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Sonographic visualization and cannulation of the axillary vein in two arm positions during mechanical ventilation: A randomized trial

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Abstract

Background: Abduction of the arm has been used for ultrasound-guided infraclavicular axillary vein cannulation. We evaluated the influence of arm position on sonographic visualization and cannulation of the axillary vein in patients receiving mechanical ventilation.

Methods: Sixty patients scheduled to undergo surgery under general anaesthesia with controlled mechanical ventilation were included in this prospective randomized study. The depth, size and distance of axillary vein to the pleura were recorded at three points: Point A, the most proximal part of the axillary vein visualized with adduction; Point A′, Point A in abduction; and Point B, the most proximal part of axillary vein visualized in abduction. Cephalic movement of the clavicle at Point A′ and the distance between Point A and Point B were noted. In Group A, cannulation was performed at Point A in the adducted arm and at Point B with the abducted arm in Group B after randomization.

Results: Abduction moved the clavicle cephalad by 2.2 ± 0.6 cm and increased sonographic visualization of the axillary vein by 2.2 ± 0.5 cm in length, when compared with adduction. The distance from the vein to pleura was higher in Point A′ ($p < 0.001$). No differences were found during cannulation in terms of first-pass success rate or number of attempts.

Conclusion: Abducted position moved the clavicle cephalad and allowed sonographic visualization of infraclavicular axillary vein approximately 2 cm more proximally than with the adducted arm, with a comparable rate of cannulation success.

Keywords

Axillary vein, ultrasonography, arm position, central venous catheterization, subclavian vein

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Introduction

The subclavian vein extends from the lateral border of first rib to the anterior scalene muscle beneath the clavicle, making ultrasound visualization and real-time guided puncture in the infraclavicular area impossible.[1,2] In contrast, the axillary vein that extends from the lateral border of first rib to the outer border of teres major is visible with ultrasound and is becoming the popular route for central venous access.[3–5] However, the overlapping of the medial one-third of clavicle over the first and second ribs and its post acoustic shadow may obscure variable length of the proximal axillary vein from sonographic visualization. Hence, ultrasound-guided axillary vein punctures are more lateral than landmark-guided subclavian punctures.[1] Recently, abduction of the arm during ultrasound-guided axillary vein cannulation has been found to increase the

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cross-sectional area of the visualized vein and cannulation in that position can reduce the rate of catheter tip malposition.[4,6–9] However, none of these studies objectively measured the effect of arm abduction on the length of the infraclavicular axillary vein visualization, when compared with adduction. We aim to evaluate the influence of arm abduction on sonographic visualization of axillary vein and compare the success rate of cannulation at the most proximal axillary vein visualized in abduction versus adduction.

Methods

This prospective randomized clinical trial was approved by the Institutional Research Council and Institutional Human Ethics Committee of Mahatma Gandhi Medical College and Research Institute, Pondicherry, India (P.G. Dissertation 10/20/2015) and registered with the Clinical Trial Registry of India (CTRI/2018/01/011390). Sixty patients undergoing elective surgery under general anaesthesia from January 2016 to August 2017 were enrolled in this study by continuous sampling. The inclusion criteria were patients classified as American Society of Anaesthesiologists I–III and those with body mass index less than 30. Exclusion criteria included patients with difficult sonoanatomy (>4 cm depth of axillary vein from the skin) and fracture of either clavicle or rib.

All patients were premedicated the day before surgery and were administered general anaesthesia with tracheal intubation at the discretion of the attending anaesthesiologist. Mechanical ventilation was volume controlled with tidal volume of 8–10 mL/kg, respiratory rate at 12/min and no positive end-expiratory pressure (PEEP). After initiating mechanical ventilation and stabilizing haemodynamics, all patients were placed in the supine position with the head turned towards the left side. A Sonosite X-Porte (SonoSite, Bothell, WA, USA) US system with multibeam (compound imaging) capability and a high-frequency linear array transducer (HFL50, 15–6 MHz) was used for the sonographic measurements.

