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Variation of the brachial plexus roots in the interscalene groove: relevance in interscalene blocks

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Abstract

Objectives: The interscalene block is utilized for regional anesthesia of the upper limb, targeting the roots and trunks of the brachial plexus in the interscalene groove. The prevalence of variation, which may affect the success of this block, has not been documented in detail with respect to side and sex, nor has a classification system been proposed.

Methods: Seventy-nine embalmed bodies were dissected bilaterally. The position of the roots and the subclavian artery relative to the anterior scalene muscle was documented and variations were classified according to prevalence. Differences in the prevalence of variation between left and right sides and between males and females were investigated.

Results: The standard position of the nerves and subclavian artery in the interscalene groove (Type 1) was present in 31.6%. Variant positions included the following passing through the belly of the anterior scalene: C5 and C6 roots (Type 2) (46.8%), C5 root (Type 3) (15.2%), C5 and C6 roots as well as the subclavian artery (Type 4) (3.8%), and lastly, C5, C6 and C7 roots (Type 5) (2.5%). Variant anatomy was statistically more prevalent in females on the right side only.

Conclusion: Variant locations of the roots and subclavian artery external to the interscalene groove were common, suggesting that ultrasound should be used to visualize variations prior to performing interscalene blocks. A classification type of variant positions has been developed for standardization.

Keywords: anatomical variation; anterior scalene muscle; brachial plexus; brachial plexus roots; interscalene block

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Introduction

The roots and trunks of the brachial plexus can be anesthetized by the interscalene block, the most commonly used brachial plexus block for procedures on the shoulder and arm.[1,2] Interscalene groove, the space between the anterior and middle scalene muscles, is the landmark for this block. The roots and trunks of the brachial plexus along with the subclavian artery are located in the interscalene groove between these two muscle.[1]

Complications of the interscalene block include temporary blockade of the recurrent laryngeal nerve, stellate ganglion and phrenic nerve, occurring from the spread of the injected anesthetic, resulting in hoarseness, Horner's syndrome and hemidiaphragmatic paresis, respectively.[3,4]

Although the roots and trunks of the brachial plexus are described as being located in the interscalene groove in anatomical textbooks,[1] several authors have reported variant positions of these nerves in relation to the scalene muscles.[5–11] In a dissection study, Harry et al.[7] observed the standard position of the roots in the interscalene groove in only 35% of individuals, of which most were bilateral, suggesting that variation is common. Variant patterns may consist of the C5 and C6 roots passing anterior to the scalene muscle or even through the muscle belly, either individually or coursing together.[6–10] The subclavian artery has also been observed passing anterior to the muscle[12] or through the fibers of the belly,[7] instead of being deep to it.

As the interscalene block is performed in the interscalene groove, the effectiveness of this block may be dimin-

ished in individuals with some or all of the roots or trunks of the brachial plexus located outside this groove.[13] Variations in the position of the roots, trunks and subclavian vessels in relation to the scalene muscles have also been implicated as a cause of thoracic outlet syndrome (TOS).[10,14]

There are few published studies reporting the prevalence of variation in the position of the roots relative to the scalene muscles,[6,7,9,10] and there is little information available about whether differences exist between left and right sides, or between males and females. To the best of our knowledge, there are no studies reported from Africa, nor has a classification system been proposed for the variant positions. The prevalence of variations, as well as the positions most likely to be encountered, are relevant to emergency physicians and anesthetists performing interscalene blocks, as the lack of knowledge may explain a reduced rate of success of the block in some patients.

The aim of the study was to document the prevalence of variation in the position of the roots of the brachial plexus and the subclavian artery relative to the scalene muscles, classify these variations as types, and to determine whether there were any statistically significant differences in prevalence between left and right sides, as well as between males and females.

Materials and Methods

A cross-sectional cadaveric study was undertaken during the years 2011 and 2012 in The University of Cape Town, Cape Town, South Africa. The posterior triangle of the neck was dissected bilaterally in 80 embalmed bodies, of whom 36 were female and 44 were male. The bodies were dissected by second- and third-year medical students, with the principal investigator completing exposure of the relevant structures. The neck was dissected to expose the posterior triangle. A midline skin incision was made, followed by lateral reflection of the skin, superficial fascia and platysma muscle, exposing the sternocleidomastoid muscle. The sternocleidomastoid and omohyoid muscles were reflected and the clavicle was disarticulated at the sternoclavicular joint, exposing the scalene muscles, clavicular part of the brachial plexus, and the subclavian vessels. Connective tissue was cleared from the surfaces of the anterior and middle scalene muscles as well as from the roots, trunks and divisions of the brachial plexus, and the subclavian artery and vein. The position of the roots and subclavian artery relative to the anterior scalene muscle was documented, and any variations in position were noted and photographed. The prevalence of variation was determined and expressed as percentages. The number of sides displaying variation was compared by means of a Fisher's exact test using the Statistical Package for Social Sciences (SPSS for Windows, version 25.0, IBM Corporation, Armonk, NY, USA) to determine whether there were any statistically significant differences between left and right sides, as well as between males and females. Statistical significance level was accepted as $p<0.05$.

