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REVIEW ARTICLE

Infraclavicular brachial plexus block in adults: a comprehensive review based on a unified nomenclature system

An-Chih Hsu[1,6] · Yu-Ting Tai[1,2,6] · Ko-Huan Lin[3] · Han-Yun Yao[1] · Han-Liang Chiang[4,5] · Bing-Ying Ho[1] · Sheng-Feng Yang[1] · Jui-An Lin[1,2,6] · Ching-Lung Ko[1]

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Abstract

Over the last decade, considerable progress has been made regarding infraclavicular brachial plexus block (ICB) in adults, especially since the introduction of ultrasound guidance. The advancements in ICB have been attributed to the development of various approaches to improve the success rate and reduce complications. This has also necessitated a unified nomenclature system to facilitate comparison among different approaches. This review aimed to propose an anatomical nomenclature system by classifying ICB approaches into proximal and distal ones to aid future research and provide practice advisories according to recent updates. We also comprehensively discuss various aspects of this nomenclature system. Our review suggests that ultrasound-guided ICB should be categorized as an advanced technique that should be performed under supervision and dual guidance. For one-shot block, the conventional distal approach is still preferred but should be modified to follow ergonomic practice, with the arm in the proper position. For continuous ICB, the proximal approach is promising for reducing local anesthetic volume and increasing efficacy. Nevertheless, further studies are warranted in this direction. We provide practice advisories to maximize safety and minimize adverse events, and recommend designing future studies on ICB according to these findings based on the unified nomenclature system.

Keywords Brachial plexus block · Infraclavicular · Adult · Terminology

Introduction

Historically, approaches to the brachial plexus have evolved from landmark guidance, stimulator guidance to ultrasound guidance. In the era of stimulator guidance, infraclavicular brachial plexus block (ICB) was developed to prevent pneumothorax, which was occasionally accompanied by its supraclavicular counterpart. Although Raj et al. [1] achieved ICB with virtually no risk of pneumothorax, anatomical variations per se and anatomically imprecise methods [2] prevented stimulator-guided ICB from gaining popularity. Thereafter, ICB has garnered increasing interest since the use of ultrasound guidance [3]. However, limitations in ultrasound-guided ICB still exist because of the inherent paradox in imaging deep targets and errors in perception regarding needle-nerve proximity [4].

Recently, an iconic study demonstrating the beneficial effect of brachial plexus block on medium-term (3-month) primary patency rates for arteriovenous fistula stressed the importance of sympathetic blockade [5]. To further investigate the therapeutic effect of the sympathetic blockade

An-Chih Hsu and Bing-Ying Ho contributed equally.

✉ Jui-An Lin
juian.lin@tmu.edu.tw

✉ Ching-Lung Ko
clko1168@gmail.com

1 Department of Anesthesiology, Wan Fang Hospital, Taipei Medical University, Taipei, Taiwan

2 Department of Anesthesiology, School of Medicine, College of Medicine, Taipei Medical University, Taipei, Taiwan

3 Division of Psychiatry, Hualien Armed Forces General Hospital, Hualien, Taiwan

4 Department of Anesthesiology, School of Medicine, College of Medicine, National Defense Medicine Center, Taipei, Taiwan

5 Department of Anesthesiology, Kaohsiung Veteran General Hospital, Kaohsiung, Taiwan

6 Pain Research Center, Wan Fang Hospital, Taipei Medical University, Taipei, Taiwan

achieved by brachial plexus block, a dose-finding study on the continuous infraclavicular brachial plexus approach is warranted, because the "continuous" approach has the potential to achieve motor-sparing sympathectomy by lowering local anesthetic concentration [6] and the "infraclavicular" approach offers better muscle anchorage for catheterization [7]. However, during a literature search, the lack of a unified nomenclature system prevented relevant comparisons of study design. For example, in ultrasound-guided ICB, what has been referred to as "medial" ICB with a sagittal puncture at the apex of the delto-pectoral groove [8] is currently considered "lateral" ICB with a sagittal puncture just medial to the coracoid process [9]. Moreover, clinicians find it confusing to communicate using the name of each ICB technique without a unified nomenclature system, let alone similar ICB approaches with different names.

This review aimed to develop an anatomical nomenclature system by classifying the ICB approaches into proximal and distal ones according to the final needle-tip position, which determines block efficacy and associated adverse events [10]. On the basis of this unified nomenclature system, we discuss topics with recent updates, including applied anatomy, overview of the reported approaches, nomenclature, typical procedures, complications, indications, and specific descriptions about the distal approach.

Applied anatomy

The brachial plexus courses from the superomedial direction across the rib towards the inferolateral direction, and its blockade in the infraclavicular space can be achieved either proximally in the costoclavicular space (Fig. 1a) or distally in the pectoralis minor space (Fig. 1b) [11]. The essential difference between these two spaces is the position of the brachial plexus to the axillary artery. The first part of the axillary artery is defined as the part proximal to the pectoralis minor, and the second part of the axillary artery is defined as the part posterior to the pectoralis minor, where the three cords surround this part of the axillary artery on three sides, with the disposition being implied by their names [11]. The brachial plexus runs in triangular clusters in the costoclavicular space, and this triangular arrangement is maintained in the medial infraclavicular fossa (the space between the costoclavicular space and the pectoralis minor space) [12] until the junction between the medial infraclavicular fossa and the proximal pectoralis minor space [13]. The costoclavicular space is the transitional zone where the divisions, formed in the supraclavicular fossa as the most compact part of the brachial plexus, group into three cords below the clavicle. However, the level of the costoclavicular space at which they consistently become the cords remains undetermined.

