Original Article

Ultrasound measurement of the distance of the phrenic nerve from the brachial plexus at the classic interscalene point and upper trunk: A volunteer-based observational study

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ABSTRACT

Background and Aims: The method of blocking the brachial plexus at the level of the upper trunk has been gaining popularity as a phrenic nerve–sparing alternative for interscalene block. We aimed to measure the distance of the phrenic nerve from the upper trunk and compare it with the distance between the phrenic nerve and the brachial plexus at the classic interscalene point by using ultrasound. **Method:** In this study, after ethical approval and trial registration, 100 brachial plexus of 50 volunteers were scanned from the emergence of the ventral rami and its course was traced to the supraclavicular fossa. The distance of the phrenic nerve from the brachial plexus was measured at two levels: the interscalene groove along the cricoid cartilage (classic interscalene block point) and from the upper trunk. The presence of anatomical variations of the brachial plexus, the classic traffic light sign, vessels across the plexus, and the location of the cervical oesophagus were also noted. **Results:** At the classic interscalene point, the C5 ventral ramus was observed to be just emerging or to have fully emerged from the transverse process. The phrenic nerve was identified in 86/100 (86%) of scans. The median (IQR) distance of the phrenic nerve from the C5 ventral ramus was 1.6 (1.1-3.9) mm and that of the phrenic nerve from the upper trunk was 17 (12-20.5) mm. Anatomical variations of the brachial plexus, the classic traffic light sign, and vessels across the plexus were seen in 27/100, 53/100, and 41/100 scans respectively. The oesophagus was consistently located on the left side of the trachea. **Conclusions:** There was a 10-fold increase in the distance of the phrenic nerve from the upper trunk when compared to that from the brachial plexus at the classic interscalene point.

Key words: Brachial plexus block, distance, interscalene, nerve block, phrenic nerve, ultrasonography, upper trunk

INTRODUCTION

The interscalene block (ISB) is a frequently used block for upper limb surgeries. One of the disadvantages of the ISB is an inevitable phrenic nerve palsy as the phrenic nerve lies close to the neural elements at this level.[1] Diaphragmatic paresis secondary to a block of the phrenic nerve is often asymptomatic; however, in patients with pre-existing respiratory insufficiency, decompensation may occur rapidly after the block.[2,3] Caudally in its course, the phrenic nerve deviates medially while the brachial plexus takes a lateral course. In a previous study on volunteers, Kessler[4] reported that the distance between the phrenic nerve

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and the brachial plexus increased by 3 mm per 1 cm when moved caudally.

Approaching the trunks of the brachial plexus under ultrasound guidance is a method that has recently been suggested as a block that provides anaesthesia similar to the interscalene block.[5] The availability of high-resolution ultrasound imaging has also made it possible to identify the phrenic nerve.[6] In the present volunteer-based, observational study, we aimed to compare the ultrasound distance between the brachial plexus and phrenic nerve at the classic interscalene point (interscalene groove along the cricoid cartilage) with the distance between the phrenic nerve and the upper trunk. Our secondary objectives were to note anatomical variations of the roots and trunks of the brachial plexus, the presence of classic traffic light sign, the ease of identification and tracking of the phrenic nerve, the ascending cervical artery (ACA), and any vessels running across the brachial plexus and to compare the findings on either side. We also noted the location of the cervical oesophagus.

METHODS

After receiving approval from the institutional research and ethics committee (MGMCRI/Res/01/2020/03/IHEC/257, dated 16/03/2021), this volunteer-based observational study was registered with the Clinical Trial Registry – India (CTRI/2022/01/039785, dated 28/01/2022, www.ctri.nic.in) and was conducted in a tertiary care university hospital in south India between February 2022 and August 2022. Volunteers who were 18–40 years of age and had a body mass index (BMI) of 18–30 kg/m^2 were included in the study. Any person having an injury, infection, or a previous surgical scar in the neck, thyroid swelling, neck swelling, post-burn contractures, and other external anatomical malformations in the neck, and those who were pregnant were all excluded from the study. Written and informed consent was obtained from all participants for use of their data for research and educational purposes after explaining to them the study protocol. The study was carried out in accordance with the principles of the Declaration of Helsinki, 2013.