A classification system was developed by allocating Type 1 as the standard position. Variant positions were assigned as subsequent types according to their prevalence.

Individuals displaying pathology or signs of surgical intervention in the posterior triangle of the neck were excluded from the analysis. The position of the phrenic nerve relative to the anterior scalene muscle and the roots of the brachial plexus could not be determined in this sample due to previous dissection by medical students.

Consent was obtained from the body donors prior to donation for teaching and research purposes; therefore, it was not necessary to seek ethical approval from the Human Research Ethics Committee of our institution. Permission was obtained from the Department of Health, Western Cape for the indigent individuals. The study was conducted in accordance with the Declaration of Helsinki (1964).

Results

Two right sides from male cadavers were excluded, resulting in a final sample of 158 sides, comprised of 44 left sides and 42 right sides from male cadavers, and 36 left sides and 36 right sides from female cadavers.

The standard location of the roots and trunks of the brachial plexus in the interscalene groove between the anterior and middle scalene muscles was observed in 50 out of the 158 sides (31.6%) (**Figure 1**, **Table 1**). Variant positions were observed in 108 sides (68.4%), in order of prevalence as the following structures passing through the belly of the anterior scalene muscle: the C5 and C6 roots in 74 sides (46.8%) (**Figure 2**), the C5 root in 24 sides (15.2%) (**Figure 3**), the C5 and C6 roots and the subclavian artery in six sides (3.8%) (**Figure 4**), and finally, the C5, C6 and C7 roots in four sides (2.5%) (**Figure 5**).

Variant positions were statistically more prevalent on the right sides of females ($p=0.005$), while there were no differences between sexes on the left side ($p=0.328$) (**Table 2**).

Variations were observed bilaterally (on both sides of the same individual) in 45 individuals and unilaterally (on one side only of the same individual) in nine individuals