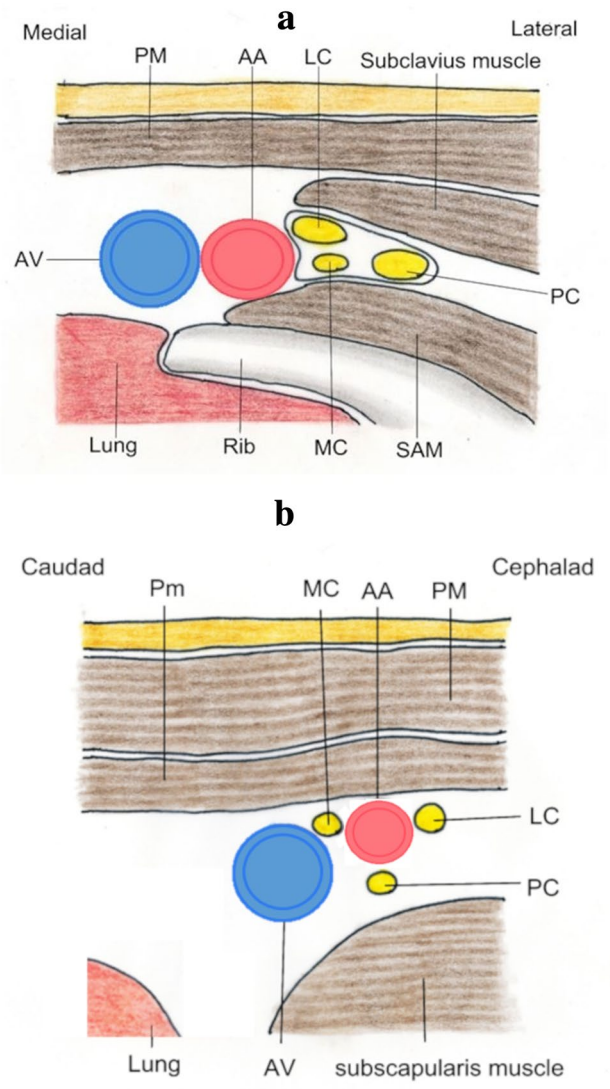


Fig. 1 Illustration of the infraclavicular space in cross section. **a** Costoclavicular space. The lateral, medial, and posterior cords (LC, MC, and PC, respectively) run together in clusters lateral to the axillary artery (AA), but they may appear in a transitional pattern similar to its supraclavicular counterpart with divisions separated by a septal plane. The brachial plexus is covered anteriorly by the pectoralis major (PM) and subclavius muscles, and posteriorly by the serratus anterior muscle (SAM) lying above the rib. The pleura is usually situated below the brachial plexus. **b** Pectoralis minor (Pm) space. The LC, PC, and MC are located around the second part of the AA and covered by the PM and Pm muscles. The subscapularis muscle lies deeper to the AA, and the pleura is seen caudal to the axillary vein (AV)

Supraclavicular brachial plexus block (SCB) and the proximal approach for ICB target the periclavicular plexus, where the nerves are usually located anterolateral to the artery. The costoclavicular space is surrounded anteriorly by the pectoralis major and subclavius, and posteriorly by the serratus anterior and the rib [13], where the first part of the axillary artery is located. At this level, the lateral, medial,

and posterior cords run along the anterolateral side in clusters, relatively superficially to the skin [8] and parallel to the artery [12] (Fig. 1a). Topographic studies show that, in the costoclavicular space, the lateral cord is the most superficial of the three and always anterior to the other two [12, 14], and the posterior cord is the most lateral of the three [12] and always cranial to the medial cord [14]. Regarding the structures lying dorsal to the lateral cord, Sala-Blanch et al. [12] concluded from a recent cadaver study that the medial cord lies directly posterior to the lateral cord (Fig. 1a). However, the results of another dissection study did not exclude the possibility of the posterior cord lying dorsal to the lateral cord [14]. Therefore, in addition to undergoing transition from divisions to cords in the costoclavicular space, the cord topography medial to the coracoid process assumes a gradual transition from the mid-clavicular plane, where the medial cord is not really medial to the axillary artery until the plexus courses further distally in the pectoralis minor space [14].

The pectoralis minor space is surrounded anteriorly by the pectoralis major and minor, posteriorly by the subscapularis and scapula, and caudally by the pleura (Fig. 1b), where the three cords (lateral, medial, and posterior cords) are termed according to their positions in relation to the second part of the axillary artery under the pectoralis minor. Further distally, the cords divide into the median nerve, radial nerve, ulnar nerve, and musculocutaneous nerve as major terminal branches (Fig. 2). The medial antebrachial cutaneous nerve and medial brachial cutaneous nerve emerge from the medial cord and innervate the medial side of the arm in combination with the intercostobrachial nerve.

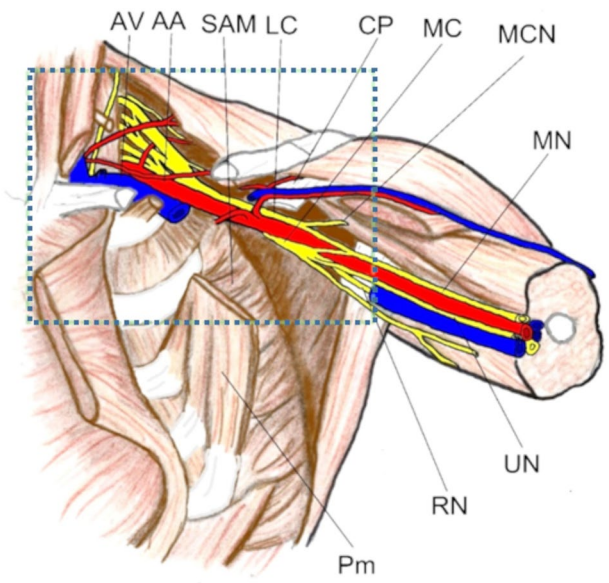


Fig. 2 Illustration of the periclavicular space showing the left brachial plexus and related anatomical structures. The brachial plexus originates from the fifth cervical to the first thoracic nerve roots to form the trunks, divisions, cords, and terminal branches. The divisions travel beneath the clavicle in clusters at the first part of the axillary artery (AA) and then become the lateral, posterior, and medial cords (LA, PC, and MC, respectively), according to their relationship to the second part of the AA. During the course, the MC can run between the AA and axillary vein (AV), exactly at the level targeted by the distal approach. The green dotted box is enlarged in Fig. 4. *SAM* serratus anterior muscle, *CP* coracoid process, *MCN* musculocutaneous nerve, *MN* median nerve, *UN* ulnar nerve, *RN* radial nerve

Overview of the reported approaches

Raj et al. [1] were credited for successfully reintroducing the ICB approach for injection below the clavicle, which was originally proposed by Bazy; however, this technique was difficult to follow. The coracoid approach was first described by Whiffler [15] as a vascular surface landmark technique. The needle is inserted inferomedially to the coracoid process along the line connecting the points, where the artery is palpated above the mid-clavicle and over the anterior chest (mostly in the delto-pectoral groove) near the axilla, and directed at a right angle to the skin, with the depth being estimated from the pulsation over the anterior chest towards the pulsation felt as high as possible in the axilla. The suitable insertion point was later modified to be 2 cm medial and 2 cm caudad to the coracoid process under stimulator guidance by Wilson et al. [16] who analyzed oblique and parasagittal magnetic resonance images. It was not until the 1990s, along with the popularization of regional anesthesia in general, that ICB became a vital part of regional anesthesia. In addition to the vertical approach with a vertical puncture at the mid-clavicle proposed by Kilka et al. [17], stimulator-guided ICB approaches continued to be reported in the 2000s, including a modified Raj approach by Borgeat et al. [18] and the lateral and sagittal approach by Klaastad et al. [2]. The ultrasound-guided ICB approach along the vascular course to obtain the transverse view of the vessels using a curved probe was first described by Ootaki et al. [3]. To overcome the steep needle angle, Hebbard and Royse [19] proposed an ultrasound-guided posterior approach with the needle inserted from the supraclavicular fossa posterior to the clavicle using a linear probe. Karmakar et al. advocated the costoclavicular approach by targeting the brachial plexus at the costoclavicular space using a linear probe [20]. Although stimulator guidance continues to be investigated in some studies, ultrasound guidance is currently the gold standard in ICB.