The volunteers were laid in the supine position with their head turned to the opposite side (without using a head pillow) and the ipsilateral arm adducted and pulled down to maximally open up the neck. All ultrasound scans were conducted using the high-frequency broadband linear array transducer (HFL 13–6 MHz) of Edge II (FUJIFILM Sonosite, Inc, Bothel, USA) ultrasound system. The scans were performed from the head, with the image screen placed in front of the physician. A scout scan of the brachial plexus from the level of the cricoid cartilage to the supraclavicular brachial plexus was done to ensure that the various neural elements, namely, the ventral rami and trunks of the brachial plexus were identified. The neural element emerging from the horseshoe-shaped transverse process with a prominent anterior tubercle was identified as the C6 ventral ramus. The C5 and C7 ventral rami were identified by dynamically scanning the plexus cranially and caudally, respectively. The phrenic nerve was identified as a small hypoechoic structure that ran medial and anterior to the anterior scalene muscle. The presence of pulsations and detection of flow using the colour Doppler was used to confirm that the structure seen was not the ascending cervical artery (ACA) that also followed a similar course [Video 1].[6] All scans were performed by two anaesthesiologists who were familiar with the sonoanatomy of the neck, and measurements were taken only when both of them were convinced about the targets.

The interscalene groove at the level of the cricoid cartilage was marked. This was taken as indicative of the point of approach for classic interscalene block. The ultrasound probe was then placed transversely with the midpoint of the probe at this point. The PART (pressure, alignment, rotation, and tilting) manoeuvre was used to obtain an optimal image of the neural element and the phrenic nerve, and the image was frozen. The neural element noted at this point was the C5 ventral ramus. The shortest distance between the C5 ventral ramus and the phrenic nerve was measured using the “calliper” key (having measurement accuracy of ±2%, and a measuring range of 0–26 cm).

From this point, the transducer was moved caudal, sequentially visualising the C5, C6, and C7 ventral rami emerging from the transverse process and up to the formation of the upper trunk. The distance of the phrenic nerve from the upper trunk was measured at this point. Both the curved distance and straight distance measurements were taken. For measuring the curved distance, the “trace” feature of the ultrasound machine (measurement accuracy ±3%) was used. In the trace option, the starting point and the endpoint of the trace are automatically joined by a straight line to give the circumference. From this circumference, the linear distance between the two points was subtracted to get the curved distance [Figure 1].

Other observations like the presence of the classic traffic light sign were recorded. In volunteers in whom the classic traffic light sign was seen, the brachial plexus elements forming the traffic light were noted. The ease of identification and tracking of the phrenic nerve was noted subjectively on a qualitative scale as "easy", "difficult", or "impossible". If tracing of the phrenic nerve was impossible, further measurements were not taken. Any anatomical variations of the C5, C6, and C7 ventral rami and trunks were recorded. Any transverse vessel crossing the brachial plexus was noted. Blood flow in the vessel was confirmed using power Doppler and colour Doppler. The relation of the vessels to the trunks of the brachial plexus was noted. The same procedure was repeated on the other side of the neck. Either side of the trachea in the suprasternal notch was scanned to identify whether the oesophagus was present on the right side or the left side.

The sample size was calculated using an online statistical calculator developed by Dhand and Khatkar. Assuming the standard deviation of the expected population to be 0.5 and employing *t* distribution to estimate sample size, the sample size was calculated as 28 to estimate a mean with 95% confidence and a precision of 0.2. We recruited 50 volunteers for the present study. The results were analysed using IBM SPSS Statistics (version 16.0) for Windows. The median distance between the brachial plexus and the phrenic nerve at the two points was compared using Mood's median test. The other variables were descriptively shown.

RESULTS

The 50 volunteers (36 men, 14 women) included in our study had a mean age of 30.5 ± 6 years and a BMI of 26.4 ± 3.2 kg/m^2. Out of the 100 brachial plexuses scanned, the phrenic nerve was easy to identify in 74 scans and difficult in 12 scans. It was impossible to identify the phrenic nerve in 14 scans.