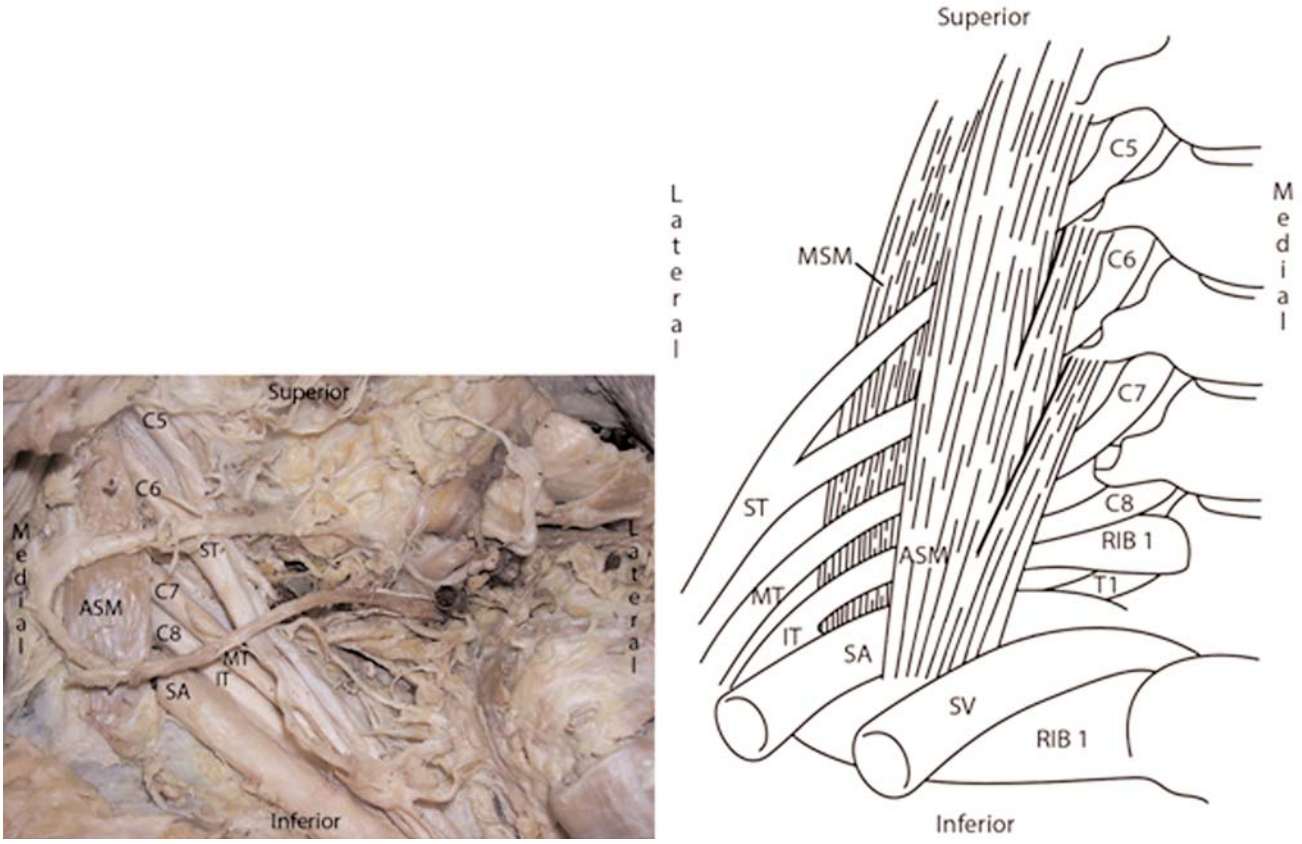


Figure 1. Location of the roots and subclavian artery (**SA**) in the interscalene groove (Type 1), deep to the anterior scalene muscle (**ASM**) in a photograph (**a**) of the left side and in a schematic illustration (**b**) of the right side. **IT:** inferior trunk; **MSM:** middle scalene muscle, **MT:** middle trunk; **ST:** superior trunk; **SV:** subclavian vein. Schematic illustration adapted from Harry et al.[7] [Color figure can be viewed in the online issue, which is available at www.anatomy.org.tr]

(**Table 3**). The standard location of the roots in the interscalene groove was observed bilaterally in 21 individuals, and unilaterally in four.

In individuals who displayed unilateral variations, the standard pattern was significantly more prevalent on the left side (p=0). With respect to structures piercing the anterior scalene the following were observed: C5 and C6 was more prevalent on the right side; C5 was roughly equal in prevalence for both sides; C5, C6 and the subclavian artery were more common on the right side; C5, C6 and C7 were more prevalent on the left side.

According to the prevalence of variant positions observed, the following classification system was developed: Type 1: standard position of all roots and the sub-

Table 1

Prevalence of the variant positions of the roots relative to the anterior scalene muscle as observed with respect to side and sex (n=158).

Position of the roots relative to the anterior scalene muscle	Total n (%)	Number of left sides (%)	Number of right sides (%)	Number of male sides (%)	Number of female sides (%)
Roots located in the interscalene groove (usual position)	50 (31.6)	29 (18.4)	21 (13.3)	37 (23.4)	13 (8.2)
C5 and C5 roots piercing the anterior scalene	74 (46.8)	34 (21.5)	40 (25.3)	32 (20.3)	42 (26.6)
C5 root piercing the anterior scalene	24 (15.2)	12 (7.6)	12 (7.6)	12 (7.6)	12 (7.6)
C5 and C6 roots and subclavian artery piercing the anterior scalene	6 (3.8)	2 (1.3)	4 (2.5)	2 (1.3)	4 (2.5)
C5, C6 and C7 roots piercing the anterior scalene	4 (2.5)	3 (1.9)	1 (0.6)	3 (1.9)	1 (0.6)