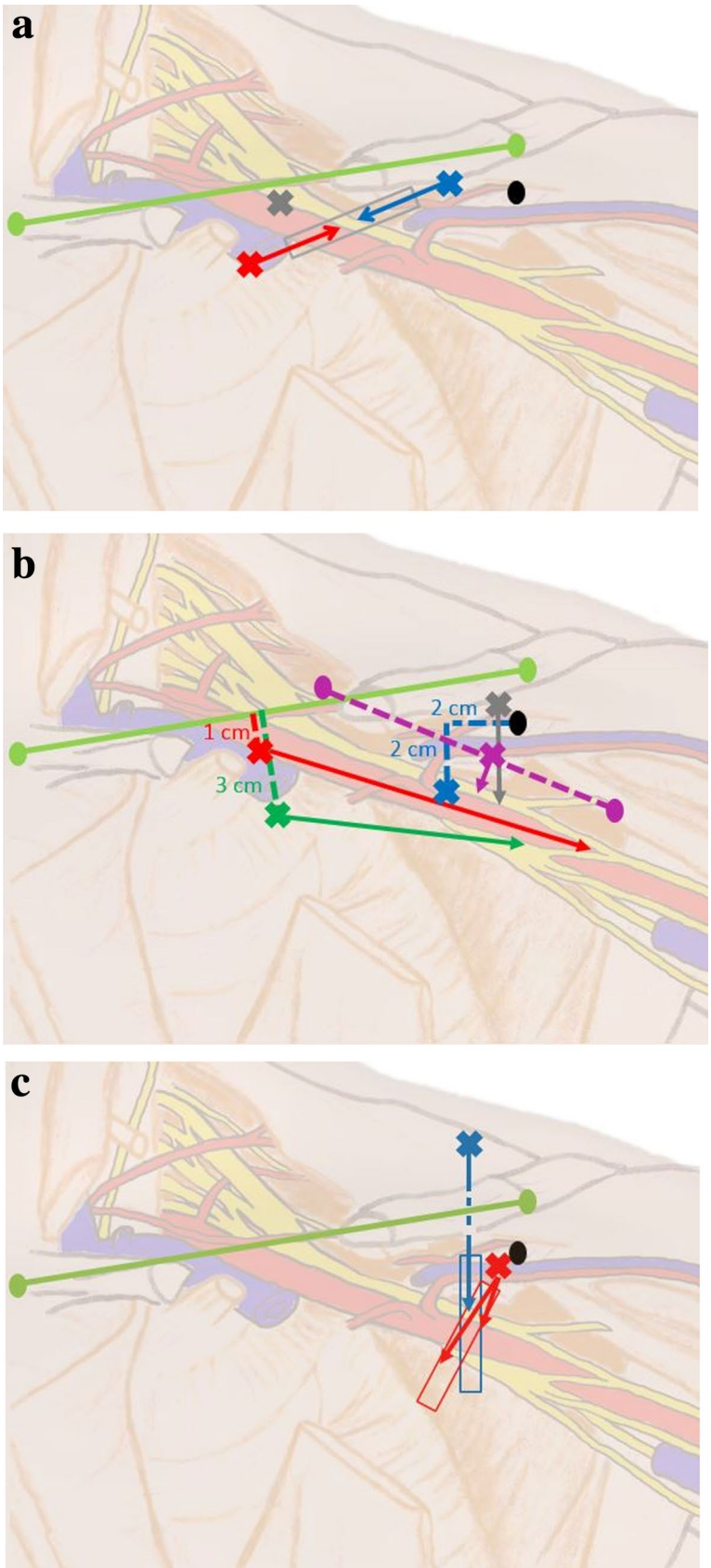
Table 1 Classification of approaches based on proximal/distal nomenclature system

References	Guidance	Block site (needle tip position)/evidence from the original report
Proximal approach		
Vertical proximal approach (vertical needle trajectory)		
Kilka et al. [17] (vertical approach) (Fig. 3a)	NS	First part of axillary artery/vertical puncture is at a point below the midpoint of the clavicle (between the fossa jugularis and the ventral process of the acromium)
Lateral proximal approach (lateral-to-medial needle trajectory)		
Karmakar et al. [20] (costoclavicular approach) (Fig. 3a)	US	
Yoshida et al. [24] (proximal approach) (Fig. 3a)	US	First part of axillary artery/all the three cords are in clusters on ultrasound
Medial proximal approach (medial-to-lateral needle trajectory)		
Nieuwveld et al. [22] (medial approach) (Fig. 3a)	US	Costoclavicular space/all descriptions and images in the method
Distal approach		
Raj et al. [1] (Raj approach) (Fig. 3b)	NS	Second part of axillary artery/the needle tip is directed laterally towards the brachial artery and placed below coracoid process on PA view of the patient
Whiffler [15] (original coracoid approach) (Fig. 3b)	Surface landmark	Second part of axillary artery/the target is immediately medial and inferior to the coracoid process. (superolateral than Wilson 1998 [16])
Wilson et al. [16] (oblique parasagittal modification of coracoid approach) (Fig. 3b)	NS	Second part of axillary artery/the MRI reveals the brachial plexus is covered by pectoralis minor muscle
Ootaki et al. [3] (original US approach) (Fig. 3c)	US	Second part of axillary artery/"Doughnut sign" is achieved below pectoralis minor muscle on ultrasound
Borgeat et al. [18] (modified Raj approach) (Fig. 3b)	NS	Median nerve/the ideal target of nerve stimulator is median nerve
Klaastad et al. [2] (lateral and sagittal approach) (Fig. 3b)	NS	Second part of axillary artery/the target is any of the three cords behind the pectoralis minor muscle
Hebbard et al. [19] (posterior approach) (Fig. 3c)	US	Second part of axillary artery/the target is covered by pectoralis major and pectoralis minor both in the ultrasound image and parasagittal drawing (a more medial approach towards the first part of axillary artery may be an option if the scapula obstructs the needle)

NS nerve stimulation, *US* ultrasound

Nomenclature

It is more straightforward to classify ICB according to the anatomical level of the axillary artery, that is, "proximal ICB" if the injection is administered at its first part, and "distal ICB" for the injection at its second part (and beyond). For example, despite the puncture site being at the mid-clavicular area, the modified Raj block cannot be classified as a proximal ICB, because it targets the median nerve at or beyond the cords [18]. Another example is posterior ICB, which should be primarily classified as a variant of distal ICB because of its final tip position towards the second part of the axillary artery despite its needle insertion point being at the supraclavicular fossa, either over the trapezius muscle [19] or medial to the trapezius muscle insertion point on the clavicle [21]. In a few cases, posterior ICB may fall in the category of proximal ICB judged sonographically according to the final needle-tip position, because needle redirection towards a more medial direction is required to reach the plexus when the needle trajectory is obstructed by the scapula [19]. Without applying this unified nomenclature system, the posterior approach (or retroclavicular approach) might be roughly categorized as a kind of proximal approach in some descriptions if the costoclavicular space is mistakenly considered the primary target [22]. On the basis of the above descriptions, the previous ICB approaches have been redefined (Table 1; Fig. 3).