Scanning and sonographic measurements

Initially, the arm was abducted at the shoulder joint, and the ultrasound probe was aligned in the sagittal plane to obtain the short-axis view of the infraclavicular axillary vein in the lateral part of chest below the clavicle. The initial aim was to identify the axillary vein as an irregular, non-pulsatile, collapsible, hypoechoic structure caudal to the axillary artery – a circular, pulsatile, non-compressible, hypoechoic structure. Then, the axillary vein was scanned proximally until the axillary artery disappeared under the clavicular acoustic shadow and the vein was detected at a point closest to that shadow. This point was marked as Point A on the skin, and the sonographic image at this point was frozen in expiration for sonographic measurements (Figure 1(a)). Then, the arm was abducted 90° at the shoulder joint with flexion at the elbow joint, and the probe was placed longitudinally at the previously marked Point A. Close monitoring was done to obtain the clavicular acoustic shadow and vein within the same image. The image was frozen at this point in expiration (Point A′) to obtain sonographic measurements and to measure the distance from the clavicular acoustic shadow to the axillary vein, which is reflective of the cephalic movement of the clavicle (Figure 1(b)). Subsequently, the probe was moved proximally until the axillary artery disappeared and the axillary vein was seen at a point closest to the clavicular acoustic shadow. This point was marked as Point B, and sonographic measurements were recorded after freezing the image in expiration (Figure 1(c)). We recorded the distance from the skin to the anterior wall of the axillary vein, the distance from the posterior wall of the vein to the pleura or rib, the posterior relation of the axillary vein (rib or pleura), the size of the axillary vein in terms of its area and circumference. The distance between Point A and Point B on the skin was measured using a scale (Figure 1(d)).

Randomization and cannulation

After obtaining the vein dimensions in both arm positions, patients were randomized into one of the groups by block randomization using a computer-generated random number. Allocation concealment was done with the use of sequentially numbered, opaque sealed envelopes. An anaesthesiologist (with more than 2 years of experience in ultrasound-guided procedures) performed the axillary vein cannulation under strict aseptic precautions. Out-of-plane technique was used for ultrasound-guided puncture and Seldinger's technique was used for cannulation. In Group A, the patients were positioned supine with the arm adducted and the cannulation was done at Point A (the most proximal point of axillary vein visualized in the adducted arm position). In Group B, the patients were positioned supine with the arm abducted 90° at the shoulder and elbow flexed, and the cannulation was done at Point B (the most proximal point of axillary vein visualized in the abducted arm position). The following parameters of cannulation success were noted:

1. First-pass success was defined as the presence of blood aspirate and successful guidewire placement in the first attempt.
2. Attempt was defined as a change of needle puncture with a maximum of three attempts allowed in the allocated arm position.
3. Failure was defined as more than three attempts in the allocated arm position.