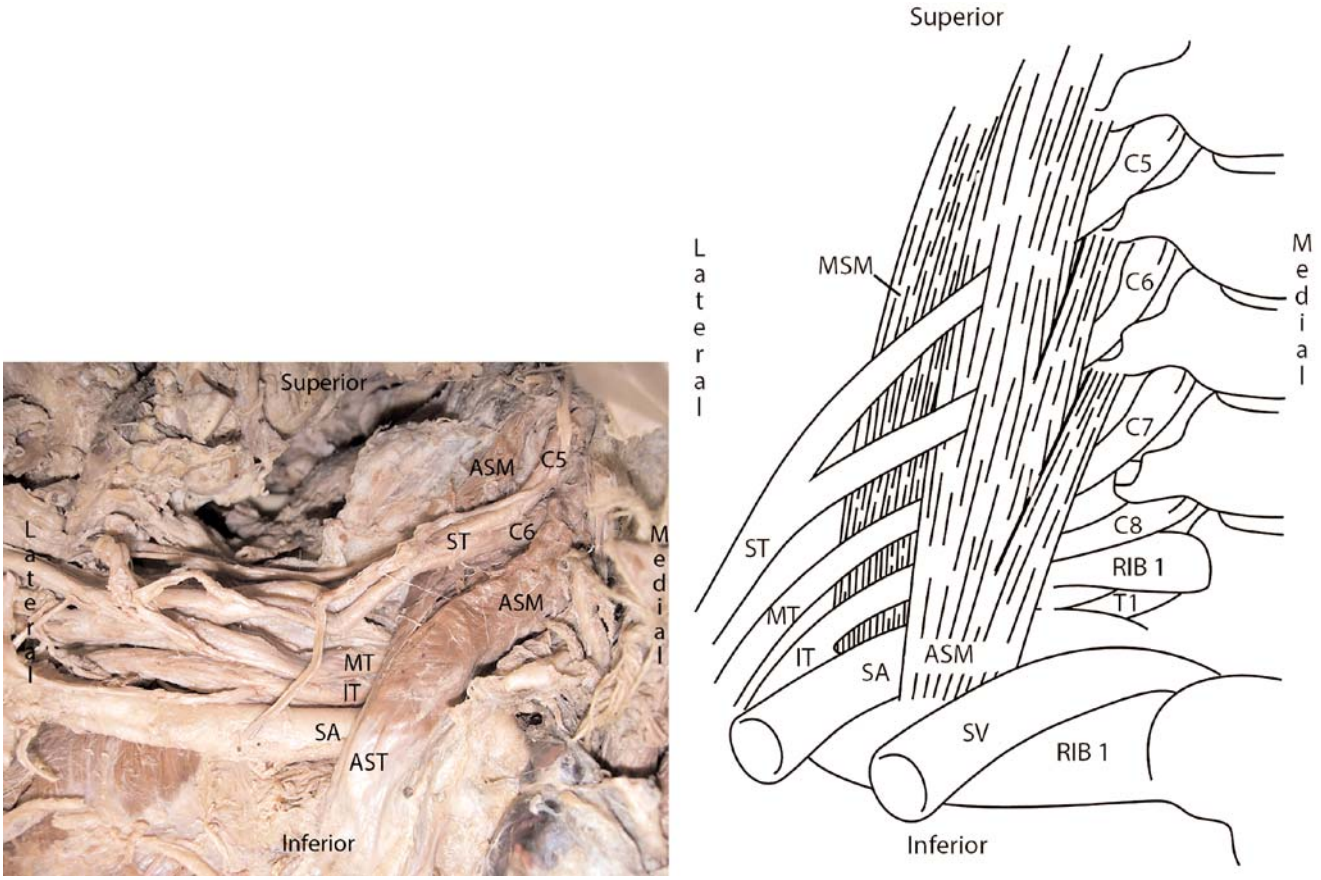


Figure 2. C5 and C6 roots passing through the belly of the anterior scalene muscle (**ASM**) (Type 2) as observed on the right side during dissection (**a**) and represented in a schematic illustration (**b**). **AST:** anterior scalene tendon; **MSM:** middle scalene muscle. **MT:** middle trunk; **IT:** inferior trunk; **SA:** subclavian artery; **ST:** superior trunk; **SV:** subclavian vein. Schematic illustration adapted from Harry et al.[7] [Color figure can be viewed in the online issue, which is available at www.anatomy.org.tr]

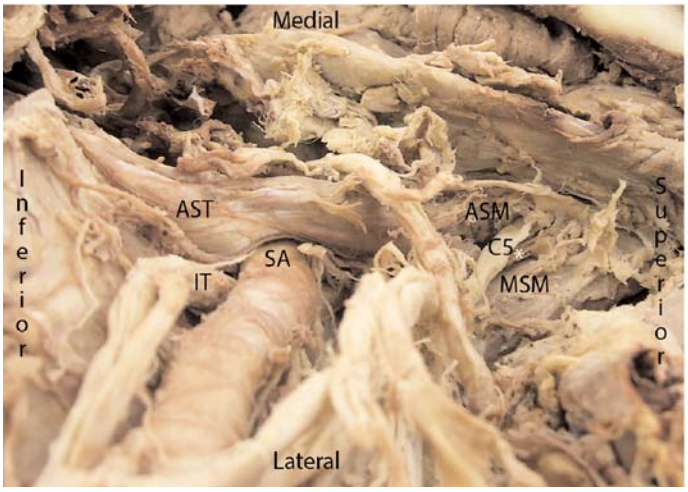
clavian artery located posterior to the anterior scalene muscle; Type 2: C5 and C6 roots passing through the anterior scalene muscle; Type 3: C5 root passing through the anterior scalene muscle; Type 4: C5 and C6 roots and the subclavian artery passing through the anterior scalene muscle; Type 5: C5, C6 and C7 roots passing through the anterior scalene muscle.

Discussion

Variant positions of the roots of the brachial plexus and the subclavian artery relative to the anterior scalene muscle were present in 68.4%, which was more common than the standard position of these structures in the interscalene groove observed in 31.6%. There are no other African studies with which to compare these results; however, this prevalence is similar to that reported by Harry et al.[7] who observed the standard position in 35% of sides in a study done in the United States. Gutton et al.[6] observed variation in 49% in an ultrasound study that was based in France and Italy. Five different position types were observed in this study.

Statistically significant differences in the prevalence of variation between males and females were found on the right side only. The standard position of the roots in the interscalene groove was more common in males, while C5 and C6 roots piercing the anterior scalene was more prevalent in females. The other variant patterns were present with similar frequencies between males and females. To the best of our knowledge, there are no other studies that compare the prevalence of variation in the position of the roots and the subclavian artery in relation to the anterior scalene muscle between sides and sexes.

Most of the variations from the standard pattern were observed bilaterally (83%), with nine individuals (17%) displaying variation on one side only. This is similar to findings of Harry et al.[7] reporting that 32% of individuals displayed bilateral variation, and only 3% displayed unilateral variations.