a
b
1 cm
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c

◂**Fig. 3** Diagrams illustrating the approaches for infraclavicular brachial plexus block. According to the nomenclature system in Table 1, these approaches are further depicted and illustrated as the proximal approach (**a**), stimulator-guided distal approach (**b**), and ultrasound-guided distal approach (**c**), with the green solid line indicating the clavicle and the rectangle representing the probe position. The arrow head indicates the needle-tip position, and the black dot denotes the coracoid process. Regarding the proximal approach (**a**), the needle insertion points are below the midpoint of the clavicle (**a**, gray cross), lateral to the probe (**a**, blue cross), and medial to the probe (**a**, red cross) for the vertical proximal approach, lateral proximal approach, and medial proximal approach, respectively. The arrow with the same color indicates its own needle trajectory. The gray cross without an arrow indicates a vertical puncture. Stimulator-guided (or landmark-guided) distal approach (**b**). For the Raj approach, the needle is inserted 3 cm below the mid-clavicle (**b**, green cross) and advanced towards the pulsation in the axilla (**b**, green arrow) at a 45° angle. For the original coracoid approach, the needle is inserted at a right angle to the skin (**b**, purple cross) towards the axillary artery, whose path and depth are inferred via arterial palpation (**b**, purple dots on the skin). For the oblique parasagittal modification of the coracoid approach, the needle is inserted 2 cm medial and 2 cm caudad to the coracoid process and directed posteriorly (**b**, blue cross). For the modified Raj approach, the needle is inserted 1 cm below the mid-clavicle and advanced towards the pulsation in the axilla (**b**, red arrow) at a 45°–60° angle. For the lateral and sagittal approach, the needle is inserted at the intersection between the clavicle and the coracoid process (**b**, gray cross) and advanced 15° posterior to the horizontal plane. The ultrasound-guided distal approach (**c**). For the original ultrasound approach (**c**, red cross), the needle is inserted after a transverse view of the artery and vein is acquired as close to the lower edge of the clavicle as possible. For the posterior approach (**c**, blue cross), the needle is inserted between the clavicle and the scapula towards the axillary artery, with the probe placed medial to the coracoid process in the parasagittal plane

Explanation of typical procedures

Proximal and distal approaches (Table 2)

The conventional distal approach for ultrasound-guided ICB [3] is popular because of its high success rate. However, the use of an acutely angled needle trajectory in this approach has led to the development of the costoclavicular [20] and posterior [19] approaches. The costoclavicular space is located deep and posterior to the midpoint of the clavicle [12]. The proximal approach to this space, as suggested by Karmakar et al. [20], involves placing the probe parallel to and below the mid-clavicle (Fig. 4, white box a), followed by the identification of the first part of the axillary artery in the space between the posterior surface of the clavicle and the rib as well as the optimization of the ultrasound image of all three cords by tilting the probe with or without caudally pivoting the medial end of the probe [23] (Fig. 5a). Yoshida et al. [24] further stressed the importance of arm abduction in ultrasound-guided proximal ICB, because abducting the arm facilitates proximal probe placement by elevating the clavicle and moves the brachial plexus more superficially by stretching the pectoralis major. Parallel placement of the probe in relation to the clavicle is recommended for the proximal approach, because sagittal placement hinders needle insertion.

The proximal approach is good because of the more superficial location of the infraclavicular plexus and rapid onset as in SCB [20]. However, the needle trajectory for the lateral proximal approach is towards the pleura. Recently, Nieuwveld et al. [22] proposed a medial-to-lateral needle trajectory (medial proximal approach) based on a concept similar to that of stimulator-guided distal ICB proposed by Raj et al. [1] (Table 1) to avoid the pleura in the proximal approach (Table 2). Regardless of the needle trajectory, the final needle-tip position should be in the middle of the three cords [20, 23, 25, 26] or in the plane separating the upper division group from the lower division group (Fig. 5b), depending on the plexus status. The lower division group gives rise to the posterior and medial cords and is separated from the upper division group by a plane, as seen in a histological section [12]. Furthermore, the posterior and medial cords are very closely apposed to each other and are bound together by a common connective tissue [12, 23]. For the medial proximal approach, hydrodissection can be used to advance the needle between the artery and the lateral cord, and local anesthetic injection starts below the latter [22] (Fig. 5b).

The posterior approach has also been proposed to overcome the acutely angled needle trajectory associated with the conventional distal approach [19]. Regarded as a variant of the distal approach, the posterior approach involves a similar placement of the probe to that in the distal approach (Fig. 4, white box b). The needle insertion point is at the supraclavicular fossa (Fig. 6a), and the needle is advanced strictly in-plane towards the same target as in conventional distal ICB [21] (Fig. 6b), which takes advantage of a needle trajectory that is vertical to the ultrasound beam. Another advantage of the posterior variant is that the needle path not only prevents the puncture of the cephalic vein and thoracoacromial artery but also avoids needle trauma to the lateral cord [27]. The posterior variant yields a similar success rate to that of the conventional distal approach, and no pneumothorax resulting from this approach has been reported thus far [21, 28, 29]. However, the posterior approach has some limitations. First, considerable anatomical variations around the clavicle, such as fullness of the supraclavicular fossa and an acutely angled clavicle, not only pose needling difficulty but also increase discomfort and the required dose of opioids during needle manipulation [29]. Second, a longer needle is needed, because this approach involves a long path passing through the blind zone (approximately 3–4 cm) [19]. Third, the blind zone below the clavicle, which consistently contains the suprascapular nerve, non-compressible

Table 2 Comprehensive comparison among ultrasound-guided approaches

Approach (distal/proximal)	Brachial plexus location	Needle trajectory	Suggested arm position	Anatomical limitation	Technical difficulty	Risk of pneumothorax	Risk of phrenic nerve block	Blind zone
Costoclavicular [20] (lateral proximal)	More superficial	Superficial	Abduction [24] (facilitation of probe placement and bringing the plexus more superficial)	None	Easier	Higher (possibly reduced if medial-to-lateral)	Intermediate	None
Medial [22] (medial proximal)	More superficial		Abduction	None	Easier (naturally ergonomic)	Possibly lower [22]	Intermediate	None
Conventional [3] (distal)	Deeper	Steep	Abduction	None	Intermediate	Lower [8]	Intermediate (possibly lower)	None
Posterior [19] (mostly distal, could be proximal if scapula obstructs the needle)	Deeper	Vertical to the ultrasound beam	Adduction [27] (facilitation of needle entry)	Yes [29] (fullness of supraclavicular fossa and an acutely angled clavicle)	Intermediate	Intermediate (avoid angle posteriorly [21])	Intermediate (possibly lower)	Yes

