BRIEF TECHNICAL REPORT

Ultrasound-Guided Costoclavicular Brachial Plexus Block
Sonoanatomy, Technique, and Block Dynamics

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Background and Objectives: This study aimed to describe in detail the relevant sonoanatomy, technique, and block dynamics of an ultrasound-guided costoclavicular brachial plexus block (BPB).

Methods: Thirty patients scheduled for hand or forearm surgery under a BPB underwent transverse ultrasound imaging of the medial infraclavicular fossa to identify the cords of the brachial plexus at the costoclavicular space (CCS). An ultrasound-guided BPB was then performed at the CCS with 20 mL of 0.5% ropivacaine. Sensory-motor blockade of the ipsilateral median, radial, ulnar, and musculocutaneous nerves were assessed at regular intervals for 30 minutes after the injection. Successful block was defined as being able to complete surgery under the BPB.

Results: The CCS was visualized as a well-defined intermuscular space lying deep and posterior to the mid-point of the clavicle. The cords of the brachial plexus were clustered together lateral to the axillary artery within the CCS. The costoclavicular BPB was successfully performed in all patients, and the median onset time for sensory and motor blockade of all the 4 nerves was 5 [5–15] and 5 [5–10] minutes, respectively. Complete sensory blockade of all the 4 nerves was achieved in 30 [20–30] minutes, and the BPB was successful in 29 (97%) of 30 patients. There were no complications directly related to the technique or the local anesthetic injection.

Conclusions: This report describes a novel technique of infraclavicular BPB at the costoclavicular space that produces rapid onset of BPB. Future research should compare the safety and efficacy of this new technique with the traditional lateral sagittal infraclavicular BPB.

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Infraclavicular brachial plexus block (ICBPB) is widely used for anesthesia or analgesia during surgery on the hand and forearm.[1–3] Today, it is most frequently performed using a sagittal ultrasound scan at the lateral infraclavicular fossa (LICF),[2–4] where the local anesthetic is injected deep to the pectoral muscles and next to the second part of the axillary artery.[2–4] However, at the LICF, the cords of the brachial plexus are located at a depth (3–6 cm),[5] they are separated from one another,[6] there is significant variation in the position of the individual cords relative to the axillary artery,[6,7] and all 3 cords are rarely visualized in a single ultrasound window.[7] This may explain why relatively large volumes of local anesthetic (up to 35–40 mL)[1,4] and/or multiple injections[1,8] are used to produce successful brachial plexus blockade during a lateral sagittal ICBPB. We have recently proposed[9] that the costoclavicular space (CCS)[9–11] may offer advantages as a site for single-injection and continuous ICBPB. At the CCS, and in contrast to that at the LICF, the cords of the brachial plexus are clustered together lateral to the axillary artery[11] and share a consistent relation to one another and to the axillary artery.[10,12] Ultrasound-guided ICBPB at the CCS, the "costoclavicular brachial plexus block (BPB)," has also been briefly described.[9] However, currently, there are limited data on the relevant sonoanatomy[9] and no clinical data on block dynamics after a costoclavicular BPB. We hypothesized that a single injection of local anesthetic at the center of the nerve cluster at the CCS, under ultrasound guidance, will produce rapid onset of BPB with a high success rate in producing surgical anesthesia. The aim of this prospective nonrandomized feasibility study was to describe in detail the relevant sonoanatomy, technique, and block dynamics of an ultrasound-guided costoclavicular BPB.

METHODS

After clinical research ethics committee (The Joint Chinese University of Hong Kong–New Territories East Cluster Clinical Research Ethics Committee) approval and written informed consent, 30 patients, 18 to 70 years old, with American Society of Anesthesiologists physical status I to III, undergoing elective hand or forearm surgery (Table 1) under a BPB were enrolled for this study. Patients with the following conditions were excluded: patient's refusal, American Society of Anesthesiologist physical status greater than III, pregnancy, neuromuscular disease, prior surgery on the infraclavicular fossa, nerve injury or neurological disorders, bleeding tendency or evidence of coagulopathy, history of allergy to local anesthetic drugs, skin infection at the site of needle insertion, or contraindication to regional anesthesia.

Preoperative Preparation

All patients recruited were seen either on the day before the surgery or the morning of surgery in the day surgery unit, and they all fasted preoperatively. During the preoperative visit, patients were also instructed on the use of a verbal rating scale (VRS) for sensory assessment (100 = normal sensation to zero = no sensation) in the areas of the skin innervated by the 4 major terminal nerves (median, lateral 3 ½ digits on the palmar aspect of the hand; radial, dorsum of hand; ulnar, medial one and half digits on the palmar aspect of the hand and hypothenar eminence; and musculocutaneous, lateral aspect of the anterior forearm) of the brachial plexus. On the day of surgery, patients were admitted to the anesthetic procedure

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TABLE 1. Demographic Data and Clinical Parameters

Demographic Data and Clinical Parameters (n = 30)	
1. Age, yrs	43.7 ± 14.5
2. Sex, M/F	23/7
3. ASA, I/II/III	23/6/1
4. BMI, kg/m^2	24.0 ± 2.8
5. Side of BPB (right/left)	18/12
6. Minimum current required to elicit a distal motor response (posterior or medial cord), mA	0.4 ± 0.1
7. Block performance time, min	6.8 ± 2.0
8. Discomfort score, VRS 0–100	25.4 ± 17.9
9. Type of surgery, a/b/c	21/8/1

Data are presented as mean ± SD except for sex, ASA physical status, side and type of surgery (a, soft tissue surgery; b, arthroscopic wrist surgery; and c, surgery involving fracture around wrist), which are presented as frequency (n).