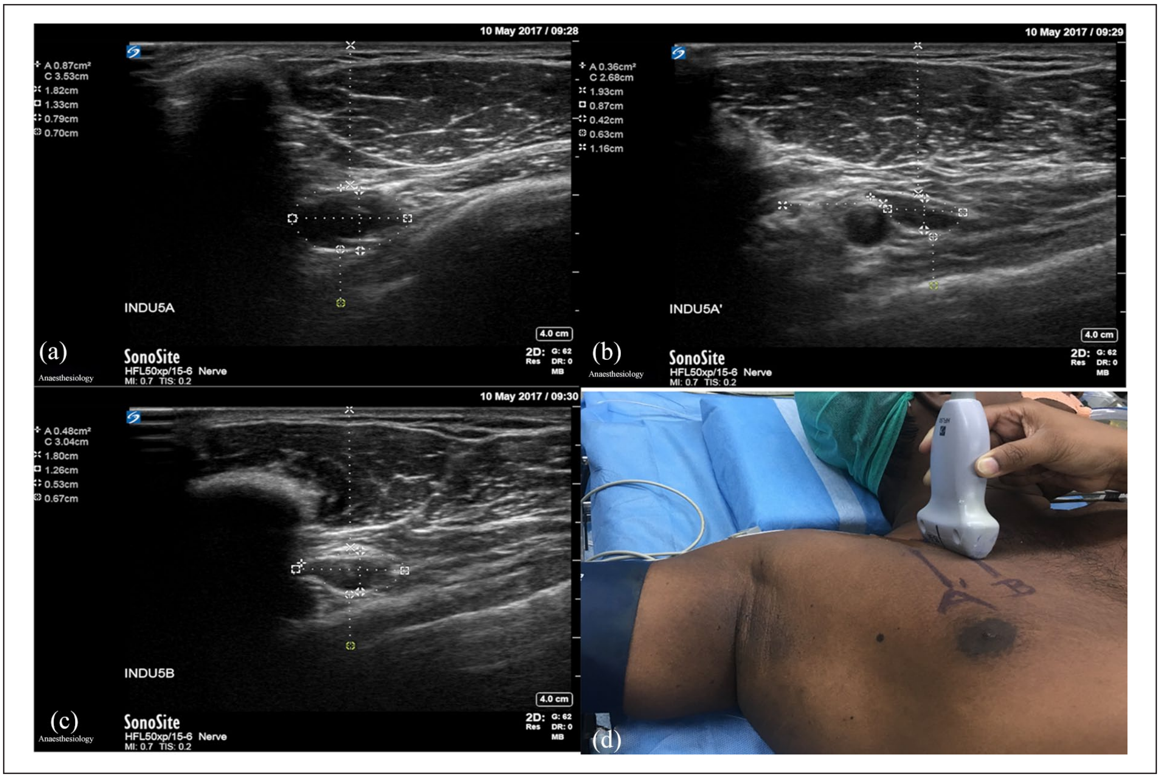

Figure 1. The sonoanatomy of infraclavicular axillary vein at three points. (a) The infraclavicular axillary vein and measurements at Point A (adduction). (b) The infraclavicular axillary vein, its measurements and distance from clavicular acoustic shadow at Point A′ (Point A in abduction). (c) The infraclavicular axillary vein and its measurements at Point B (abduction). (d) Skin markings of Point A (most proximal part in adduction) and Point B (most proximal part in abduction).

If venous puncture was unsuccessful after three attempts, the position of the arm was changed to that of the other group; if cannulation was still unsuccessful in both arm positions, the internal jugular vein was cannulated under ultrasound guidance for central venous access. Complications including arterial puncture and pneumothorax were noted.

Statistical analysis

SPSS for Mac 21.0 (SPSS Inc., Chicago, IL, USA) was used for statistical analysis. A p-value less than 0.05 was considered statistically significant. Normality of the data was evaluated using the Kolmogorov–Smirnov test. Data were represented as a ratio (percentage), mean ± standard deviation (SD) and median (interquartile range (IQR)). Repeated-measures analysis of variance (ANOVA) was used for sonographic measurements among three points, and the least significant difference (LSD) was used for post hoc comparisons. The chi-square test and t-tests were used to compare non-parametric and parametric variables, respectively.

Sample size was calculated using the 'Power and Sample Size Online Calculator' (HyLown Consulting LLC, Atlanta, GA, USA). During the pilot study, we found that the abduction of the arm consistently moved the clavicular shadow cephalad in all the patients and exposed a considerable length of axillary vein proximally. We could not obtain any previous clinical literature addressing this aspect and we are unaware of the implication of this anatomical finding during cannulation. Hence, we took first-pass success rate as an outcome measure for sample size calculation. In a study by Vezzani et al.,[10] the first-pass success rate was 72% during ultrasound-guided infraclavicular axillary vein cannulation with the arm in the adducted position. The estimated sample size was 54 patients (27 in each group) to demonstrate equal success rate with a non-inferiority margin of 50% of the first-pass success rate (36%) with the abducted arm position, a power of 80% and an α error of 0.05. In consideration of potential dropouts, 60 patients were recruited for this study.