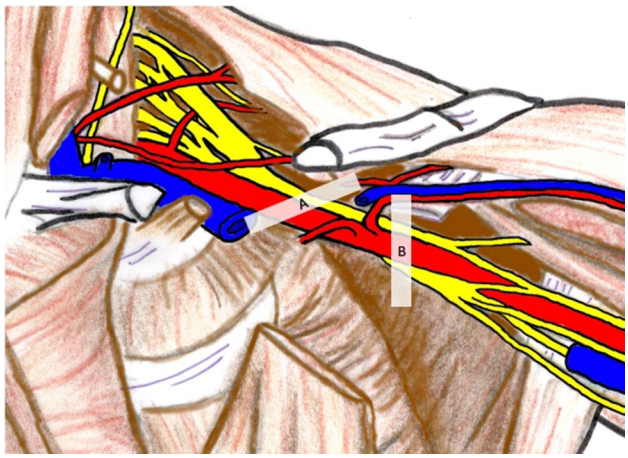

Fig. 4 Focused anatomy of the brachial plexus and related probe positions. The dotted box in Fig. 2 is further elaborated. The proximal approach for infraclavicular brachial plexus block (ICB) places the ultrasound probe parallel and below the clavicle (white box **A**). The brachial plexus gathers in clusters, located anterolateral to the axillary artery in the ultrasound image (Fig. 5a). The distal approach involves placing the probe medial to the coracoid process (white box **B**), where the probe is used to identify the three cords around the axillary vessels when the medial cord emerges between the axillary artery and vein

vessels [30], and other unwanted structures, makes needle advancement unsafe and alignment of the needle trajectory with the probe difficult [29]. Fourth, lateral cord sparing is occasionally encountered because of the more caudal "pushing" of the needle tip [27]. Therefore, despite the advantage of the posterior approach as a part of a single-penetration double-injection technique for shoulder anesthesia [31], debates persist regarding the routine use of the posterior approach for ICB [29].

Clinical efficacy and safer needle trajectory support the popularity of the distal approach. This approach is performed by placing the probe parasagittally medial to the coracoid process (Fig. 6c) while visualizing the axillary artery and vein with the medial cord in between (Fig. 6b, e). The needle is inserted in-plane towards the posterior part of the axillary artery (Fig. 6b). At the cost of resolution and an undistorted image, a microconvex probe might be recommended (Fig. 6e), because it provides better penetration and superior needle visibility than does the linear probe for deep targets [32] as well as more space for needle insertion than does the traditional curvilinear probe. Although visualization of the individual cords using ultrasound is not always possible in the distal approach, a U-shaped spread has been proposed as the endpoint of local anesthetic deposition [33]. Injection should be performed at the level, where the medial cord just emerges between the artery and the vein (Fig. 6d, e), because the medial cord will run anteriorly (away from the U-shaped spread) when the brachial plexus extends

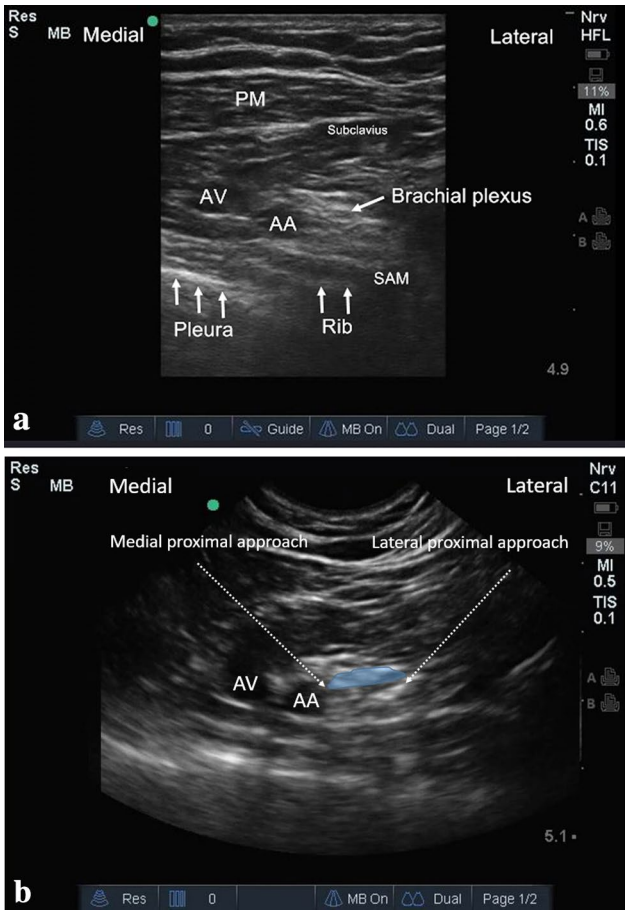

Fig. 5 Ultrasound-guided proximal approach for infraclavicular brachial plexus block. **a** Ultrasound image of the costoclavicular space acquired using a linear probe. The relationship between the axillary artery (AA) and the brachial plexus is roughly identical to that in supraclavicular brachial plexus block. Please also refer to Fig. 1 for an illustration of the costoclavicular space. In this image, the brachial plexus is more of a division than one would think. **b** Ultrasound image of the costoclavicular space acquired using a microconvex probe. The needle is inserted in-plane either lateral-to-medial (lateral proximal approach) or medial-to-lateral (medial proximal approach) to reach the space between the cords or enters the plane between the upper division group and lower division group. When still in transition from the divisions, the spread is considered adequate if the injectate separates the division groups from each other by hydrodissecting the plane in between

further distally [8]. In obese patients, the median angle of needle insertion in relation to the anterior chest wall is 50° (33°–60°), and other techniques such as hydrolocation are required to complete ICB in 39% of these patients. However, the needling angle is only moderately, but not strongly, correlated with the body mass index; thus, clinicians should not choose an alternative approach based only on the body mass index without performing a preprocedural scan [34]. As with other deep regional blocks, physical ergonomics should be maximized to work efficiently, safely, and comfortably [35], and therefore, the importance of ergonomic practice, including arm position, should be stressed.

Complications

The incidence of pneumothorax in ICB without ultrasound guidance has been reported to be between 0.2 and 0.7% [36, 37]. Theoretically, imaging the needle with in-plane ultrasound guidance should eliminate this risk, but for deep regional blocks, the condition is satisfied only in experienced hands. In one case, pneumothorax occurred 2 h after ultrasound-guided distal ICB, possibly because the procedure was performed by an inexperienced resident with poor visibility of the needle tip [38]. Gauss et al. reported that pneumothorax after ultrasound-guided ICB was detected in 2 of 2963 patients (0.06%) when the procedures were performed by residents or inexperienced anesthesiologists (< 20 blocks) without adequate supervision [36]. Ultrasound-guided ICB is generally considered a safe technique in terms of pneumothorax, but should be classified as an advanced technique requiring an experienced hand or performance under supervision.