ASA indicates American Society of Anesthesiologists; BMI, body mass index; F, female; M, male.

room 1 hour before surgery and no premedication was prescribed. On arrival, intravenous access was established (20- to 22-G intravenous catheter) on the contralateral hand or forearm and standard monitoring (electrocardiogram, noninvasive blood pressure, and SaO_2) was instituted. "Time out" (regional anesthesia preprocedural checklist) procedure was also performed.

The Ultrasound Scan Sequence

A Philips iU22 ultrasound system (Philips Healthcare, Andover, Massachusetts) with a high-frequency linear array (L12-5, 12–5 MHz, 50-mm footprint) transducer was used for the scan. Patients were positioned supine, with the ipsilateral arm abducted for the scan (Fig. 1). A soft padding (jelly pad) was placed behind the back, in the interscapular area, and the head was turned slightly to the contralateral side for the BPB. The following anatomic landmarks were then identified and marked on the skin: clavicle, mid-point of the clavicle, and the tip of the coracoid process (Fig. 1). A liberal amount of ultrasound gel was applied to the skin for acoustic coupling, and a transverse scan was performed in 5 sequential steps, over 5 contiguous sites (Fig. 2) over the medial infraclavicular fossa, to ensure consistency and better define the sonoanatomy relevant for the costoclavicular BPB. Additionally, as the ultrasound transducer was manipulated from a medial to lateral direction and over the 5 contiguous sites, the orientation of the transducer was slightly oblique (transverse-oblique) laterally (steps 3–5) to try and maintain the ultrasound beam at right angles to the underlying neurovascular structures (Fig. 2). The ultrasound scan sequence included the following steps: Step 1: the transducer was placed directly over the mid-point of the clavicle in the transverse orientation with its orientation marker directed laterally (outward). Step 2: the transducer was gently moved caudally until it slipped off the inferior border of the clavicle and the axillary artery (first part) and vein were visualized. Maintaining the same transducer position, it was gently tilted cephalad to direct the ultrasound beam toward the CCS, that is, the space between the posterior surface of the clavicle and the second rib (Fig. 3B).[9,11] The ultrasound image was optimized until all 3 cords of the brachial plexus were clearly visualized lateral to the axillary artery (Fig. 3C). If the ultrasound image was not optimal, the medial end of the ultrasound transducer was also gently pivoted caudally to try to align the ultrasound beam at right angles to the underlying neurovascular structures and thereby minimize anisotropy. Step 3: the transducer was gently manipulated laterally, maintaining the same transverse orientation and applying minimal pressure over the area scanned, until the cephalic vein was visualized (Fig. 3D). Step 4: the transducer was moved further laterally until the thoracoacromial artery was seen to emerge from the axillary artery (second part) (Fig. 3E). Step 5: the ultrasound transducer was moved further laterally to the LICF (Fig. 3F). Optimized ultrasound images were captured digitally from each site as a video file for subsequent review.

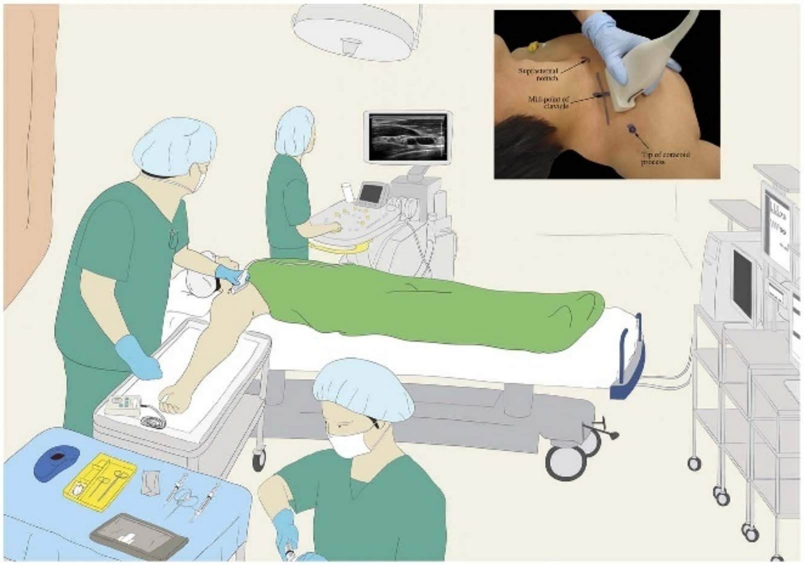

FIGURE 1. Illustration shows position of the patient, anesthesiologist, ultrasound system, and orientation of the ultrasound transducer during the costoclavicular BPB. Inset image shows position and alignment of the transducer relative to the mid-point of the clavicle during the ultrasound scan.