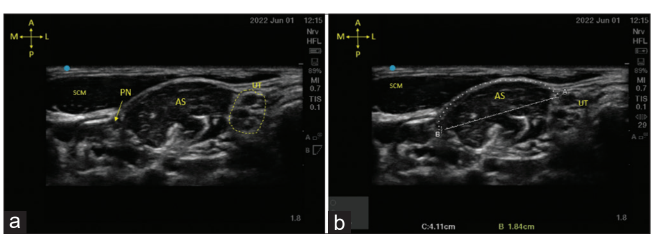

Figure 1: (a) Phrenic nerve and the upper trunk. (b) Measurement of the curved distance and the straight distance of the phrenic nerve from the upper trunk. (PN = Phrenic nerve, AS = Anterior scalene muscle, SCM = Sternocleidomastoid muscle, UT = Upper trunk of the brachial plexus)

At the classic interscalene point, the neural element identified was the C5 ventral ramus. The C5 ventral ramus was observed to be just emerging or to have fully emerged from the transverse process. The distance from the C5 ventral ramus to the phrenic nerve could not be measured in 30 scans, either due to anatomical variation in the emergence of C5 root (24 scans [13 on the left side, 11 on the right side]) or due to our inability to identify the phrenic nerve (6 scans [4 on the left side and 2 on the right side]). The distance between the phrenic nerve and C5 root could therefore be measured in 33 left and 37 right-side scans. The distance between the upper trunk and the phrenic nerve could not be measured in 13 left-side scans (in 11 scans, the phrenic nerve could not be traced; in two scans, it had run off much medial; and in one, the formation of the upper trunk happened only in the supraclavicular area) and 6 right-side scans (the phrenic nerve could not be traced). The median (IQR) distance of the phrenic nerve from the upper trunk (17 [12 to 20.5] mm) was significantly greater than the distance of the phrenic nerve from the C5 ventral ramus (1.6 [1.1 to 3.9] mm; $P = 0.001$) [Figure 2].

There was no difference in the median (IQR) distance between the phrenic nerve and the C5 ventral ramus when the left side [1.6 (1.1 to 4.5)] mm was compared

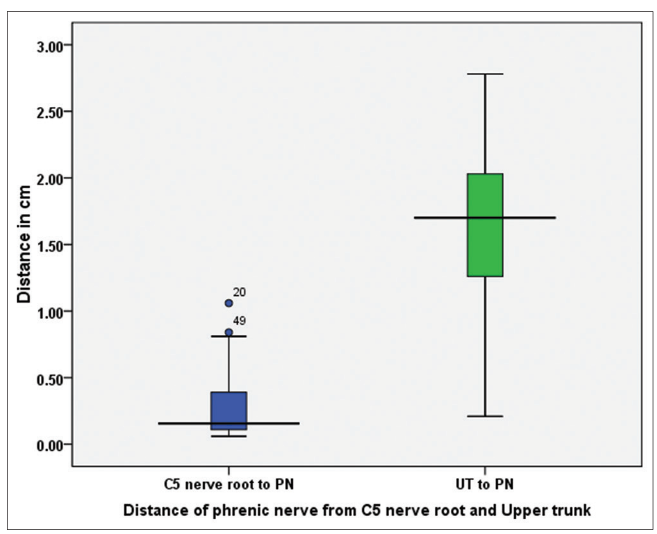

Figure 2: Distance of the phrenic nerve (PN) from C5 ventral rami and the upper trunk. The horizontal line denotes the median. Box edges indicate 25th and 75th percentiles. The bottom whisker denotes 0th–25th percentile and the top whisker denotes 75th-100th percentiles. "●" denotes the outliers

with the right side [1.5 (1.2 to 3.7)] mm. There was no difference in the mean ± SD distance (curved and straight distance) between the phrenic nerve and the upper trunk when the left side (17 ± 4.8 mm, 15 ± 4.4 mm, respectively) was compared with the right side (15.5 ± 6.1 mm, 14 ± 5 mm, respectively). The straight distance between the upper trunk and phrenic nerve was shorter than the curved distance between them by about 1.5–2 mm.