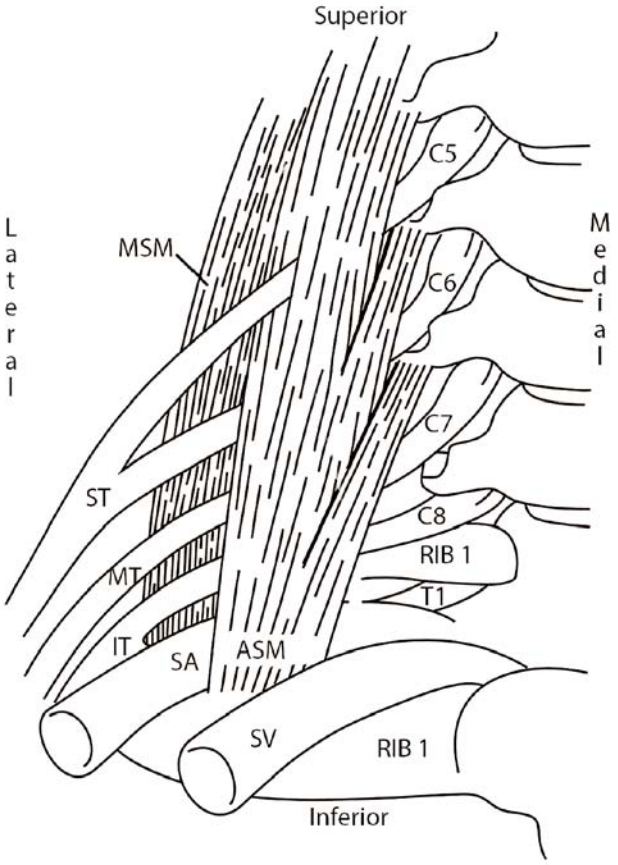


Figure 3. C5 root passing through the belly of the anterior scalene muscle (**ASM**) (Type 3). *Indicates the slip of muscle deep to C5 in a photograph of the dissection (**a**) on the left side; (**b**) is a schematic illustration of the variation on the right side. **AST:** anterior scalene tendon; **IT:** inferior trunk; **MSM:** middle scalene muscle; **MT:** middle trunk; **SA:** subclavian artery; **ST:** superior trunk; **SV:** subclavian vein. Schematic illustration adapted from Harry et al.[7] [Color figure can be viewed in the online issue, which is available at www.anatomy.org.tr]

The C5 and C6 roots piercing the anterior scalene was the most commonly observed position in this study (46.8%), with a higher prevalence than that reported in the literature. Harry et al.[7] observed this position in 15%, Matejcik[9] in 1% of a Slovakian sample. Nair and Sahoo[15] and Chin et al.[5] both described case reports of this position in two patients from India and Canada, respectively. The anterior scalene muscle inserting on either side of the subclavian artery, in combination with the C5 and C6 roots piercing this muscle was observed in 3.8% in this study, higher than the 1% observed by Harry et al.[7] Inuzuka,[12] in a case report, described the anterior scalene muscle situated posterior to the subclavian artery unilaterally in one Japanese individual , while in 1928, Adachi[16] reported the incidence of this variant position as 0.6% in Japanese and 1.2% in European individuals.

The C5 root has been described in the literature as piercing the anterior scalene, or more rarely, passing anterior to this muscle.[6,7,9,10,17] In this study, the C5 root was observed as passing through the muscle in 15.2%, similar to the 13% reported by Harry et al.,[7] but higher than the 3.3% recorded by Kessler and Gray.[17] The C5 root passing anterior to the anterior scalene was not observed in the current study; however, Gutton et al.[6] observed this position in 8%, Kessler and Gray[17] in 6.5%, Harry et al.[7] and Natsis et al.[10] in 3%, Matejcik[9] in 1%. Loukas et al.[8] described this position in a case report of a Caucasian cadaver. Natsis et al.,[10] who studied 93 cadavers in Greece, observed the C5 root passing anterior to the anterior scalene and the C6 root piercing the muscle in one individual. This variation was not observed in the present study.

The C5, C6 and C7 roots pierced the anterior scalene muscle in 2.5% in the present study. To the best of our knowledge, there is no other study that reports this variation. Other positions, such as all of the roots passing anterior to the scalene muscles, have also been reported in case reports.[11] Natsis et al.[10] observed the incidence of the