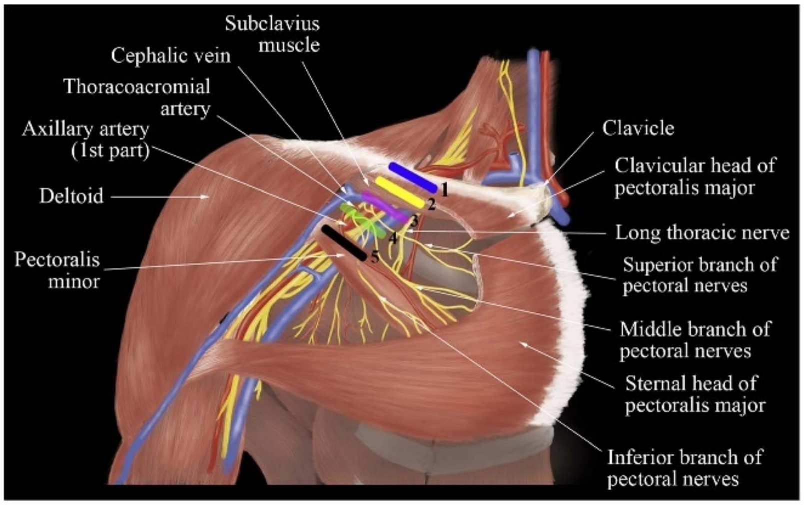

FIGURE 2. Illustration shows the 5 positions of the ultrasound transducer relative to the underlying anatomy of the medial infraclavicular fossa during the scan sequence to define the anatomy relevant for costoclavicular BPB.

Costoclavicular BPB

The BPB was performed using both ultrasound guidance and peripheral nerve stimulation. The latter was used to purely confirm the identity of the cords by observing the elicited motor response. The optimized ultrasound view obtained during step 2 of the scan sequence previously described (Fig. 3C) was used as the target ultrasound window for the BPB. Care was taken to avoid needle insertion with the cephalic vein (Fig. 3D) or thoracoacromial artery (Fig. 3E) in view, as this would indicate needle insertion distal to the CCS. For the same reason, it was imperative that the subclavius muscle was visualized at all times during the needle

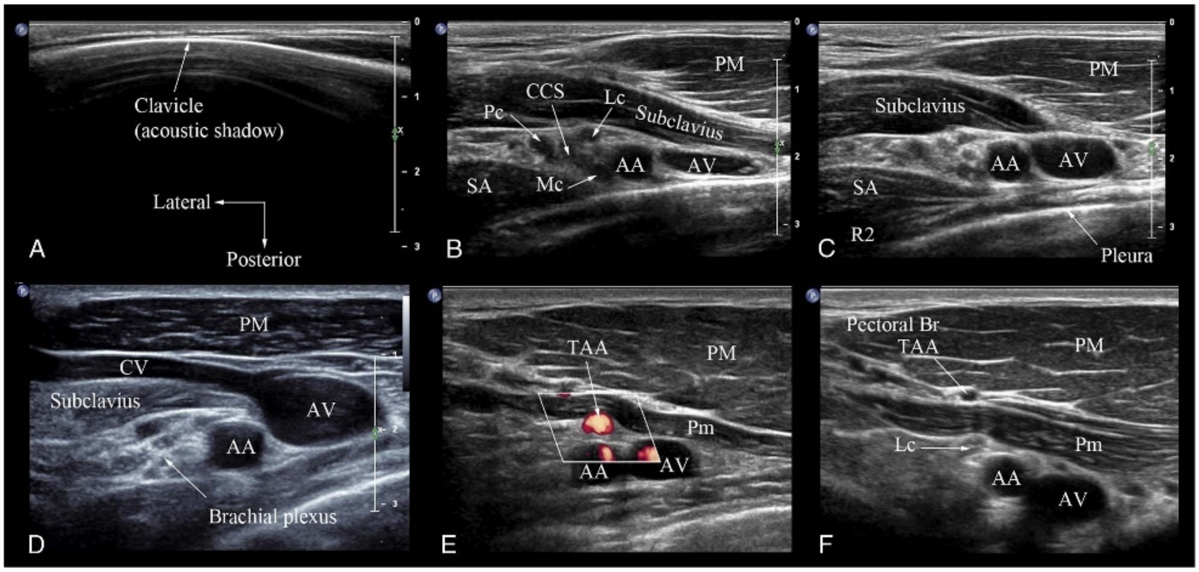

FIGURE 3. Transverse sonograms show the sonoanatomy relevant for costoclavicular BPB. Note that orientation label has been placed over (A). A, Sonogram obtained with the transducer placed directly over the clavicle. Note the large acoustic shadow of the clavicle (step 1). B, Sonogram shows the CCS immediately caudal to the mid-point of the clavicle (step 2). C, Optimized sonogram of the CCS shows cords lying lateral to the axillary artery (AA) and between the subclavius and serratus anterior (upper slip) muscles. D, Sonogram shows the cephalic vein (CV) arching over the cords of the brachial plexus to join the axillary vein (AV) from a lateral to medial direction (step 3). E, Power Doppler sonogram shows the origin of the thoracoacromial artery (TAA) from the AA close to the upper border of the pectoralis minor muscle (Pm) (step 4). F, Lateral infraclavicular fossa deep to the pectoralis major (PM) and Pm muscles (Step 5). Note the pectoral branch of the TAA in the intermuscular plane between the PM and Pm muscles. Lc, lateral cord; Mc, medial cord; Pc, posterior cord; R2, second rib; SA, serratus anterior.