Anatomical variations of the brachial plexus in terms of the emergence of C5 and C6 ventral rami in relation to the scalene muscles and the formation of the upper trunk were noted in 20/50 volunteers [Table 1, Figure 3, Video 2, Video 3, Video 4, Video 5, Video 6]. Similar variations were noted bilaterally in 7/50 volunteers.

The classic traffic light sign was seen in 53 scans. In 49 of the 53 scans, the traffic light sign was formed by C5 and the two divisions of C6, whereas in the remaining four, it was formed by C5, C6, and C7 ventral rami. The presence of an artery across the brachial plexus elements was noted in 41 scans: in 5, it was superficial to the upper trunk; in 21, between the upper trunk and middle trunk; and in 15, it was between the middle trunk and lower trunk [Figure 4]. The ACA could be identified in 55 of the 100 scans. In 49/50 volunteers, the oesophagus was located on the left side of the suprasternal trachea. In one volunteer, it could be identified neither on the left side nor on the right side.

An additional bony structure was noticed bilateral during the scanning of the neck in one volunteer. He consented to undergo a chest X-ray. A bilateral, incomplete cervical rib was identified. The subclavian vein was located higher up in the supraclavicular fossa in two volunteers. The confluence of the internal jugular vein and the subclavian vein and the formation of the brachiocephalic vein also occurred higher up in the neck in both of them.

DISCUSSION

Our study shows that approaching the brachial plexus at the level of the trunk is advantageous in terms of distance from the phrenic nerve. In an earlier study

Table 1: Description of the anatomical variation of the brachial plexus element observed and their incidence

Anatomical variations observed	Total (*n*=100)
Variations of ventral root	
C5 ventral ramus emerge medial to AS or within two digitations of AS [Video 2]	16
C5 and C6 ventral rami emerge inside AS	8
C6 ventral ramus emerge inside AS	2
Variations of the trunk	
Upper trunk splits into divisions higher up in the ISG.	1
Upper trunk formation in the supraclavicular area [Video 3]	1
Upper trunk formation inside AS [Video 4]	2*
Upper trunk rotates anterior to MS and joins the rest of the plexus in the supraclavicular area from the lateral side.	1
C5 ventral ramus does not join C6 to form upper trunk. C5 becomes multi-fascicular and splits into anterior and posterior divisions. [Video 5, 6].	2

AS=Anterior scalene, MS=Middle scalene, ISG=Interscalene groove. *This variation was observed bilaterally in the same volunteer

