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ANATOMIC BASES OF MEDICAL, RADIOLOGICAL AND SURGICAL TEACHING ANATOMY

Anatomical basis for ultrasound-guided regional anaesthesia at the junction of the axilla and the upper arm

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Abstract

Purpose Ultrasound (US) has emerged in the field of regional anaesthesia in the past few years, as it allows physicians to simultaneously see the needle, the targeted nerves, and the vessels to avoid. Nevertheless, anatomical knowledge is essential for identifying all of the structures seen on the US screen. US also allows an in vivo approach to the variations of nerves and vessels. The aim of this study was to describe the anatomical structures of the axilla through a dissection, an anatomical section and US images performed during daily regional anaesthesia. This work will also discuss the usefulness of US in studying anatomical variations of vasculonervous structures.

Methods The axillary region of an embalmed adult cadaver was dissected in the department of Anatomy, and anatomical sections of another embalmed and frozen cadaver were also performed. During the same period, fortuitous anatomical variations discovered during daily routine axillary US-guided nerve blocks were recorded in the department of Anaesthesiology.

Results The anatomical dissection and sections allowed correlations to be made and structures to be identified on the US images. The most frequent anatomical variations found were double axillary artery, numerous axillary veins, variant location of the musculocutaneous nerve and posterior location of the brachial plexus in relation to the axillary artery.

Conclusion Anatomical knowledge is of major importance for US-guided regional anaesthesia. US scan offers a new approach to anatomical variations of the vasculonervous bundle at the junction of the axilla and the upper arm.

Keywords Anatomy · Axilla · Ultrasound · Variations · Regional anaesthesia · Brachial plexus

Introduction

Based on the anatomical relationship between the brachial plexus nerves and the axillary artery (AA), regional anaesthesia at the junction between the axilla and the upper arm is a standard technique for upper limb surgery. This axillary block has many advantages such as reduced intraoperative time, reduced opioid consumption, and significantly fewer severe adverse events, especially cardiac arrest and seizure [1]. It is possible to accurately identify each nerve using electrical stimulation through an insulated needle, as it elicits a specific motor response. Multistimulation provides high success rates as soon as the four main nerves are separately anesthetized [15]. However, nerve stimulation remains a blind technique based on superficial landmarks, which can lead to increased time consumption, or failure in the event of anatomical variations [13].

Ultrasound (US) guidance is a new way of practising regional anaesthesia as it allows the anaesthetist to simultaneously see the needle, the targeted nerves, and the vessels. US can either be used alone or in combination with electrical stimulation in a process known as "dual guidance". Anatomical knowledge is essential for identifying all of the structures seen on the US screen, from the skin to the

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deepest muscles including the vasculonervous structures in between. However, descriptions remain rare. Bradley and O'Donnell [3] described anatomy on US imaging of the axilla, but their atlas focuses mainly on musculoskeletal structures. US description of the nerves is more detailed in the atlas of Tsui et al. [17] but this description is compared to magnetic resonance imaging technique without any discussion of anatomical variations. Indeed, US also allows an in vivo approach to the variations of nerves and vessels, which may differ in number and location.

The aim of this study is to describe the anatomical structures seen on US images during a brachial plexus block at the junction of the axilla and the upper arm. Anatomy will firstly be explored using the dissection of an embalmed cadaver, and secondly using the anatomical sections of an embalmed and frozen cadaver. This will enable a correlation to be made between the anatomical sections and the US images of regional anaesthesia. A second objective of this article is to highlight the usefulness of this technique in studying the anatomical variations in the vasculonervous components of the axilla.

Materials and methods

This study was conducted during the same period in both the department of Anatomy and the department of Anaesthesiology. In the department of Anatomy, the material was obtained from the anatomical dissection of an embalmed adult human cadaver and anatomical section of a second embalmed and frozen human cadaver. The left arm was placed in a position commonly used for regional anaesthesia: abducted to 90°, the elbow in complete extension and the forearm in supination. The dissection was conducted in such a way as to highlight both the axilla fossa walls and the vasculonervous structures. At each stage, anatomical structures were photographed and the digital pictures recorded on hard disk. The anatomical sections were made every centimetre along the same plane as the US beam, i.e. parallel to the lateral wall of the thorax, from the elbow to the axilla. Anatomical structures could then be followed and identified on each section.