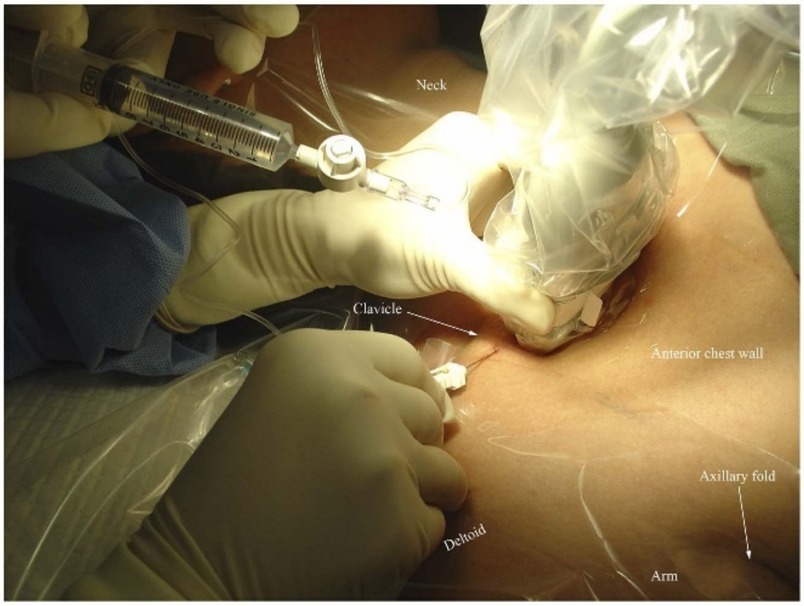

FIGURE 4. Ultrasound-guided costoclavicular BPB. The block needle is inserted in-plane and from a lateral to medial direction. An injection pressure monitor (BSmart injection pressure monitor, B. Braun Melsungen AG, Melsungen, Germany) was attached to the extension tubing of the block needle to ensure that the opening pressure was less than 15 psi throughout the injection.

insertion (Fig. 3C). After strict aseptic precautions and skin infiltration (2–3 mL of lidocaine 1%), an 80-mm, 22-gauge, insulated nerve block needle (SonoPlex Stim cannula; Pajunk, Geisingen, Germany), connected to a peripheral nerve stimulator (0.5 mA, 0.1 millisecond, 1 Hz), was inserted in-plane and from a lateral-to-medial direction (Fig. 4). Since the cords of the brachial plexus are located lateral to the axillary artery[11] and they exhibit a consistent topographical arrangement at the CCS[12] (Fig. 5A), we aimed to place the needle tip at the center of the nerve cluster by advancing the needle through the gap between the lateral and posterior cord and advancing it toward the medial cord (Fig. 5B). A medial (finger flexion) or posterior (elbow or wrist extension) cord motor response to the peripheral nerve stimulation, with the needle tip in the center of the nerve cluster (Fig. 6C), was considered as the desired motor response. Once this was elicited, no attempt was made to reduce or optimize the current threshold of the peripheral nerve stimulator. Pronation of the forearm (lateral cord), elbow flexion (lateral cord), or contraction of the deltoid muscle (posterior cord) were not accepted, and the position of the needle tip was adjusted. Sonographic criteria were also used to define correct needle tip position and they included the following: (*a*) visualization of the needle tip at the center of the nerve cluster, (*b*) spread of a test bolus injection of 1 to 2 mL of 5% dextrose at the center of the nerve cluster but without any obvious swelling of the cords of the brachial plexus (Fig. 6C). Injection pressure was also monitored during the local anesthetic injection, using a BSmart injection pressure monitor (B. Braun Melsungen AG, Melsungen, Germany). The aim was to ensure that the opening pressure was less than 15 psi throughout the injection. If the opening pressure was greater than 15 psi, the local anesthetic injection was immediately discontinued and the position of the needle tip adjusted before the injection was recommenced. A total volume of 20 mL of 0.5% ropivacaine was injected in small aliquots and at a single site over 2 to 3 minutes.

Outcome Measures After the BPB

All outcomes after the BPB were assessed by an independent observer (research nurse). For timing, the end of the local anesthetic (LA) injection was defined as the completion of the BPB (time = 0). Block performance time was defined as the time it took from the start of the skin infiltration to completion of the LA injection. Any complication directly related to the BPB (vascular puncture, pleural puncture, intraneural injection, or local anesthetic toxicity) was also recorded. Patients were also asked to rate the degree of discomfort experienced during the block performance (VRS, 0–100). Sensory block, defined as loss of sensation to cold (ice), in the cutaneous distribution of the ipsilateral median (MN), radial (RN), ulnar (UN), and musculocutaneous (MCN) nerves were assessed and graded according to a VRS (100-0; 100, normal sensation; and 0, no sensation). Motor blockade of each of the 4 nerves in the ipsilateral upper limb was also assessed and graded using a 3-point qualitative scale (2, normal motor power; 1, paresis; and 0, paralysis). Thumb opposition with the index finger, thumb opposition with the little finger, wrist extension, and elbow flexion were used to test motor blockade of the MN, UN, RN, and MCN, respectively. The sensory-motor assessment was performed at regular intervals for 30 minutes (5, 10, 20, and 30 minutes) after the BPB. An overall sensory score was also calculated for every patient, and at each time point assessed, by averaging the VRS sensory score of all the 4 nerves tested. Onset of sensory and motor blockade for each nerve was defined as the time (onset time) it took to achieve a sensory VRS of 30 or less[13] and motor grade 1 or less, respectively. An overall onset time for sensory and motor blockade with all 4 nerves considered together was also calculated. Time to readiness for surgery was defined as the time it took to achieve an overall sensory score of 30 or less and motor grade of 1 or less, in all the 4 nerves tested. The block was considered a success if it was possible to complete