Results

Of the 90 patients who were screened, 60 met the inclusion and exclusion criteria (Figure 2).

Sonographic measurements were taken in all patients. Demographic variables were comparable between groups (Table 1).

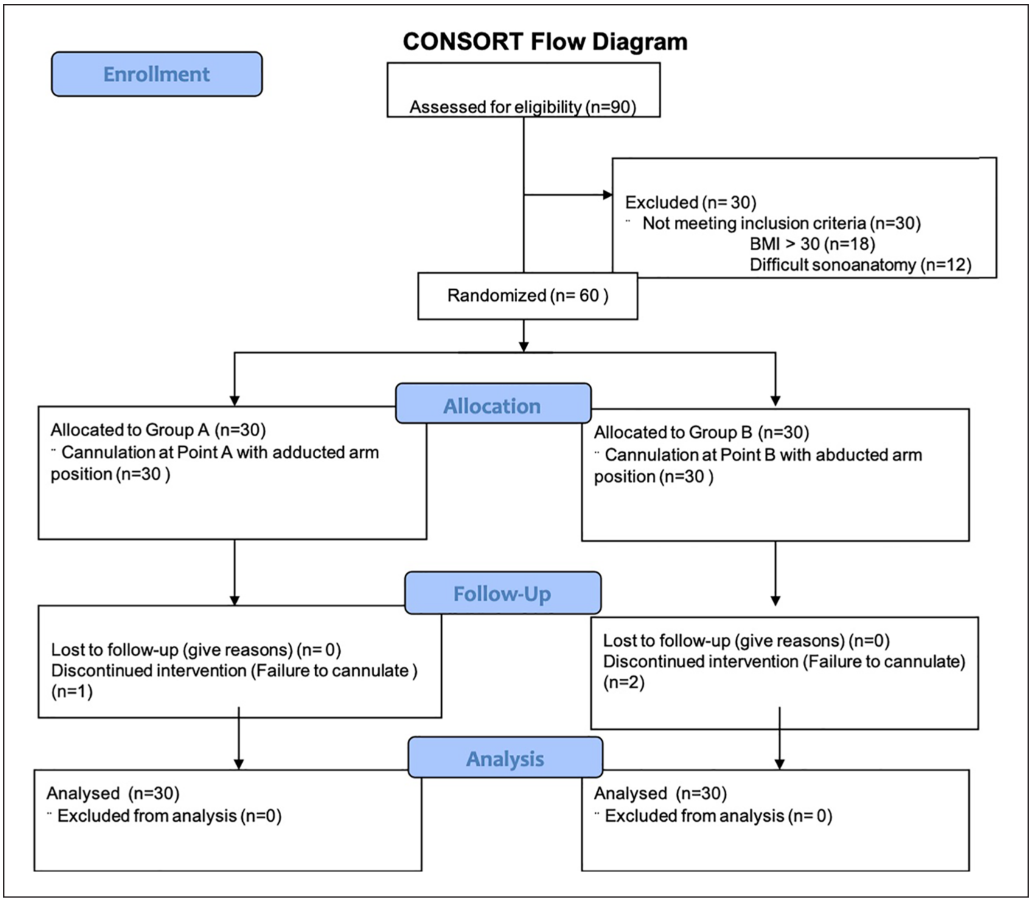

Figure 2. Consort flow diagram.

Table 1. Patient characteristics for infraclavicular vein cannulation between the two arm positions.

	Adducted arm (n = 30)	Abducted arm (n = 30)	p-value
Age, years	53 ± 15	54 ± 16	0.790
Gender (M/F)	25/5	20/10	0.136
Weight, kg	58.4 ± 8.6	56.7 ± 7.5	0.419
Height, m	1.6 ± 0.1	1.6 ± 0.1	0.592
BMI, kg/m^2	23.7 ± 3.2	22.7 ± 2.3	0.186

M/F: male/female; BMI: body mass index.
Values are mean ± SD or ratio.