In the department of Anaesthesiology, regional anaesthesia was performed for the purposes of upper extremity surgery or post-operative pain control, under both US and electrical nerve stimulation guidance and in accordance with French guidelines [6]. Briefly, a linear, 12 MHz, 4-cm wide US probe (Logiq-e, GE healthcare, Milwaukee, WI, USA) was applied perpendicular to the skin, in the axilla at the intersection of the *biceps brachii* and *pectoralis major*. The US probe was then slowly moved downwards from the axilla to the elbow joint, to follow the possible path of each vasculonervous structure. The block was performed with a 22-gauge, 50-mm insulated needle inserted along the same plane as the US beam. For each nerve, a nerve stimulator elicited typical distal muscular responses [4]. When an anatomical variation was discovered, an US scan image of the axilla was recorded on hard disk and constituted the study material.

Results

Axillary dissection

Before incision, superficial landmarks allowed four regions to be identified at the junction between the trunk and the upper arm. The pectoral region corresponded to the *pectoralis major,* and was separated from the deltoid region by the deltopectoral triangle and the axilla. The anterior brachial region comprised the *biceps brachii* and *brachialis* (Fig. 1).

Below the skin, the anterior wall of the axilla was formed by the *pectoralis major* and its fascia. Just below, the *pectoralis minor* and *subclavius* were enclosed by the clavipectoral fascia. The medial wall consisted of the first five ribs, covered by the insertions of the *serratus anterior*. The posterior wall was formed by the *subscapularis* and the *latissimus dorsi* and *teres major.* The lateral wall was quite narrow and formed by the *coracobrachialis* and the short head of the *biceps brachii*. The *biceps brachii* and the *brachialis* formed the boundary of the anterior part of the medial bicipital groove. Finally, the floor of the axilla was formed by fascia skin spanning the distance between the inferior margins of the four walls (Fig. 2).

The AA originated from the subclavian artery at the level of the first rib and crossed the axilla to the lower margin of the *teres major* muscle, where it became the brachial

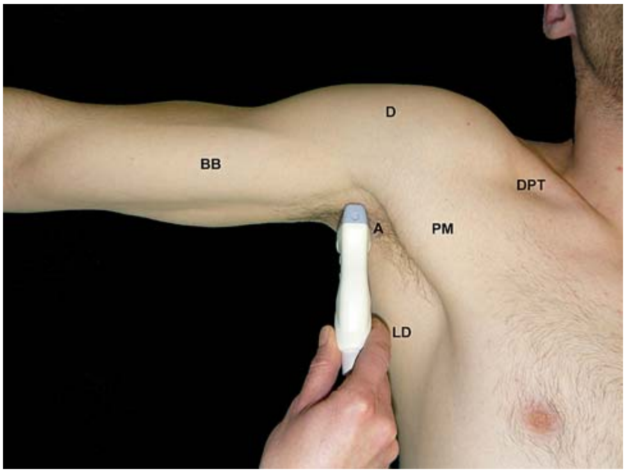

Fig. 1 Anatomical view of the axilla, superficial landmarks: PM, *pectoralis major*; D, *deltoid*; DPT, delto pectoral triangle; BB, *biceps brachii*; A, axilla; LD *latissimus dorsi*

Fig. 2 Dissection of the axilla: 1, *deltoid*; 2, *pectoralis major (sectioned)*; 3, *pectoralis minor*; 4, *serratus anterior*; 5, *latissimus dorsi*; 6, short head of the *biceps brachii*; 7, *coracobrachialis*

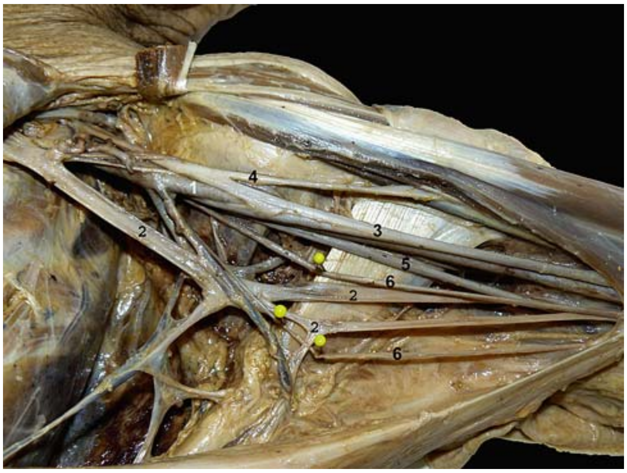

Fig. 3 Dissection of the vasculonervous elements in the axilla: 1, axillary artery; 2, axillary vein (reclined position); 3, median nerve; 4, musculocutaneous nerve; 5, ulnar nerve; 6, medial antibrachial cutaneous nerve and medial brachial cutaneous nerve (reclined position)