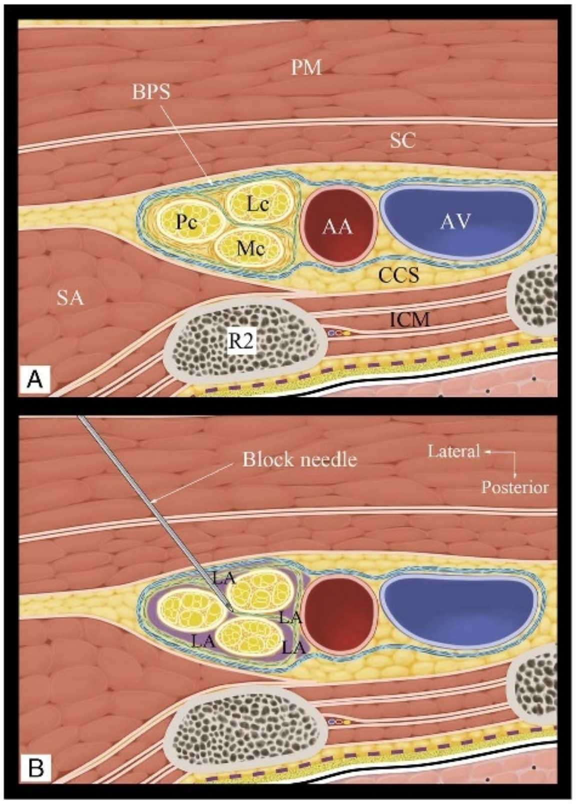

FIGURE 5. Illustration shows the following: A, Anatomy of the CCS and the anatomic relation of the cords to one another and to the axillary artery (A) and the path taken by the block needle during a costoclavicular BPB (B). The block needle was advanced from a lateral to medial direction and through the gap between the lateral and posterior cord and directed toward the medial cord. AA, axillary artery; AV, axillary vein; BPS, brachial plexus sheath; ICM, intercostal muscles; Lc, lateral cord; Mc, medial cord; PC, posterior cord; PM, pectoralis major; SA, serratus anterior; SC, subclavius muscle.

surgery without having to perform a rescue nerve block, infiltrate local anesthetic at the surgical field, or convert to general anesthesia with induction of unconsciousness, administration of systemic opioids and airway support. Patients were seen or contacted via telephone by a research nurse on the day after their surgery (within 24 hours) to ascertain that there was no residual block, persistent neurologic deficit, or both. Additionally, any report of persistent neurologic symptoms or deficit at the 1-week follow-up visit with the surgeon was conveyed back to the research team.

Statistical Analysis

SPSS for Windows version 18.0 (SPSS Inc, Chicago, Illinois) was used for statistical analysis. For continuous variables, normality of the data was tested using the Kolmogorov-Smirnov test. Data are presented as mean ± standard deviation (SD) or median [interquartile range (IQR)] depending on the distribution of the data. Repeated-measures analysis of variance, Cochran Q test, and Friedman test were used as appropriate to compare the sensory and motor block scores, as well as the onset time of sensory and motor blockade between the 4 nerves tested. Bonferroni, McNemar, and Wilcoxon signed ranks tests were used for the post hoc pairwise comparison. $P \leq 0.05$ was considered statistically significant.

RESULTS

Demographic data and clinical parameters are presented in Table 1. Ultrasound imaging of the CCS was successfully performed on all 30 patients. The CCS was visualized as a well-defined intermuscular space between the clavicular head of the pectoralis major and subclavius muscle anteriorly, and the serratus anterior muscle overlying the second rib posteriorly (Fig. 3B). All 3 cords of the brachial plexus were identified in a single transverse sonogram of the CCS (Fig. 3B), and they were visualized lying immediately lateral to the axillary artery. The cords exhibited a triangular arrangement, with the lateral cord lying most superficial and anterior to both the medial and posterior cords (Fig. 3B). The medial cord was directly posterior to the lateral cord but medial to the posterior cord (Fig. 3B). The posterior cord was immediately lateral to the medial cord and posterolateral to the lateral cord (Fig. 3B). The parietal pleura was deeper in location than both the cords and axillary vessels at the CCS. The cephalic vein was seen arching over the cords, from a lateral to medial direction, to join the axillary vein in the ultrasound window immediately distal to the CCS (Fig. 3C). The thoracoacromial artery, which originates from the axillary artery near the upper border of the pectoralis minor muscle, was seen in the ultrasound window immediately distal to the cephalic vein (Fig. 3D) but proximal to the LICF (Fig. 3F).

