm should be abducted to a 90-degree angle. The transducer should be placed on the medial surface of the arm in the axilla perpendicular to the long axis of the arm. Scanning is conducted by moving the transducer from the axillary apex to mid-arm depth, along the course of the axillary artery. To optimize the image obtained during scanning, the transducer should be bent alternately in the distal and proximal directions (“tilt”). Frequently, even small changes in the transducer bending angle in relation to the skin could improve the visibility of nerves structures by limiting anisotropy effect.

The brachial plexus nerves within the axilla remain in relatively stable spatial relationship with the other anatomical structures, especially the axillary artery and particular muscle groups. For this reason, the crucial thing to finding nerves is determining the anatomical structure of the axilla: vessels, muscles and bones (Fig. 1). The anatomical variability of nerve location is relatively small and highly predictable.

The basic anatomic point of reference for localization of the brachial plexus in the axilla is the axillary artery. This is an anechoic (dark), circular, pulsating structure. Its visualization is very easy and does not cause problems, even for beginners. After finding an artery, the transducer should be established in that way, to have the vessel in the middle of the screen. The obtained image is turned 90 degrees in relation to actual location of the anatomical structures. The elements placed on the screen to the left or right of the artery are placed above or below it, respectively. From a practical point of view, using the same convention of setting up the transducer is very useful. The convention used by the authors assumes the application of the transducer to the arm with the tag directed up. According to this, the left side of the screen always reflects the upper part of the arm, and the right side of the screen shows the lower part of arm, regardless of which limb is scanned. The image obtained on the screen is always turned approximately 90 degrees in relation to the actual location of the anatomical structures. This convention is used in the following sections during description of ultrasound images as well as on figures.

The axillary artery is usually accompanied by more than one axillary vein, most commonly two. The veins are most frequently localized below and superficial in relation to the artery (e.g., on the screen to the right and slightly superior to the artery). Distinguishing the arteries and veins is very easy. Contrary to the arterial image, which is characterized by an even, circular shape, veins have very thin walls and therefore take different forms and are easily compressible. Entire interruption of blood flow in the veins is possible, even with small increases in the transducer pressure on the skin. The application of color Doppler imaging to distinguish arteries from axillary veins based on blood flow direction is usually dispensable.

In the lower part of the screen, there is a hyperecho-genic, oval outline of the humerus with an acoustic shadow below bone surface. In patients with well-developed muscles, it may be necessary to increase the imaging depth to visualize the humerus.

The neurovascular bundle goes into the space with a triangular shape. Two sides of the triangle are determined by nearby muscle groups, and the third is subcutaneous tissue. Superficially (at the top of the screen), there is usually a thin layer of fat tissue, with subcutaneous fascia underneath. From the top (on the left side of the screen), the neurovascular bundle is limited by the bellies of the biceps (more superficially), and lying more deeply is the smaller coracobrachialis muscle. From the bottom (below and to the
right from the artery), the neurovascular bundle is limited by the common trailer of the latissimus dorsi muscle and teres major muscle (more proximally) or medial and long heads of triceps of arm (more distally).

Particularly readable ultrasonography images could be obtained with the transducer put on the skin close to axilla apex. In this setting, both above and below the artery, there is the trailer of the latissimus dorsi muscle, which makes an evident, arched line with a protrusion directed upward. The hyperechogenic fascia of that muscle is a border of neurovascular bundle, and below it, there are no other nerve structures (Figure 1). After moving the transducer approximately 2–3 cm in a distal direction, the trailer of the latissimus dorsi muscle disappears from the field of view, and the bellies of triceps appear. On this level, the inferior border of the neurovascular bundle is already not as clear as it is on the level of the latissimus dorsi muscle trailer (Fig. 2).

Use of ultrasonography during brachial plexus block allows the direct visualization of the nerves of the brachial plexus. The four main brachial plexus nerves that are easiest to image are: median, musculocutaneous, ulnar and radial (Figure 3). The axillary artery is still the prime point of reference. When describing the locations of particular nerves in relation to that artery, it is more convenient to present them in correspondence to hour positions on the clock.

The lack of nerve compressibility is a factor that helps localize them in the tissues. Vessels, muscles or connective tissue have some elasticity, and they are subject to yield and flatten after increasing pressure. In contrast, peripheral nerves are “hard” incompressible structures; therefore, after pressing them with a transducer, only yielding of the surrounding tissues is visible, and the nerves do not show susceptibility to squeezing. As a result, peripheral nerves are visible on the screen as “rigid” areas that do not yield and frequently protrude into the surrounding structures. This is especially well visible in places where a nerve adjoins a vessel, particularly a vein. With transducer pressure, the clamping of vessel is visible, with protrusion of the nerve into the vein lumen or shifting a nerve on the artery perimeter. Another feature of nerves is their specific behavior during

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**Figure 2.** Schematic diagram and ultrasound image of the proximal part of the arm

**Figure 3.** Typical location of the brachial plexus nerves in relation to the axillary artery
needle insertion. If the blocked nerve does not lie in a narrow fascial space between muscles bellies, during contact with needle, especially one that is inserted contiguously to its perimeter, there is a visible characteristic “rotation” and “rolling” of the nerve pushed by the needle [14, 15].