artery. This in turn branched into the deep artery of the arm just below the *teres major*. The axillary vein was a continuation of the brachial vein and began at the lower margin of the *teres major*. It ran along the medial side of the AA and terminated at the lateral margin of the first rib, where it became the subclavian vein. The axillary vein tributaries included the basilic and the cephalic veins.

The brachial plexus cords divided into five terminal branches behind the *pectoralis minor*. The lateral cord then divided into the lateral root of the median nerve (MN) and the musculocutaneous nerve (MCN) at the lower border of the *teres major*. The posterior cord branched into the axillary nerve at the lower border of the *subscapularis* and the radial nerve (RN), which continued along the inferior and posterior surfaces of the AA in front of the tendons of the *latissimus dorsi* and *teres major*. The medial cord branched into the medial root of the MN, and the ulnar nerve (UN) ran along the medial and anterior surfaces of the AA. The medial antibrachial cutaneous and the medial brachial cutaneous nerves rose from the medial cord, and ran down the ulnar side of the arm, medial to the brachial artery. The MN rose from its two roots embracing the lower part of the AA. The MCN pierced the *coracobrachialis* and passed obliquely between the *biceps brachii* and the *brachialis.* The RN travelled from the medial to the lateral side of the humerus in a groove within the deep artery of the arm. The UN laid medial to both the AA and the brachial artery. The axillary nerve passed downwards to the lower border of the *subscapularis* and then wound backwards (Fig. 3).

Correlation between anatomical sections and US images

The degree to which US waves reflect off a structure and return to the probe determines the signal intensity on an arbitrary grey scale. Structures like bones (humerus) that strongly reflect US appear whiter or hyperechoic. In contrast, hypoechoic structures (blood in vessels) weakly reflect US and appear darker. In transverse scans, the nerves appear as multiple round or oval hypoechoic areas encircled by a relatively hyperechoic horizon. These hyperechoic structures are the fascicles of the nerves and the hypoechoic background represents the connective tissue between neuronal structures. Furthermore, nerves reflect US in an anisotropic manner; essentially, the visibility of the nerves depends on the angle of the US relative to the long axis of the nerve.

Correlations between anatomical sections and US images were made and the most frequent layouts are illustrated in Figs. 4, 5 and 6a. All the vasculonervous elements were found anterior to the *teres major* tendon. The AA shared a central position. There were two veins and the four main nerves around the AA.

Anatomical variations of the vasculonervous components of the axilla

We chose to highlight the most relevant patterns of the variations recorded during daily US-guided regional anaesthesia. Double AA was found several times during the 5-month study. The artery identity was confirmed by pulsation, resistance to probe compression, and pulse wave and colour flow Doppler imaging techniques. The two equal arteries did not differ in size from a standard single artery. The variant artery ran laterally and the regular one continued medially. The brachial plexus was located between the two arteries (Fig. 6b). The deep artery of the arm originated from the variant artery, and travelled with the radial nerve in the radial groove of the humerus.

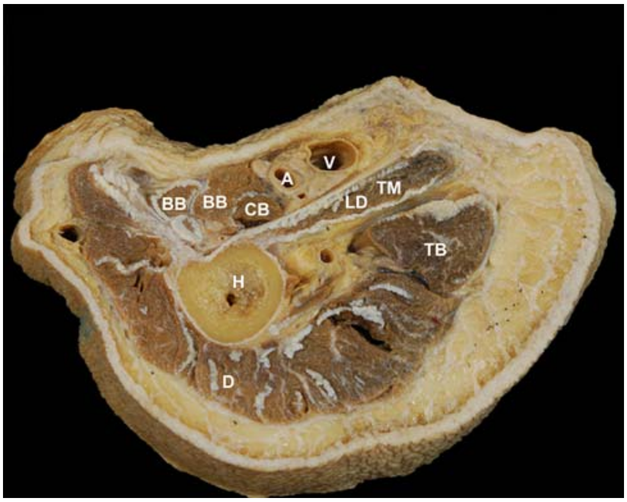

Fig. 4 Anatomical section of the junction between the axilla and the upper arm: D, *deltoid*; TB, *triceps brachii*; LD TM, *latissimus dorsi* and *teres major*; CB, coracobrachialis; BB, *biceps brachii*; A, axillary artery; V, axillary vein