The costoclavicular BPB was successfully performed on all 30 patients. Details of the sensory and motor blockade after the BPB are presented in Figure 7. Sensory score for the MN was significantly higher than that of the RN ($P = 0.008$; mean difference, 12.3; 95% confidence interval, 2.5–22.1) at 5 minutes after the BPB, but otherwise, there were no differences in the sensory or motor scores between the 4 nerves at any time point during the study (Fig. 7). The median onset time for sensory and motor blockade of all the 4 nerves was 5 [5–15] and 5 [5–10] minutes, respectively, and there were no differences between the individual nerves (Table 2). Complete sensory blockade of all the 4 nerves was achieved in 30 [20–30] minutes, and there was no difference between the individual nerves ($P = 0.06$; MN, 20 [10–40] minutes; UN, 20 [10–30] minutes; RN, 20[5–30] minutes, and MCN, 30 [17.5–40] minutes). Complete motor blockade of all the 4 nerves was achieved in 20 [20–30] minutes, and it was significantly ($P < 0.005$) slower for the MN nerve (30 [20–40] minutes) when compared to the RN (20 [10–30] minutes; $P = 0.001$), UN (20 [5–20] minutes, $P = 0.002$) and MCN (20 [10–30] min, $P = 0.003$). The number of patients who developed complete sensory blockade of each of the 4 nerves at various time points during the study was also comparable (Table 3), but fewer patients developed complete motor blockade of the MN ($P < 0.05$) during the first 20 minutes after the BPB (Table 4). The median time to readiness for surgery was 10 [5–20] minutes, and the BPB was effective for surgical anesthesia in 29 of 30 patients studied (success rate, 97%). There were no complications directly related to the technique or the LA injection, and recovery from the BPB was uneventful.

DISCUSSION

This study aimed to describe in detail the relevant sonoanatomy, technique, and block dynamics of an ultrasound-guided costoclavicular BPB. Using ultrasound, the CCS was visualized as a well-defined intermuscular space, lying deep and posterior to the mid-point of the clavicle and between the clavicular head of the pectoralis

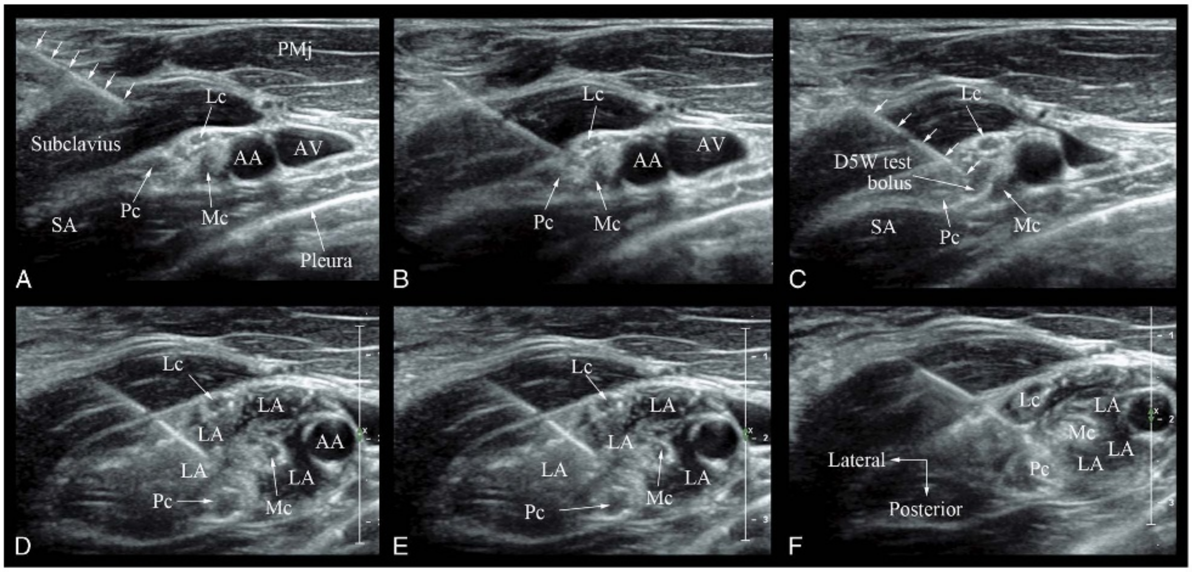

FIGURE 6. A sequence of transverse sonograms captured during an ultrasound-guided costoclavicular BPB. Note that the orientation label has been placed over Figure 6F. A, The block needle is inserted in-plane from a lateral to medial direction; the needle tip is being advanced through the gap between the lateral and medial cord (B), with the needle tip positioned at the center of the nerve cluster (C). D-F, Note the effect of the test bolus injection of 1 to 2 mL dextrose 5% during and after LA injection .

major and subclavius muscle anteriorly and the upper slips of the serratus anterior muscle and the second rib posteriorly. All 3 cords of the brachial plexus were visualized in a single transverse sonogram of the CCS. The cords were clustered together lateral to the axillary artery, and they exhibited a consistent triangular arrangement. It was feasible to guide a block needle to the center of the nerve (cord) cluster using ultrasound guidance and causing minimal discomfort to the patient. Under the conditions of this study, the costoclavicular BPB produced rapid onset of sensory-motor blockade of the MN, RN, UN, and MCN that was effective for surgical anesthesia in all but one of the patients studied (success rate, 97%). We believe this is the first study to describe in detail the sonoanatomy, technique, and block dynamics of a costoclavicular BPB.