**MEDIAN NERVE**

The median nerve (C5-T1) is formed from two parts: lateral and medial cords, which merge on the anterior surface of the brachial artery. The characteristic feature of the median nerve is its contiguity with the artery (axillary and subsequently brachial) during the whole course along the arm. The nerve is a circular/oval hypoechogenic structure, divided by one or more hyperechogenic septum. The nerve fits tightly to the artery and is usually located at 10:00–12:00 (Fig. 3). Squeezing the tissue with the transducer often shows shifting of nerve along the artery perimeter. Scanning the course of the artery along the arm, there is a visible accompanying median nerve. It runs lateral to the brachial artery, together with the vessel up to olecranon fossa. Above the elbow, the nerve crosses an artery and goes on its medial surface. If there are any problems with imaging of the median nerve on the level of the axilla, the brachial artery should be visualized in the distal part of the arm, and the median nerve should be identified and subsequently followed through its course retrograde to the level of the planned block.

**MEDIAL CUTANEOUS NERVE OF THE FOREARM**

The medial cutaneous nerve of the forearm departs from the medial cord, goes along the neurovascular bundle, into the middle of the arm, pops the fascia and splits into terminal branches. It supplies sensory nerves to the skin of anterior and medial part of the forearm and to the distal part of the arm [13]. It is located in the immediate vicinity of the median nerve, very close to artery (12:00 on the clock). The median nerve is relatively small, so its imaging is not always possible.

**MUSCULOCUTANEOUS NERVE**

Musculocutaneous nerve (C5, C6) departs from lateral cord of brachial plexus, most frequently on a high level within the axilla, and then runs in fascial spaces between two parts of the coracobrachialis muscle or between biceps of arm and coracobrachialis muscle. On the level of the axilla apex, it usually runs apart from neurovascular bundle. To image the musculocutaneous nerve, the transducer should be put over the biceps belly, which is also used to visualize an artery in the lateral-bottom part of the screen. The nerve is located approximately one to three cm from artery (to the left from artery on the screen) and it is visible as a hyperechogenic structure within fascial space dividing muscle bellies. The cross-section of the nerve changes along its course and starts with an oval (on the level departure from neurovascular bundle), becomes fusiform (in intramuscular part), and results in a triangular shape at the output from coracobrachialis muscle. There is a huge variability in the musculocutaneous nerve location.

The most common variant differing from the typical course of musculocutaneous nerve is a low point of departure from the lateral cord of the brachial plexus. In this case, on the level of the axilla apex, the musculocutaneous nerve is not present between the biceps of the arm and the coracobrachialis muscle, but it instead accompanies the median nerve. Most frequently, both nerves diverge after local anesthetic agent administration, but in several cases, the musculocutaneous nerve makes a common trunk with the median nerve. The variant with a low departure of musculocutaneous nerve is fairly common, occurring in up to 30% of patients [17–19]. Musculocutaneous nerve lying in typical place (within coracobrachialis muscle) is clearly visible on ultrasound image, and its identification is not difficult. If imaging of the musculocutaneous nerve in typical place, i.e., within arm flexors, is impossible, the anatomical variability of its location should be considered, first considering its common course with the median nerve. In this case, scanning of the median nerve in the distal direction can occasionally allow for the visualization and demerging of a seemingly single nerve trunk that lies next to the axillary artery into two branches: nerve trunk running together with brachial artery (median nerve) and nerve trunk galling between arm flexors (musculocutaneous nerve). A lack of possibility for imaging the place of nerve division suggests a common trunk of the median nerve and the musculocutaneous nerve. In this case, stimulation of the nerves could confirm the course of the musculocutaneous nerve fibers within the trunk of the median nerve. Inserting the end of a needle very close to the nerve and changing its location slightly could allow a motor response typical for the median nerve and musculocutaneous nerve to be obtained. Anecdotal descriptions are also available about a distinct location of the musculocutaneous nerve, e.g., just below skin fascia or laterally and above to neurovascular bundle [20]. Distal to the coracobrachialis muscle, the musculocutaneous nerve falls between the biceps and brachialis muscles. The lateral cutaneous nerve of the forearm, which is a terminal branch of the musculocutaneous nerve, emerges under the skin, directly above the elbow, lateral to the median vein, on the surface of the brachioradialis muscle. The musculocutaneous nerve is supplied by the lateral cutaneous nerve of the forearm the sensory fibers to lateral surface of forearm and wrist, up to the radial styloid process. Additionally, the musculocutaneous nerve supplies motor fibers to the anterior group of the arm muscles, which is responsible for the flexion and rotation of the forearm (biceps of arm, coracobrachialis muscle, brachialis muscle) [13].
ULNAR NERVE