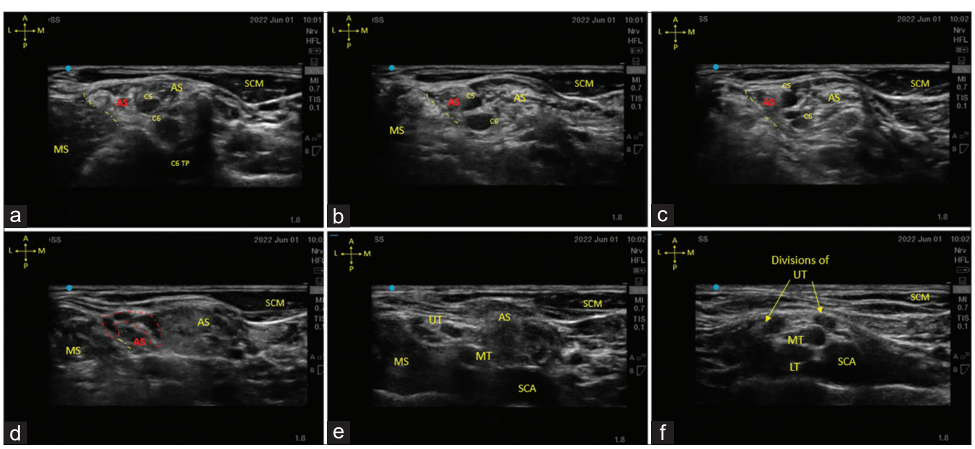

Figure 3: Sequential images showing the formation of the upper trunk inside the anterior scalene muscle. (a) The C5 ventral ramus has emerged and the C6 ventral ramus is emerging from the horseshoe transverse process and lying between the digitations of the anterior scalene muscle. The interscalene groove is represented using the "----" line. (b) The C6 ventral ramus has emerged from the transverse process. (c) The C6 ventral ramus has split into two divisions. (d) The C5 and C6 ventral rami have become multi-fascicular and are seen rotating laterally over the lateral chunk of the anterior scalene. (e) The upper trunk is lying in the interscalene groove. (f) The upper trunk has split into the anterior and posterior divisions. (AS = Anterior scalene muscle, MS = Middle scalene muscle, SCM = Sternocleidomastoid muscle, TP = Transverse process, UT = Upper trunk of the brachial plexus, MT = Middle trunk of the brachial plexus, LT = Lower trunk of the brachial plexus, SCA = Subclavian artery)

using surface landmarks, Kessler[4] reported an increase of 0.3 cm between the brachial plexus and the phrenic nerve for a caudal movement of 1 cm. In our study, we used an ultrasound-defined landmark, namely, the upper trunk, which can be consistently applied for ultrasound-guided brachial plexus block.

Two important measures to be employed to identify and trace the tiny phrenic nerve are to get the best focus by using the minimum possible depth and a slow controlled movement of the transducer during dynamic tracking. Using a higher resolution transducer of 10–16 MHz, Canella *et al.*[6] were able to localise the phrenic nerve in 100% of scans. With the HFL 13–6 MHz transducer, we could identify the phrenic nerve in 86/100 (86%) of scans. Of the 81 scans in which the distance between the phrenic nerve and the upper trunk was measured, the distance was <1 cm in 11 scans (1 left side and 10 right sides). The shortest distance noted between the phrenic nerve and the upper trunk was 0.21 cm [Figure 5].

The ideal anatomy of the interscalene brachial plexus is seen only in 60% of individuals, with the most common variation being the relationship of the C5 ventral ramus to the anterior scalene. The abnormal relationship of the anterior scalene with the C5 and C6 nerve roots has also been frequently reported. Whether these anatomical variations influence the effectiveness of a block is debatable. However, in two scans—one in which the upper trunk rotated laterally, anterior to the middle scalene and one in which the C5 ventral ramus did not enter the interscalene groove at all but joined the rest of the plexus in the supraclavicular area—the upper trunk was conspicuously absent in the interscalene groove, and a block was bound to fail if an interscalene injection is made. With such a high incidence of anatomical variations of the interscalene plexus, optimal endpoints with nerve stimulation may not always be achieved.

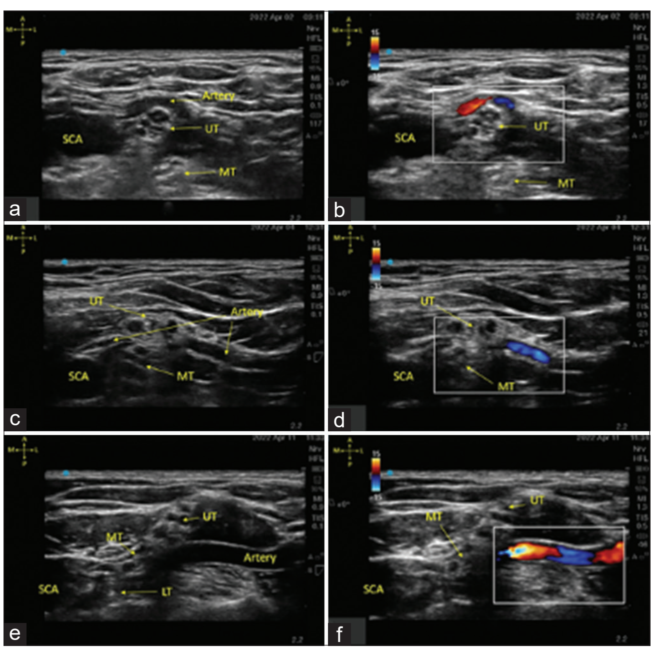

Figure 4: Presence of a transverse artery crossing the brachial plexus (a) above the upper trunk, (c) between the upper and middle trunks, and (e) between the middle and lower trunks. (b, d, f) Corresponding images showing the flow of blood on colour Doppler imaging. (UT = Upper trunk of the brachial plexus, MT = Middle trunk of the brachial plexus, LT = Lower trunk of the brachial plexus, SCA = Subclavian artery)