The CCS was visualized as a well-defined space lying deep and posterior to the mid-point of the clavicle. The axillary vessels and cords of the brachial plexus were seen to traverse the CCS, with the latter lying lateral to the axillary artery. The cords appeared hypoechoic, they were clustered together and exhibited a consistent anatomic arrangement relative to one another and to the axillary artery. Currently, there are limited data on the anatomy of the CCS,[9–11] but our findings are in agreement with what we have recently demonstrated in cadavers.[11] The compact arrangement, and consistent anatomic relationship, of the cords at the

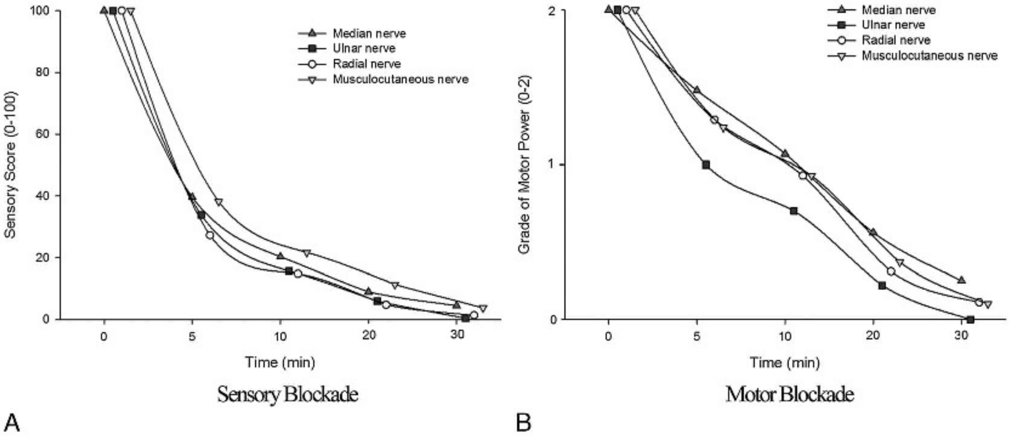

FIGURE 7. Sensory-motor blockade of the median, ulnar, radial and musculocutaneous nerves during the first 30 minutes after the costoclavicular BPB. Data are presented as the median value. The interquartile range for each data point has been removed for clarity.

TABLE 2. Onset Times of Sensory and Motor Blockade for the Median, Ulnar, Radial, and Musculocutaneous Nerves and all 4 Nerves Considered Together After the Costoclavicular BPB

	Sensory Block (min)	Motor Block (min)
1. Median nerve	10 [5–10]	5 [5–10]
2. Ulnar nerve	5 [5–10]	5 [5–8.75]
3. Radial nerve	5 [5–10]	5 [5–8.75]
4. Musculocutaneous nerve	5 [5–20]	5 [5–16.25]
5. *P* value	0.21	0.92
6. Overall (all 4 nerves)	5 [5–15]	5 [5–10]

Data are presented as median [IQR]. *P* values represents the results for the comparison (Friedman test) of the onset time for sensory and motor blockade between the individual nerves.

CCS are in contrast to that seen at the LICF, where the cords are separate from one another[5–7] and there is significant variation in the position of the individual cords relative to the axillary artery.[6,7] This may explain the high success rate of the costoclavicular BPB that we have demonstrated in this study despite using a single injection of a relatively small volume of local anesthetic (20 mL). However, although our results are encouraging, this was a nonrandomized study and there are no comparative data. It is also not known if a multiple-injection technique, targeting the individual cords, might produce better results. Therefore, randomized trials comparing the efficacy of a costoclavicular BPB with the traditional lateral sagittal ICBPB are warranted in the future.

The local anesthetic was injected at the center of the nerve (cord) cluster within the CCS during the costoclavicular BPB. There are no comparable data, but Kilka et al have also described an infraclavicular BPB at the proximal part of the medial infraclavicular fossa, the "vertical infraclavicular brachial plexus block" (VIB),[14] using anatomic landmarks and peripheral nerve stimulation. Published data suggest that the local anesthetic is injected distal to the subclavius muscle,[12] and thus, the CCS, during a VIB. Nevertheless, the topography of the cords at the CCS and where a VIB is performed is almost identical, and the local anesthetic is also injected close to the medial and posterior cords[15] in both techniques. Therefore, the costoclavicular BPB and VIB may produce comparable sensory-motor block characteristics that deserve investigation in the future.

The costoclavicular BPB produced rapid onset of sensory-motor blockade with a median time to readiness for surgery, as previously defined, of 10 [5–20] minutes, and it was effective for surgical anesthesia in 97% of patients studied. Failure in the solitary patient was due to incomplete sensory-motor blockade of the MN, which was successfully managed using a rescue MN block at the mid-forearm. There are no comparable data, and no direct comparison can be made with previously published data because different drugs and criteria to define the onset time of BPB were used. Nevertheless, the onset time of sensory blockade for the 4 major nerves of the brachial plexus that we have demonstrated in this study seems to be faster than data previously reported with the lateral sagittal ICBPB.[16,17] Future research should compare block dynamics of a costoclavicular BPB with the lateral sagittal ICBPB. Complete motor blockade of all the 4 nerves was also achieved relatively quickly, but it was significantly slower for the MN when compared to the other 3 nerves. There are no comparable data; and the exact reason for this variable onset of motor blockade is not clear, but our results suggest that the onset of motor blockade was faster for the posterior and medial cords than for the lateral cord. At the CCS, the posterior and medial cords are very closely apposed to each other,[10–12] bound together by a common connective tissue,[11] and they also run separate from the lateral cord.[11] Since the local anesthetic was injected at the center of the nerve cluster and close to all 3 cords in this study, we can only speculate that preferential spread of local anesthetic to the medial and posterior cords may have produced the variable onset of motor blockade in this study. Additionally, the role of connective tissue barriers in preventing access of the local anesthetic to the lateral cord cannot be excluded and deserves investigation in the future.