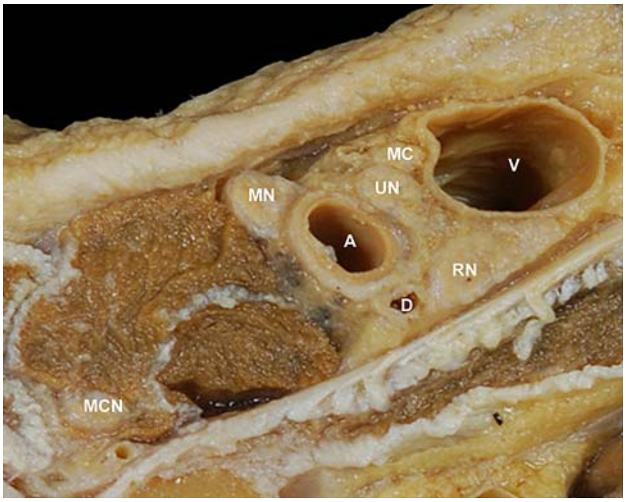

Fig. 5 Anatomical section of the junction between the axilla and the upper arm (details): A, axillary artery; D, deep artery of the arm; V, axillary vein; MN, median nerve; UN, ulnar nerve; MC, medial antibrachial cutaneous nerve; MCN, musculocutaneous nerve; RN radial nerve

Veins have been found to be different in number (from only one to seven), size and location in relationship to the AA or the UN, and the medial brachial and antibrachial cutaneous nerves. The venous identity was confirmed using compressed pattern and colour flow Doppler imaging (Fig. 6d).

In some cases, a single structure was seen anterior and lateral to the artery. This structure was considered to be a fusion of the MCN and the MN as electrical nerve stimulation elicited motor responses of both these nerves. The size of the structure appeared to be the sum of the size of each