In three dissected cadavers, Canella *et al*.[6] identified the ACA medial to the phrenic nerve, and the artery followed a course similar to that of the phrenic nerve. In the same study, using ultrasound on volunteers, the authors could identify the ACA only in 70% of patients. In our study, we could identify the ACA in 55/100 (55%) scans. When observed, the vessel always ran medial to the phrenic nerve. Two ultrasonographic parameters that can be applied to differentiate an artery from a nerve are the appreciation of pulsations and the detection of flow on colour Doppler. We could easily pick up pulsations of the vessel and the synchrony of pulsations with the pulse oximeter; however, in such small vessels, the flow could not be detected on colour Doppler.[7]

Apart from the classic traffic light sign seen in 53 scans, in 25 scans, we could also identify four hypoechoic structures formed by C5, two divisions of C6, and the C7 ventral rami. In the remaining 22 scans, the ventral rami had become multi-fascicular.[8] As previously

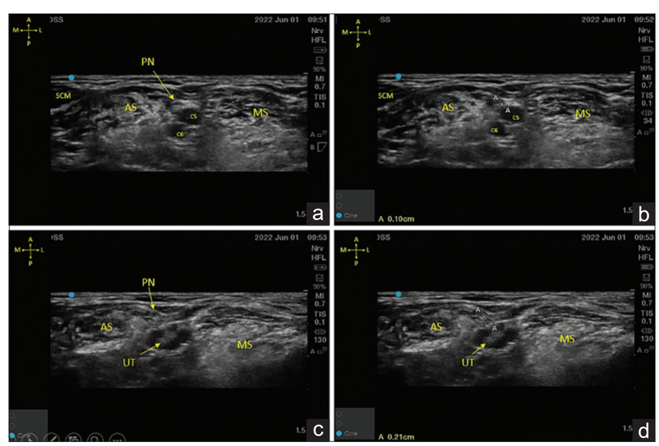

Figure 5: (a and c) Distance of the phrenic nerve from the C5 ventral ramus and the upper trunk. (b, d) Corresponding images showing the measured distance. (UT = Upper trunk of the brachial plexus, PN = Phrenic nerve, AS = Anterior scalene muscle, MS = Middle scalene muscle, SCM = Sternocleidomastoid muscle)

reported in 49 scans, the traffic light was formed by C5 and the two divisions of C6.[8–10] It was, however, not a dictum, because the traffic light was seen to be formed by C5, C6, and C7 ventral rami in four scans.

The common location of the cervical oesophagus was to the left of the trachea in 49/50 volunteers. In one volunteer, it could be identified neither on the right nor on the left side. Vessels may run across the supraclavicular brachial plexus, and the use of colour Doppler examination before needling needs to be reinforced. No particular position of the vessels can be described. We, however, did not identify even a single prefixed brachial plexus.

Our study had the following limitation. Identification of the phrenic nerve using objective methods like nerve stimulation was not used as it is invasive. Despite the young age group employed in our study, the phrenic nerve could not be identified in all scans. The ability to identify the phrenic nerve may be more difficult in older populations due to the changes in echogenicity of the tissues that accompany ageing.[11] We did not perform any interobserver analysis of our ultrasonographic assessments.

CONCLUSION

Approaching the brachial plexus at the level of the upper trunk has a clear advantage in terms of distance acquired from the phrenic nerve. When compared to the brachial plexus at the classical interscalene point, the distance between the phrenic nerve and the upper trunk is ten times greater.

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Conflicts of interest
There are no conflicts of interest.

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