We chose to use 20 mL of local anesthetic for the BPB, as this was based on a pilot study at the institution of the primary investigator (M.K.K.). There are no comparable data, but the volume used is significantly lower than what is generally used for a lateral sagittal ICBPB.[4,18] Given the difference in the anatomical arrangement of the cords at the CCS and LICF (previously discussed), it seems plausible to use lower volumes of local anesthetic at the CCS for BPB. Future research to determine the optimal dose or volume of local anesthetic required to produce BPB at the CCS is warranted.

There were no complications directly related to the technique or the local anesthetic injection. However, because of the close proximity of the cords to the cephalic vein, axillary vessels, and the pleura at the CCS, there is potential for inadvertent vascular and/or pleural puncture. We believe the position of the cords relative to the axillary artery and the pleura at the CCS, combined with ultrasound guidance, and a lateral- to medial-directed needle insertion as described in this report, may confer protection against vascular and pleural puncture because the needle tip is more likely to encounter the cords of the brachial plexus before the artery and pleura. Since ours was a feasibility study with a small sample size,

TABLE 3. Number of Patients Who Developed Complete Sensory Blockade (sensory score = 0) of the 4 Nerves at Various Time Points During the Study

	Median Nerve	Ulnar Nerve	Radial Nerve	Musculocutaneous Nerve	*P*	Overall (all 4 Nerves)
5 min	3/30 (10%)	4/30 (13.3%)	8/30 (26.7%)	2/30 (6.7%)	0.123	3/30 (10%)
10 min	8/30 (26.7%)	9/30 (30%)	13/30 (43.3%)	7/30 (23.3%)	0.068	4/30 (13.3%)
20 min	16/30 (53.3%)	21/30 (70%)	21/30 (70%)	14/30 (46.7%)	0.132	8/30 (26.7%)
30 min	23/30 (76.7%)	28/30 (93.3%)	27/30 (90%)	21/30 (70%)	0.069	18/30 (60%)

Data are presented as frequency, n (%). *P* value represents the Cochrane Q test results for comparion between the 4 nerves.

TABLE 4. Number of Patients Who Developed Complete Motor Blockade (Motor Scale = 0) of the 4 Nerves at Various Time Points During the Study

	Median Nerve	Ulnar Nerve	Radial Nerve	Musculocutaneous Nerve	*P*	Overall (all 4 Nerves)
5 min	0/30 (0%)	6/23 (26.1%)	2/29 (6.9%)	4/30 (13.3%)	0.05*	2/30 (6.7%)
10 min	2/30 (6.7%)	9/23 (39.1%)	9/29 (31.0%)	11/30 (36.7%)	0.024†‡§	4/30 (13.3%)
20 min	13/30 (43.3%)	18/23 (78.3%)	21/29 (72.4%)	20/30 (66.7%)	0.07‖	19/30 (63.3%)
30 min	18/30 (60%)	23/23 (100%)	26/29 (89.7%)	27/30 (90%)	0.10	25/30 (83.3%)

Data are presented as frequency, n (%). *P* value represents the Cochrane Q test results for comparion between the 4 nerves. Pairwise comparison using McNemar test show.

**P* = 0.03 for median nerve (MN) vs ulnar nerve (UN) at 5 minutes; †*P* = 0.02 for MN vs UN at 10 minutes; ‡*P* = 0.02 for MN vs radial nerve (RN); §*P* = 0.004 for MN vs musculocutaneous nerve at 10 minutes; and ‖*P* = 0.02 for MN vs RN at 20 minutes.

it is not possible to comment on the safety of the technique. Future research to establish the safety and advantages of the costoclavicular BPB is warranted.

Limitations of this study are that it was not randomized, it lacked a comparator group, and patients were also of low body mass index. We did not randomize our patients because this was the first study to evaluate the feasibility and block dynamics of the costoclavicular BPB technique. The body mass index of patients was low but is consistent with the typical patient at the primary investigator's institution. Therefore, our results may not apply to the obese, and future research should evaluate the feasibility of the costoclavicular BPB technique in obese patients. Additionally, the ipsilateral arm had to be abducted to create space for the in-plane needle insertion. Therefore, our technique may not apply to patients who are unable to abduct the arm unless one inserts the needle out of plane, which also deserves investigation in the future.

CONCLUSIONS

In conclusion, we have described in detail the sonoanatomy relevant for brachial plexus block at the CCS. We have also demonstrated that it is feasible to perform ultrasound-guided costoclavicular BPB. A single injection of local anesthetic at the center of the nerve cluster at the costoclavicular space produces rapid onset of sensory-motor blockade of the 4 major nerves of the brachial plexus that is effective for surgical anesthesia (success rate, 97%). Future research to establish the safety, efficacy, and reliability of the costoclavicular BPB compared with the traditional lateral sagittal ICBPB is warranted.

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