Among the adverse events of ICB, phrenic nerve block is the one potentially affecting vital signs. The more distal the approach to the brachial plexus, the less likely local anesthetic injection would result in diaphragmatic movement impairment [10, 39]. Most symptomatic cases of phrenic nerve block after ICB pertain to the vertical approach for proximal ICB [40, 41], wherein Horner's syndrome indicative of paravertebral spread (thus adjacent phrenic nerve involvement) consistently predicts a change in ipsilateral diaphragmatic movement, even though hemidiaphragmatic dysfunction could also occur independently [10]. Theoretically, the reduction of local anesthetic volume is more important for the proximal approach (phrenic nerve involvement) than for the distal approach (accessary phrenic nerve involvement). The more proximal the needle tip is placed, the less volume should be administered to avoid supraclavicular spread (and thus phrenic nerve involvement) [39], because the supraclavicular spread obviously yields a higher rate of hemidiaphragmatic paralysis than does its infraclavicular counterpart [42]. A recent study using reconstructed computed tomography images demonstrated that an anesthetic volume as low as 20 mL in the medial proximal approach could reach the interscalene region [22]. However, symptomatic hemidiaphragmatic paralysis still occurs, albeit transiently, in distal ICB regardless of the guiding modality (both ultrasound guidance [39] and stimulator guidance [43]). Existence of an accessory phrenic nerve is not uncommon (nearly 30% [44]), and its location may have been in close proximity to the site, where distal ICB is performed, thereby accounting for the transient hemidiaphragmatic paresis in such instances [39]. Although the distal approach may have a lower incidence of diaphragmatic paralysis than does the proximal approach [39], a recent analysis showed that the

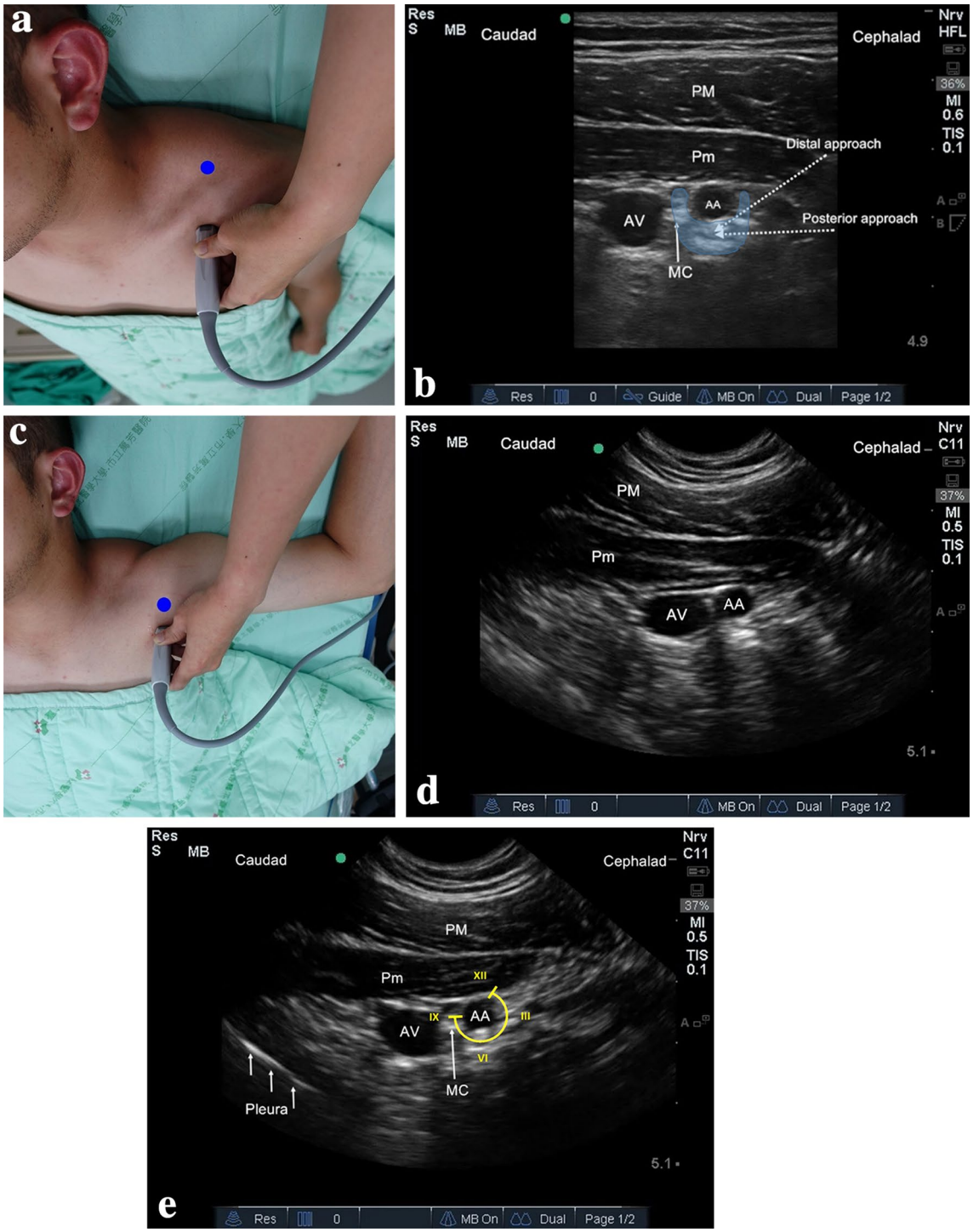

Fig. 6 Ultrasound-guided distal approach for infraclavicular brachial plexus block. **a** Probe and patient positions for the posterior approach. The blue dot represents the puncture point at the supraclavicular fossa, penetrating below the clavicle with the needle in-plane. **b** Ultrasound image of the pectoralis minor space acquired using a linear probe. The pleura is usually not observed or is obscured at the corner of the venous side owing to the limited scanning range. With regard to the posterior approach, the needle shaft is perpendicular to the ultrasound beam and advanced caudally towards the same target site as the distal approach using a linear probe. The blue shaded area shows the U-shaped spread. **c** Suggested probe and patient positions for the distal approach. The blue dot indicates the needle insertion point, cephalad to the probe anterior to the clavicle. **d** Ultrasound image of the pectoralis minor space acquired using a microconvex probe before the medial cord emerges in between the axillary artery and vein. **e** Medial cord is seen between the axillary artery and vein. Using a microconvex probe, the U-shaped spread should cover more than a 1-o'clock to 9-o'clock periarterial sector to ensure the block takes effect

Table 3 Arm positioning for ultrasound-guided approaches

References	Approach	Arm position	Case number	Results
Bigeleisen et al. [8]	Distal and proximal	Arm abduction 110° and externally rotating the shoulder	202	In the proximal approach, brachial plexus moves away from the thorax and closer to the surface of the skin
Ruíz et al. [53]	Distal	Arm abduction 0°, 45°, 90°	26	Arm abduction 90° has shortest distance from the axillary artery to the skin
Auyong et al. [54]	Distal	Arm abduction 90° with elbow flexed	Technical report	Cranial-posterior clavicle displacement allow a shallow angle of needle path
Yoshida et al. [24]	Proximal	Arm abduction 90°	Technical report	Moves the brachial plexus away from the thorax and closer to the dermal surface by stretching pectoralis major muscle

incidence is still remarkable in the distal approach [26], and the use of long-acting local anesthetics should be avoided in patients with respiratory depression to minimize the duration of ventilatory exacerbation.