Compared to adduction, abduction of the arm increased sonographic visualization of the vein proximally by up to 2.2 ± 0.5 cm (range: 1.1–3.5 cm), as measured by the distance between Point A and Point B. The clavicle was moved cephalad by a mean of 2.2 ± 0.6 cm (range: 1.1–3.5 cm), as measured in Point A′. Compared with the adducted arm (Point A), the size of the vein became smaller (by area, A = 2 mm^2 and circumference, C = 3 mm) in abduction (Point A′ and Point B) and the proximal part of the vein became superficial (Point B: 17 ± 0.5 mm) by 3 mm relative to the distal part (Point A: 20 ± 0.5 mm and Point A′: 20 ± 0.6 mm). The pleura moved away from the vein in the abducted arm at Point A′ (9 ± 0.6 mm), when compared with Point A (6 ± 0.2 mm) and Point B (6 ± 0.2 mm) (Figure 3). In 90% of the patients in the adducted arm position (Point A), the pleura was located posteriorly to the vein, whereas this was observed in 42% (Point A′) and 48% (Point B) of those in abduction.

There were no significant differences during cannulation in terms of the first-pass success rate, number of attempts, or overall success rate between the groups (Table 2). None of the patients had arterial puncture or pneumothorax.

Discussion

In this prospective randomized study, we compared the length of visualized infraclavicular axillary vein and its cannulation success using ultrasound in adducted and abducted arm positions. We found that the costoclavicular space opened during abduction of the arm, due to the cephalic movement of lateral end of the clavicle