The ulnar nerve (C8-T1) is formed from the anterior part of the medial cord and initially runs medially and superficially in relations to brachial artery. In the area of the axilla apex, the ulnar nerve usually lies at 1:00–3:00 in relation to the axillary artery. In case of the position corresponding to 1:00, it is located immediately next to the artery, generally in the immediate vicinity of the median nerve and medial cutaneous nerve of the forearm. In this case, it is sufficient to administer the anesthetic agent in one site to blockade all three nerves. If the ulnar nerve is in the position corresponding to 3:00, it is usually located some distance from the artery, and the axillary vein is superficial to the ulnar nerve, which concomitantly separates the ulnar nerve from the median and medial cutaneous nerves of the forearm. In this case, increasing the transducer pressure causes the ulnar nerve to protrude into the vein lumen. Further along the course of the arm, the ulnar nerve grows apart from the artery. Its characteristic feature is a superficial, undersurface course along the arm, superficial to the long head of the triceps. The nerve is heading to the ulnar nerve sulcus and lies on the posterior surface of the medial epicondyle of humerus.

RADIAL NERVE

The radial nerve (C5-T1) is formed from the posterior cord. In the axilla, it runs medially and posterior to the brachial artery, falling in its immediate vicinity. In relation to the artery, it is usually located between 4:00 and 6:00. Direct imaging of the radial nerve is not easy, and some difficulties in its visualization or precise determination of nerves location can be observed in up to 40% of patients [21]. This is mainly a result of its immediate vicinity to the vessel. Directly under the axillary artery, there is a hyperechogenic artefact, i.e., enhancement of the fluid area. This brighter field could mimic the radial nerve and an overlapping nerve placed in this site, which could impede the identification of nerve. Relation of the radial nerve to fascial spaces could help in...
its identification. In the proximal part of the axilla, the radial nerve falls on the anterior surface of the common trailer of the tendon of the latissimus dorsi muscle and teres major muscle. This tendon is approximately 30 mm wide and forms a clearly visible, hyperechogenic, oval line with a protrusion directed upward [22]. The radial nerve is located superficially in relation to this space, below or slightly distal to a vessel (to the right on the screen), and this segment seems to be optimal for radial nerve blocking. Distal to this tendon, the radial nerve departs from neurovascular bundle and goes deeper to the humerus between the long head and medial head of the triceps (Fig. 6). The radial nerve is placed in the fascial surface and divides the heads of the triceps running to the posterior surface of humerus. The radial nerve is accompanied by the profound brachial artery. Within this band of connective tissue, the radial nerve is difficult to image, which could result from its skewed course within this part in relation to the ultrasound beam, contrary to the rest of the brachial plexus nerves, running parallel to the skin surface. For this reason, the anisotropy effect contributes to its poor visibility. In contrast, the profound brachial artery coming together with the radial nerve makes it easy to identify as a hypoechogenic, pulsating structure. In case of any doubts, the location of the artery could be confirmed using the color Doppler mode. Considering the difficulties in the direct visualization of the radial nerve, using of nerves stimulators to confirm its location could be justified. During its further course, the radial nerve twines around humerus in the bone sulcus of corresponding name (radial nerve sulcus). In the distal one third of the arm, the radial nerve pops the lateral intermuscular septum and falls between the brachialis muscle and the brachoradialis muscle.

**MEDIAL CUTANEOUS NERVE OF THE ARM**

The medial cutaneous nerve of the arm departs from the medial cord, merges with the intercostobrachial nerve, pops the axillary fascia and splits into branches that are supplied with sensory fibers of the skin of the axilla and medial surface of the arm. On the level of the axilla, the medial cutaneous nerve of the forearm is difficult to image and usually accompanies median nerve and is blocked together with it [13].

**SUMMARY**

Technically, ultrasound-guided axillary brachial plexus block is not a difficult procedure. Nevertheless, without detailed knowledge of the anatomy of the brachial plexus and the most common anatomical variants, the use of ultrasoundography does not always facilitate efficient anesthesia. Thorough knowledge of anatomy increases the chances of avoiding failure of the block, even in cases with an impossible visualization of all nerve structures.

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