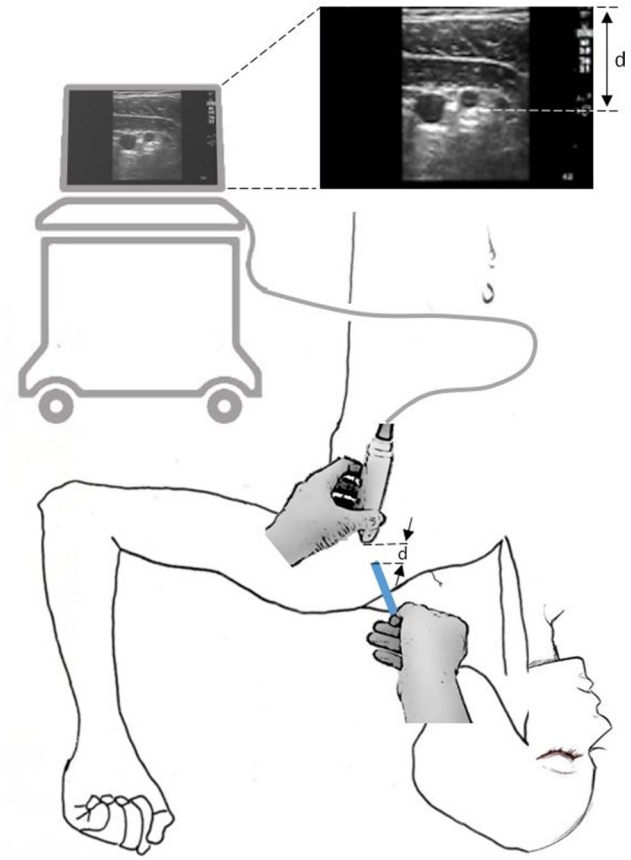

Fig. 7 Ergonomic practice for distal infraclavicular brachial plexus block (ICB). The patient is placed in the supine position. With the arm abducted at 90°, the elbow flexed, and the head turned to the non-operative side, a Houdini clavicle is created to facilitate needle insertion according to the plexus depth "d" measured using the ultrasound image for the purpose of making the needle trajectory perpendicular to the ultrasound beam to mimic the posterior approach anterior to the clavicle. The operator is cranial to the patient, with his dominant hand holding the needle to advance it along the visual axis

Indications and contraindications

Although ICB, SCB, and axillary brachial plexus block are generally considered for surgeries distal to the elbow [45], evidence reveals that ICB should be the block of choice owing to the following reasons. First, SCB risks ulnar sparing, because the eighth cervical and first thoracic nerve roots are sometimes not blocked [46]. Second, multiple injections are necessary for axillary brachial plexus block. A cadaver study revealed that at least 35% of the musculocutaneous nerves emerge before the coracoid process [47]. Third, ICB yields lower tourniquet pain [48]. Thus, compared with SCB and axillary brachial plexus nerve block, ICB is a superior choice for surgery distal to the elbow. For prolonged brachial plexus block, ICB provides better analgesia [49] and a more stable catheter placement [50] than does SCB.

Neither the proximal nor distal approach for ICB is contraindicated in patients with normal lung function. Although well tolerated by healthy subjects, potential hemidiaphragmatic paralysis carries a prohibitive risk for patients with pulmonary pathology, who may be unable to withstand the 30% reduction in forced vital capacity [42]. Therefore, efforts should be made towards diaphragm-sparing blocks in patients with borderline lung function. For shoulder surgery, distal ICB has recently been suggested as the most promising modality in combination with suprascapular nerve block (ICB-SSB) to achieve a surgical plane while preserving maximal diaphragmatic function [42]. Two recent studies examining the respiratory effect of ICB-SSB for arthroscopic shoulder surgery, either with [51] or without [52] superficial cervical plexus block, demonstrated that ICB-SSB does not result in diaphragmatic paralysis. Although in their studies, diaphragmatic function was evaluated using chest radiography [51] or standard spirometry/ultrasonography [52], caution should be used when extrapolating these results to patients with impaired respiratory function because of the small case numbers (< 20) in both these studies.

Specific description of the distal approach

Impact of arm position (Table 3)

The conventional approach for distal ICB involves placing the ipsilateral arm at the patient's side. However, problems such as the depth of the brachial plexus and proximity of the clavicle to the probe are encountered. All these factors result in a steep needle angle and invisible needle path. Recent studies have claimed that alternative positioning techniques facilitate the performance of ICB. Ruiz et al. [53] reported that the three cords are easily influenced by arm position. They measured the distance between the axillary artery and the skin in different arm positions (neutral position, abduction at 45°, and abduction at 90°) and discovered that the distance was shortest in abduction at 90°. Auyong et al. [54] suggested a position with the arm abducted at 90° and the elbow flexed, which is termed the "Houdini clavicle" as a part of the ergonomic position (Fig. 6c). This arm position not only makes the brachial plexus more superficial, but also displaces the clavicle cranioposteriorly, which creates a wider space for needle manipulation and enables a less steep angle of the needle path through which the needle could be inserted 2–4 cm cranially to the probe. Rocking the probe may help align the needle [55], but it is not always possible in obese patients. Therefore, the aforementioned arm position should be considered whenever possible to facilitate distal ICB. To compare between the approaches, performing ICB in the optimal body position (Table 2) with a suitable needle insertion point is also of paramount importance. Although a recent report demonstrated that the posterior approach is associated with better needle visibility and less anesthesia-related time than is the conventional distal approach when using the same linear probe with the arm adducted [28], parameters can be compared only if the procedures are performed in their optimal conditions (such as an abducted arm for conventional distal ICB).

Ergonomic practice for ultrasound-guided distal ICB (Fig. 7)

According to recent advancements in physical ergonomics [56, 57], maintaining the eye, hand, needle, linear probe, and ultrasound machine all in the same plane greatly facilitates needle visualization by allowing the insertion of the needle in-plane along the visual axis [35]. With the Houdini clavicle, we suggest that the distance below the probe for needle insertion should be based on the distance from the bottom of the probe to the plexus measured on the ultrasound image [58], instead of inserting it approximately 2–4 cm cranially to the probe in the original description [54], to achieve a nearly horizontal needle trajectory mimicking the posterior approach but avoiding the blind zone produced by the clavicle. To bring in the needle earlier into the ultrasound image, the probe can be slided cranially to catch the needle immediately after it enters the subcutaneous tissue. When there is enough space to accommodate the abducted arm and flexed elbow in the same bed, the head-up position may help avoid gel contamination by placing the probe in the gravity-dependent part below the needle insertion point as a general rule [59–61]. Otherwise, a true echogenic needle could overcome the difficulty of placing the needle in-plane for deep regional blocks [35] if the space between the probe and the clavicle is limited (thus resulting in an inevitable steep-angle needle trajectory).