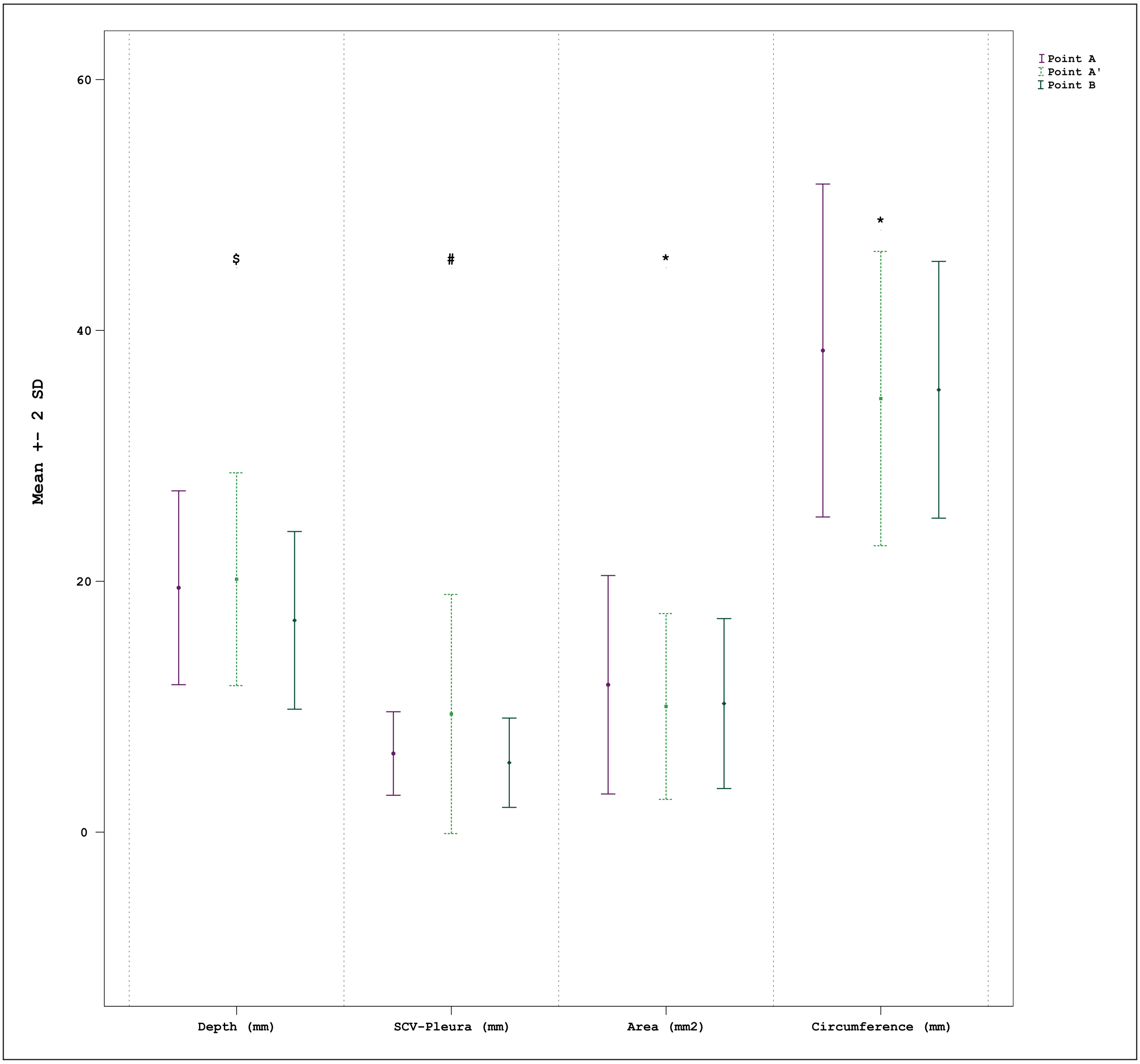

Figure 3. The depth, distance to pleura or rib and dimensions (circumference and area) of infraclavicular axillary vein at all three points.

— represents Point A (most proximal part in adducted arm position), --- represents Point A′ (Point A in abducted arm position) and — represents Point B (most proximal part in abducted arm position). $ denotes $p < 0.001$ between Point B versus Point A and Point A′. # denotes $p < 0.001$ between Point A′ versus Point A and Point B. * denotes $p < 0.001$ between Point A versus Point A′ and Point B.

Table 2. Infraclavicular vein cannulation dynamics in adduction and abduction.

	Adducted arm (n = 30)	Abducted arm (n = 30)	p-value
First-pass success rate	21/30 (70%)	24/30 (80%)	0.371
Overall success rate	29/30 (97%)	28/30 (93%)	0.554
Number of attempts (1/2/3)	21/6/2	24/3/1	0.469

Values are ratio or percentage.

and its attending post acoustic shadow. This primary anatomical change enabled us to scan an additional 2 cm length of the proximal infraclavicular axillary vein. Even though the vein became superficial (3 mm) and smaller (2 mm^2), the change was clinically insignificant. The first-pass success rate, number of attempts and complications of cannulation at the proximal part of the axillary vein, with the arm in abducted position, were comparable to those with the arm in adducted position.

The length of infraclavicular axillary vein amenable to ultrasound visualization was the part between the outer border of the teres major distally and the clavicular acoustic shadow proximally, where the vein disappears before entering the thorax. With the available length of axillary vein to standardize the point of venous measurement, we took the proximal-most part of the vein that was visible close to the clavicular acoustic shadow at each arm position (Point A and Point B). Similarly, the venous dimension may change with respect to angle at which the ultrasound beam intersects the vein (transverse vs oblique view) and phase of respiration (inspiration and expiration). Hence, we standardized the view by sagittal probe position over the clavicle and recorded the measurement from the frozen image captured at the end of expiration in an uninterrupted ventilatory cycle. These techniques facilitated reliable and repeatable sonographic measurements.

We found that abduction of the arm moved the post acoustic shadow of the clavicle by 2 cm. Similar to the findings of our study, Cantú-Martínez et al.[11] reported that the clavicle moved cephalad by 1 cm when the arm was switched from an adducted to abducted arm position in cadavers. Moreover, studies of the biomechanics of shoulder movement revealed a 4° clavicular elevation for every 10° elevation of the humerus.[12] Thus, abduction opens the costoclavicular space and allows sonographic visualization of the proximal axillary vein more than in the adducted arm position. Sadek et al.[7] reported a 50% increase in the cross-sectional area of the vein in the long axis and no change in the short axis. Increase in long-axis view may be due to the additional length of the proximal part of the vein visualized, as in our study.