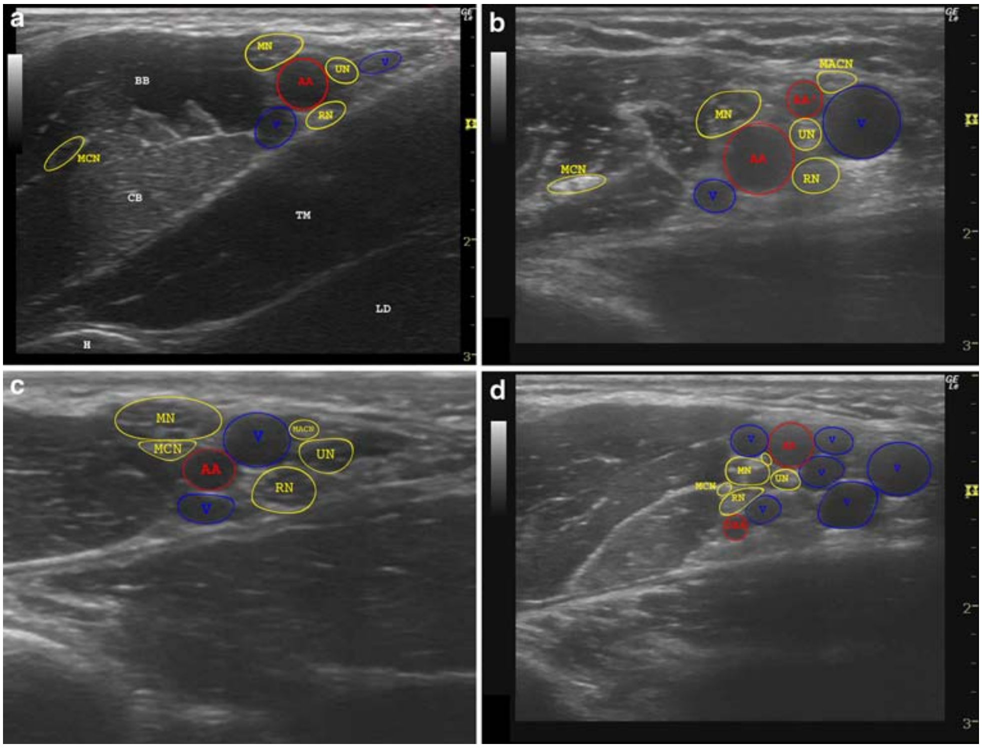

Fig. 6 **a–d** US scan picture at the junction between the axilla and the upper arm: H, humerus; LD, *latissimus dorsi*; TM, *teres major*; CB, *coracobrachialis*; BB, *biceps brachii*; AA, axillary artery; AA', variant axillary artery; DAA, deep artery of the arm; V, vein; MN, median nerve; UN, ulnar nerve; MCN, musculocutaneous nerve; RN, radial nerve; MACN, medial antibrachial cutaneous nerve

nerve (Fig. 6c). By following the structure distally to the elbow, the separation of these nerves was observed.

In some less frequent cases, the four nerves of the brachial plexus were located and electrically identified on the posterior and medial side of the AA (Fig. 6d).

Discussion

Axillary dissection

We found a standard anatomical layout on the dissection of the embalmed cadaver. This is not surprising considering the low frequency of anatomical variations.

Correlation between anatomical sections and US images

Anatomical sections allowed true identification of the anatomical structures seen on US imaging. It is important to note the close relationship between the RN (which is always more difficult to visualise) and the deep artery of the arm. Both share the same path at the posterior side of the AA and quickly drop in the direction of the humerus.

The main difference between the anatomical section and US imaging can be explained by the blood volume in the vessels, especially in the veins which appeared to take up more space.

US allowed a dynamic approach to anatomy in living people. For example, nerves appeared to be highly mobile depending on the pressure of the probe which can collapse the veins, but also with the needle movement and the local anaesthetic injection. This has already been shown [11, 14], and may be a protective factor against direct injuries that can occur during blind regional anaesthesia.

Anatomical variations of the vasculonervous components of the axilla

The aim of this study was to show the usefulness of US imaging for describing vasculonervous anatomy and its most interesting variations at the axilla. We think this knowledge may help anaesthetists to use US techniques to perform regional anaesthesia. In contrast, the study was not designed to provide an extensive description of topographic variations in vasculonervous structures.

Double AA is a classical but rare variation in anatomical studies [2, 10, 16]. However, as the brachial plexus was located between the two arteries, such a variation could increase the risk of vascular puncture during regional anaesthesia guided only by electrical nerve stimulation. Should such a puncture occur, an aspiration test before injection would prevent intravascular injection and compression would limit the risk of haematoma.

Many venous variations exist but they remain poorly documented in anatomical literature [2, 9]. Here again, US imaging could decrease the risk of intravascular injection even if it has still not been shown that US is more efficient than aspiration testing.

The relationship between the MCN and the MN varies. It can either be a close contact or a fusion like in our work. By following the structure distally to the elbow, the separation of these nerves can be observed. Such a case has been reported previously [12], and this description is in accordance with several dissection works [2, 7]. In some cases, the fusion of the two nerves is complete from axilla to elbow, but this was not identified in our work [8]. Unfortunately, US did not allow us to visualize the connecting branch between the MCN and the MN as described in other dissection works [5]. This kind of variation could explain situations where the MCN (or MN) cannot be found with single electrical nerve stimulation after having injected local anaesthetics on the MN (or MCN respectively).

The posterior location of the brachial plexus nerves was less frequent. The close relationship between these four nerves on the posterior and medial side of the AA suggests that the whole brachial plexus is situated in this unusual position [2]. Nevertheless, it is not possible to clearly assess the level of fusion between all the nerves. Trying to localise the four main nerves with electrical nerve stimulation and injecting local anaesthetics around them at the same time would be a real challenge.

Conclusion

Anatomical knowledge is of major importance when practicing axillary regional anaesthesia. The use of US scans, with or without nerve stimulation, can offer a new approach to anatomical variations of the vasculonervous bundle at the junction of the axilla and the upper arm. It is likely that this new anatomical approach could be extended to other regions.

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