Minimum effective volume

Historically, a large amount of local anesthetic was needed for stimulator-guided ICB, with variable success rates. Although ultrasound is purported to decrease the amount of local anesthetic required, a paradox seems to exist, because it is true only for some blocks but not for others. The truth might be explained by the choice of technique, wherein a sparing effect is noted only when the neural structure can be visualized with the local anesthetic being incrementally injected to surround the neural structure [62].

Regarding the minimum effective volume for ultrasound-guided distal ICB, Sandhu et al. reported that a mean volume of 16.1 mL of 2% lidocaine with epinephrine (5 μg/mL) was required for three injections around each cord to achieve a 93% (14/15) success rate. Meanwhile, the reduction of lidocaine dosage permits rapid recovery, but brings about the need for placing an indwelling catheter to administer additional boluses when surgery lasts longer than 1 h [63]. For the single-injection technique, a larger volume is invariably required, even with ultrasound guidance [62]. A recent cadaver study demonstrated that incomplete fascial layers are the reason why multiple injections or increased volume for single injections may be needed to maximize the efficacy of distal ICB [64]. The minimum effective volume of a single injection has been reported to be 31 mL (95% of patients) and 35 mL (90% of patients) for the endpoints of U-shaped spread [65] and "double-bubble" sign [62], respectively.

Catheterization

Ultrasound guidance has a shorter performance time and higher rates of successful catheter placement and surgical block than does stimulator guidance [66, 67]. The catheter tip should be placed at 6 o'clock of the axillary artery for distal ICB, but a larger amount of local anesthetic is needed to cover all the three cords. Proximal placement

of the catheter has been suggested by Karmakar et al. [20] and Yoshida et al. [24], wherein the cords are clustered in the proximal infraclavicular space. Compared to catheterization via the distal approach, catheterization via the proximal approach is promising with respect to reduced local anesthetic volume and increased efficacy. Recently, catheter stability achieved by piercing the pectoralis major and subclavius muscles into the supraclavicular space has also been reported [68].

Endpoint predicting a successful ICB: perspectives on the physical barrier

With regard to distal ICB, the septum surrounding the axillary artery influences the spread of the local anesthetic. Not only the septum found posterolaterally, but also the septum lying anterior to the axillary artery may partly explain the low success rates when performing stimulator-guided ICB with a single injection [69], as well as the higher success rate in posterior cord stimulation than in lateral cord or medial cord stimulation [70]. Existence of the septum posterolateral to the axillary artery results in unilateral spread of the local anesthetic when the needle tip is placed in the lateral aspect of the neurovascular bundle, but the septum is not always sonographically visible [71]. Lévesque et al. suggested fascial click using a non-cutting needle, U-shaped spread, and anterior displacement of the axillary artery to complete an ultrasound-guided distal ICB [72]. However, a fascial click is non-specific, or even absent, especially when a sharp-tipped needle is used. Anterior movement of the axillary artery is unnecessary, because a slow and low volume injection of the local anesthetic can also lead to a successful block without causing anterior movement. From a practical perspective, the endpoint of distal ICB should be a U-shaped distribution observed during local anesthetic injection posterior to the axillary artery, and the needle tip should be adjusted to achieve the goal if unilateral spread occurs. Although Tran et al. suggested that the double-bubble sign can be deemed as the endpoint [73], the local anesthetic bubble only involves a small dorsal segment of the artery and does not cover the periarterial sector, where the cords usually reside [65].

Block failure in case of U-shaped spread in distal ICB

A consensus has been achieved regarding the fact that a successful distal ICB can be predicted if the U-shaped spread is observed [72], but the rate of complete block at 30 min after injection remains 86% [33]. Bigeleisen and Wilson [8] reported that ulnar nerve block sets up slowly because of the variable course of the medial cord running along the axillary artery at the level of distal ICB. We suggest that distal ICB be performed at the plane, where a gap just appears between the axillary artery and the axillary vein (Fig. 6b, d, e) to help ensure that a U-shaped spread occurs before the medial cord courses anterior to the axillary artery (as stated in "Explanation of typical procedures"). Furthermore, the definition of the U-shaped spread should be clarified. Sauter et al. [74] used magnetic resonance imaging to identify the periarterial sector, where the cords are normally found in the parasagittal plane tangential to the medial surface of the coracoid process. Considering the artery as a clock face with the 12-o'clock position being ventral and the 9-o'clock position being caudal, the so-called U-shaped spread should cover more than a periarterial sector from 1 to 9 o'clock (Fig. 6e) in the microconvex view, where the cords usually reside [65, 74], to exclude the possibility of technical failure.

As for anatomical failure, Benkhadra et al. [75] performed bilateral ultrasound-guided ICB in 20 cadavers after injecting 0.5 mL/kg of 0.02% methylene blue in a U-shaped spread. All three cords were stained in 33 of 40 blocks, with an anatomical success rate of 82.5%. Among the seven failed blocks, three showed staining of only one or two cords and four blocks showed no staining. After dissection for the failed blocks, most of the staining solution was found in the thoracoscapular space. Current endpoints for ultrasound-guided ICB, either the U-shaped spread or double-bubble sign, are usually achieved without direct visualization of the nerve cords, and these endpoints could change over time if the ultrasound equipment improves in terms of resolution, penetration, and structure differentiation [33].

Conclusion

Based on the current knowledge on applied anatomy, previously reported approaches can be adequately classified and compared by this unified nomenclature system to facilitate future study design. Ultrasound-guided ICB should be categorized as an advanced technique requiring an experienced hand or performance under supervision. To maximize safety and minimize adverse events (such as pleural puncture and minimizing supraclavicular spread) in one-shot block, the conventional distal approach is still preferred; however, it should be modified to follow ergonomic practice with the arm in the proper position. A large volume and needle-tip adjustment for a U-shaped spread is usually required to overcome the frequently encountered physical barriers and usually invisible neural targets during distal ICB. Therefore, dual guidance (ultrasound and half-the-air setting) should be considered the essential monitoring standard as with other deep regional blocks [35]. The proximal approach not only serves as an alternative when anatomical anomalies in the pectoralis minor space are encountered, but also has the potential to reduce local anesthetic volume and increase

efficacy owing to clustered neural targets in the proximal infraclavicular space, which is especially promising when using the continuous technique. Future studies on ICB should be designed according to these findings.

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Compliance with ethical standards

Conflict of interest The authors declare that there is no conflict of interests.

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