Similar observations that arm position did not affect the vein size have been observed.[7,8] Pittiruti et al.[9] showed that 90° abduction with a forward position of the shoulder released pectoralis minor pressure and increased the anteroposterior and laterolateral axillary vein diameter by 3 mm. In contrast, we found that the vein became smaller by 3 mm^2 with abduction which is clinically insignificant. A possible explanation is that we studied paralyzed and mechanically ventilated patients compared to spontaneously breathing patients in their study.

The vein became superficial by 3 mm indicating that the axillary vein ascends up over the anterior chest wall to enter into the thoracic inlet and could be observed only when the proximal vein was exposed with the arm in abduction.[7] Similarly, pleura was present posterior to the vein in 50% of patients with the arm abducted compared to 90% with the arm adducted. Abduction of the arm moved the pleura away from the vein by 3 mm at Point A′. Even though minimum changes in the tilting of the probe could change the posterior relationship from pleura to rib or vice versa, recognizing these features may reduce the risk of injury to the lung when cannulation is performed by inexperienced personnel or in obese patients.

Ahn et al.[6] also found that there was no difference in the success rate or occurrence of complications between the two arm positions during ultrasound-guided infraclavicular axillary vein cannulation, although our cannulation points in two arm positions were different from them. The first-pass success rate, number of attempts and immediate complications such as pneumothorax and haemothorax between the groups are dependent on the patient's anatomy and experience level of the personnel performing the procedure. The fact that an experienced anaesthesiologist performed all the cannulation in normovolaemic, non-obese patients receiving mechanical ventilation could explain our findings.

Even though we did not study the final catheter tip position following cannulation at two different arm positions, Ahn et al.[6] reported that the incidence of catheter misplacement was higher (3.9% vs 0.4%) in the adducted than in abducted arm position and hypothesized that the upward movement of the shoulder decreased the angle between the subclavian vein and the internal jugular vein during abduction. On the contrary, a more proximal cannulation by landmark guidance may cause catheter pinch-off syndrome by compression of the subclavian vein between the first rib and clavicle.[13,14] This may lead to serious complications, such as catheter embolization due to tearing or transection. These complications may be prevented by cannulation at the most proximal part of axillary vein visualized in abduction. Thus, the proximal axillary vein in the abducted arm position may be an ideal site for infraclavicular axillary vein cannulation. However, further studies with larger sample size involving long-term catheters are required to confirm this hypothesis.

We recognize the following limitations in our study: (1) we could not study the immediate and late catheter misplacement and delayed complications, such as thrombosis and catheter-related infection, between the groups, as our study population required short-term central venous access; (2) the sonographic measurements were obtained in a non-randomized and non-blinded manner, as the points were measured in a sequential manner; (3) patients with obesity or altered anatomy at the puncture site were excluded in our study, which may have limited our statistical significance from getting extrapolated as clinical significance in those patients; (4) all of our cannulations were performed by one experienced anaesthesiologist, which may have influenced the success rate found in the study; and (5) we did not study the influence of the abducted arm position in spontaneously breathing patients and on respiratory variation.

We conclude that 90° arm abduction at the shoulder with flexion at the elbow moves the clavicular post acoustic shadow cephalad and allows sonographic visualization of the proximal axillary vein approximately 2 cm more than that during adduction. This allowed us to puncture ~2 cm of proximal axillary vein in the abducted position with no difference in first-pass success rate, number of attempts, and complications during ultrasound-guided cannulation (by experienced personnel) in non-obese patients receiving mechanical ventilation. We conclude that the abducted arm position is an ideal position for ultrasound-guided infraclavicular axillary vein cannulation. Studies with larger sample sizes and those that evaluate long-term use of catheters are required to confirm our findings.

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Clinical trial number and registry

Clinical Trial Registry of India (CTRI/2018/01/011390), http://ctri.nic.in/Clinicaltrials/login.php

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