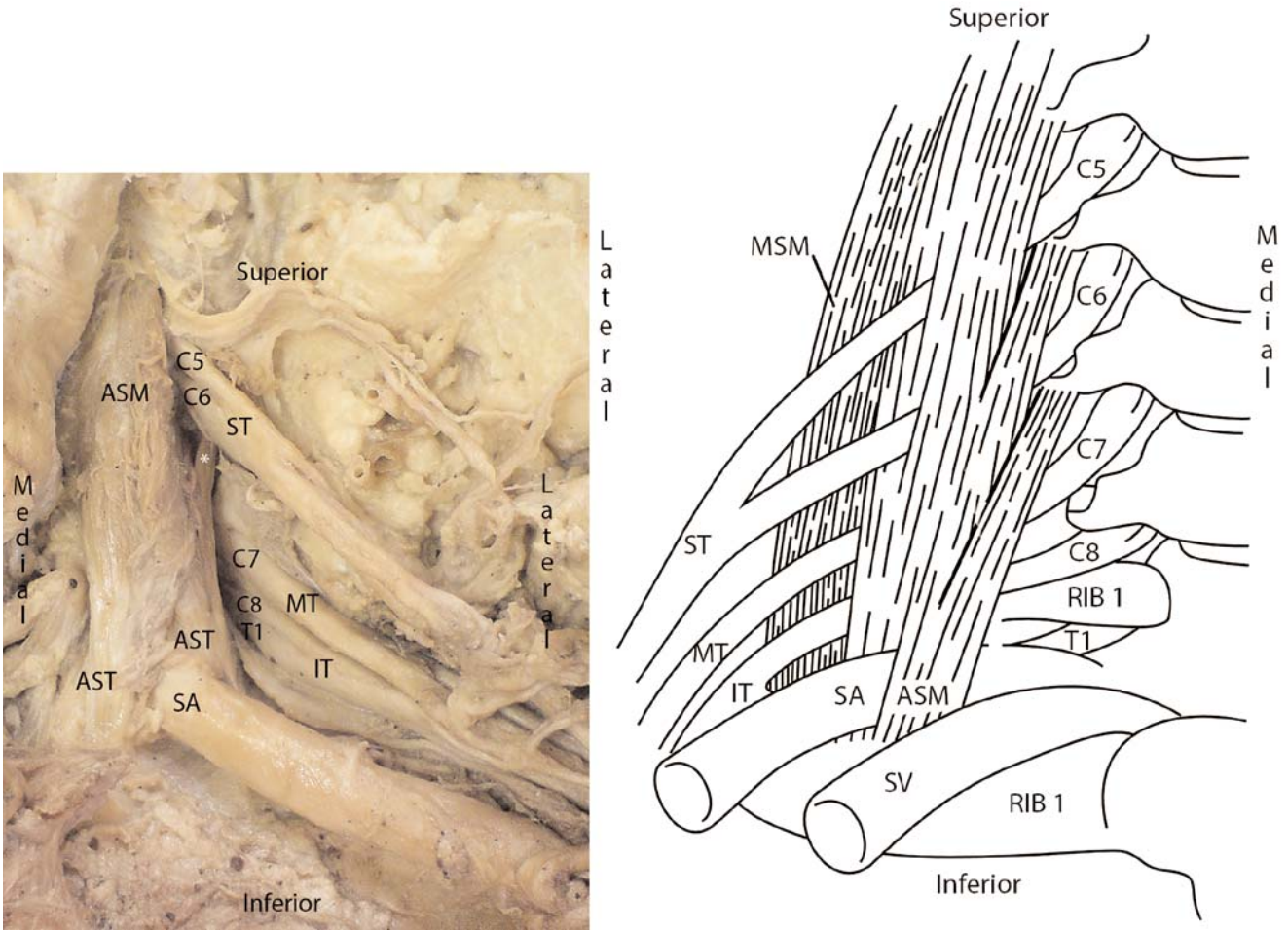


Figure 4. C5 and C6 roots piercing the anterior scalene muscle (**ASM**), while the anterior scalene tendon (**AST**) inserted on either side of the subclavian artery (**SA**) (Type 4). ***Indicates the slip of muscle deep to C5 and C6 on the left side (**a**); (**b**) is a schematic illustration of this variation on the right side. **IT:** inferior trunk; **MSM:** middle scalene muscle; **MT:** middle trunk; **ST:** superior trunk; **SV:** subclavian vein. Schematic illustration adapted from Harry et al.[7] [Color figure can be viewed in the online issue, which is available at www.anatomy.org.tr]

superior trunk passing anterior to, or through the anterior scalene as 2.2% and 6.5%, respectively. In a study from the United States, Leonhard et al.[18] reported that the superior trunk pierced the muscle in 33.3% of individuals, while the middle trunk showed this position in only one side.

Variation in the position of nerves relative to muscles may occur as a result of changes in cell signaling in mesodermal tissue during embryological development. Paraaxial mesoderm differentiates into muscle tissue during the fifth week of development, while growth cones of axons are guided along their path of development by chemicals known as chemo-attractants and chemo-repulsants. Signaling between the growth cones and mesoderm determines the anatomical relationship that will form between the developing nerve and muscle tissue. Changes in the standard chemical signaling may result in variation in the position of nerves relative to adjacent muscles.[19]

The subclavian artery is the continuation of the seventh intersegmental artery of the dorsal aorta, which becomes the dominant artery entering the upper limb bud.[20] Occasionally, other intersegmental arteries may become dominant, such as the sixth, eighth or ninth, resulting in a variant position of the subclavian and axillary artery in relation to the nerves of the brachial plexus.[20] Inuzuka[12] described the subclavian artery lying anterior to the anterior scalene muscle; the artery in this case originated from the eighth intersegmental artery.

There are implications of variations in the position of the roots of the brachial plexus relative to the anterior scalene muscle when performing an interscalene brachial plexus block. In cases where the roots are located outside

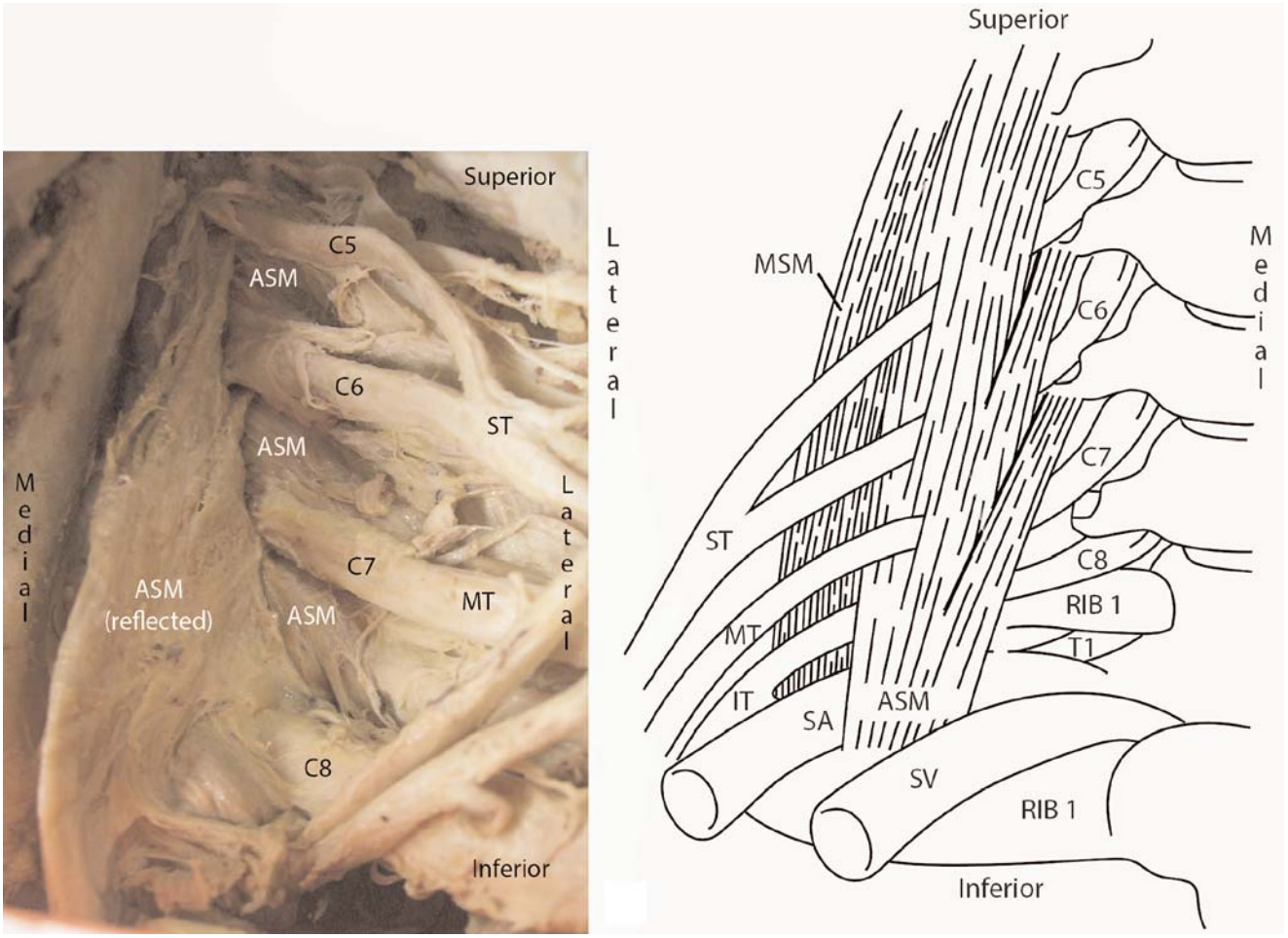


Figure 5. C5, C6 and C7 roots piercing the anterior scalene muscle (**ASM**) (Type 5) as observed on the left side during dissection (**a**); (**b**) is a schematic illustration of this variation on the right side. **IT:** inferior trunk; **MSM:** middle scalene muscle; **MT:** middle trunk; **SA:** subclavian artery; **ST:** superior trunk; **SV:** subclavian vein. Schematic illustration adapted from Harry et al.[7] [Color figure can be viewed in the online issue, which is available at www.anatomy.org.tr]

of the interscalene groove, which is the injection site for this block, the block may not adequately anesthetize the upper limb.[13] These cases include the variant positions observed in this study where the C5, C6 or C7 roots pierced the anterior scalene, instead of passing posterior to the muscle in the interscalene groove. As the standard position of all the roots in the interscalene groove was observed in approximately one-third of this sample,

Table 2

Prevalence of the variant positions of the roots relative to the anterior scalene muscle as observed between the left and right sides of both sexes (n=158).

Position of the roots relative to the anterior scalene muscle	Left sides of males (n=44) (%)	Right sides of males (n=42) (%)	Left sides of females (n = 36) (%)	Right sides of females (n = 36) (%)
Roots located in the interscalene groove (usual position)	20 (45.5)	17 (40.5)	9 (25.0)	4 (11.1)
C5 and C5 roots piercing the anterior scalene	16 (36.4)	16 (38.1)	18 (50.0)	24 (66.7)
C5 root piercing the anterior scalene	5 (11.4)	7 (16.7)	7 (19.4)	5 (13.9)
C5 and C6 roots and subclavian artery piercing the anterior scalene	1 (2.3)	1 (2.4)	1 (2.8)	3 (8.3)
C5, C6 and C7 roots piercing the anterior scalene	2 (4.5)	1 (2.4)	1 (2.8)	0 (8.0)

Table 3
Prevalence of the variant positions of the roots relative to the anterior scalene muscle with regards to bilateral or unilateral presentation in individuals (n=79).

Position of the roots relative to the anterior scalene muscle	Total	Bilateral (no. of individuals)	Unilateral (no. of upper limbs)
Roots located in the interscalene groove (usual position)	50	21	8
C5 and C5 roots piercing the anterior scalene	74	34	6
C5 root piercing the anterior scalene	24	8	8
C5 and C6 roots and subclavian artery piercing the anterior scalene	6	2	2
C5, C6 and C7 roots piercing the anterior scalene	4	1	2

emergency physicians and anesthetists should be aware of the possibility that the interscalene block may not be effective in a considerable percentage of individuals presenting for regional anesthesia of the upper limb. Depending on the area of the upper limb requiring anesthesia, an alternative block, such as the supraclavicular approach may be preferred. However, variations in the position of the roots and trunks in relation to the scalene muscles can be easily identified on ultrasound imaging.[13,21] Ultrasound guided visualization of the roots can be employed, and if variations are identified, the interscalene approach can be utilized with anesthetic injected into adjacent areas in addition to the interscalene groove, ensuring that these variant nerves are blocked and adequate anesthesia is obtained.[2,21] Kessler and Gray,[17] upon detecting variant passage of C5 either anterior to or through the anterior scalene, perform the interscalene block 1 to 2 cm caudal to the cricoid cartilage to ensure adequate blockade.

The passage of the roots of the brachial plexus and the subclavian artery through the anterior scalene muscle may lead to the compression of these structures, resulting in thoracic outlet syndrome (TOS).[10,14,22] Neurogenic TOS is characterized by numbness and tingling of the upper limb, while vascular causes of TOS include symptoms of pallor, coolness, fatigue, muscle cramps and swelling.[22] Muscle weakness may be present in the deltoid, biceps brachii, triceps brachii and rotator cuff muscles as well as the extensors of the forearm.[10] Pain is often described in the neck; however, it may radiate to the rhomboid, suprascapular, trapezius, deltoid and lateral arm areas.[10] In addition, pain in the pectoral region may be experienced as "pseudoangina". Thus, it is important for clinicians to distinguish between TOS and angina.

All but one of the 219 patients with TOS examined by Redman and Robbs[14] had some form of brachial plexus anomaly or variation. Although the majority of these cadavers were postfixed with T2 contributing to the inferior trunk and subsequently prone to being stretched over rib one, some patients had variant positions of the roots in relation to the scalene muscles.[14] Compression of the nerve roots by the anterior scalene may disrupt blood flow, resulting in ischemia of the nerves.[10] Patients may experience symptomatic relief when these muscles are relaxed.[22] Abnormal fibromuscular bands attaching onto the first rib have also been implicated in neurogenic TOS.[10,14,22] Conduction speed tests of the median nerve may assist in diagnosing neurogenic TOS.[14] The passage of the subclavian artery through the anterior scalene may play a role in TOS, although further studies are required.

Although the sample size was small, this study found variant positions to be more prevalent in females on the right side, which may increase the risk of above-mentioned symptoms and complications in this subset. Emergency physicians should be aware of the possibility of asymmetrical variations in patients.

A classification system has been proposed according to the prevalence of variant positions observed in this study. This system may assist anatomists and clinicians with describing variant positions observed during dissections, surgery or medical imaging. As further variant patterns are revealed in future studies, the classification may be updated accordingly.

The origin and position of the phrenic nerve were not able to be determined in this sample. We are currently documenting the phrenic nerve in detail in a separate study, to determine whether variations in its origin and /or course may increase the risk of iatrogenic blockade during interscalene blocks. There was no medical history available for the cadavers, and it was not known whether any of the individuals suffered from TOS during their lifetimes. The study was retrospective and studies assessing interscalene anatomy in patients for whom

interscalene blocks were unsuccessful may reveal more information about which variant positions result in a reduced efficiency of peripheral blocks.

Conclusion

Variation in the position of the roots of the brachial plexus relative to the anterior scalene muscle occurred with a higher prevalence than the standard position in the interscalene groove. Variant patterns included the C5, C6 and or C7 roots piercing the anterior scalene muscle, which have implications for a successful interscalene brachial plexus block. The subclavian artery was also observed passing through the anterior scalene muscle. Patients should be assessed for variant anatomy with ultrasound in cases where interscalene blocks are not effective. Variant positions of the roots and subclavian artery in relation to the scalene muscles may be a contributing factor in neurogenic TOS. A classification of variant positions has been developed to assist anatomists and surgeons with the description of variations.

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