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Article

Interconnected Anatomy and Clinical Relevance of the Dorsal Scapular and Long Thoracic Nerves: A Donor Study

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Abstract: Background: The dorsal scapular nerve (DSN) and the long thoracic nerve (LTN) exhibit variable anatomical pathways, which may contribute to upper back pain and impaired scapular movement in affected patients. This study investigates these variations to enhance clinicians' diagnostic and surgical approaches. **Methods**: Bilateral cervical regions of 32 formalin-embalmed donors (64 sides) were dissected to document the origin of the DSN, the relationship with the scalene muscles of the DSN, and anatomical connections between the DSN and LTN. Measurements of the distance between the mastoid process and the piercing point of the DSN to the scalene muscle were obtained with digital calipers. Additional measurements were obtained from the medial border of the scapula at two specific locations: the scapular spine (zone 1) and the midpoint between the scapular spine and the inferior angle of the scapula (zone 2). **Results**: The DSN demonstrated four distinct cervical spinal nerve root origins and five unique scalene muscle piercing patterns. The average distance between the DSNs scalene muscle piercing point and the mastoid process was 94.87 ± 10.09 mm, with significantly greater distances observed in male donors compared to female donors ($p < 0.001$). Connections between the DSN and LTN were identified in 65.2% of the examined cervical regions. The mean distance of the DSN from the medial border of the scapula at zone 2 was significantly greater than at zone 1 ($p < 0.001$). **Conclusion**: Anatomical variation findings and classification of the DSN provide valuable insights, offering guidance involving clinical procedures of the scalene and rhomboid musculature to minimize the risk of iatrogenic injury. The documented variations may also assist in the diagnosis and management of DSN-related pathologies such as DSN neuropathy.

Keywords: dorsal scapular nerve; dorsal scapular nerve neuropathy; long thoracic nerve; scalene muscles; back pain

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1. Introduction

The dorsal scapular nerve (DSN) is traditionally described as a motor nerve innervating the rhomboid major, rhomboid minor, and levator scapulae muscles. It originates from the anterior ramus of the fifth cervical spinal nerve root (C5) of the brachial plexus (Figure 1) [1,2]. Despite its standard description, studies have reported significant variability in the DSNs origin [2–8]. En route to its targeted musculature, the DSN is classically known to pierce the middle scalene muscle [2,8,9] but this relationship has also been shown to vary significantly [4,6,8,10].

The long thoracic nerve (LTN) originates from the anterior rami of the C5-7 spinal nerve roots of the brachial plexus (Figure 1) [1,11]. Classically, the C5 and C6 spinal nerve roots converge within the middle scalene muscle before joining the C7 spinal nerve root [11]. The LTN has also demonstrated variability in scalene muscle piercing patterns, which may correlate with pain pathologies in the upper back and dysfunctional scapular movement patterns [7,12]. Additionally, recent studies have highlighted the known anatomical connections between the DSN and LTN sparking further research into their relationship [3,4,13].

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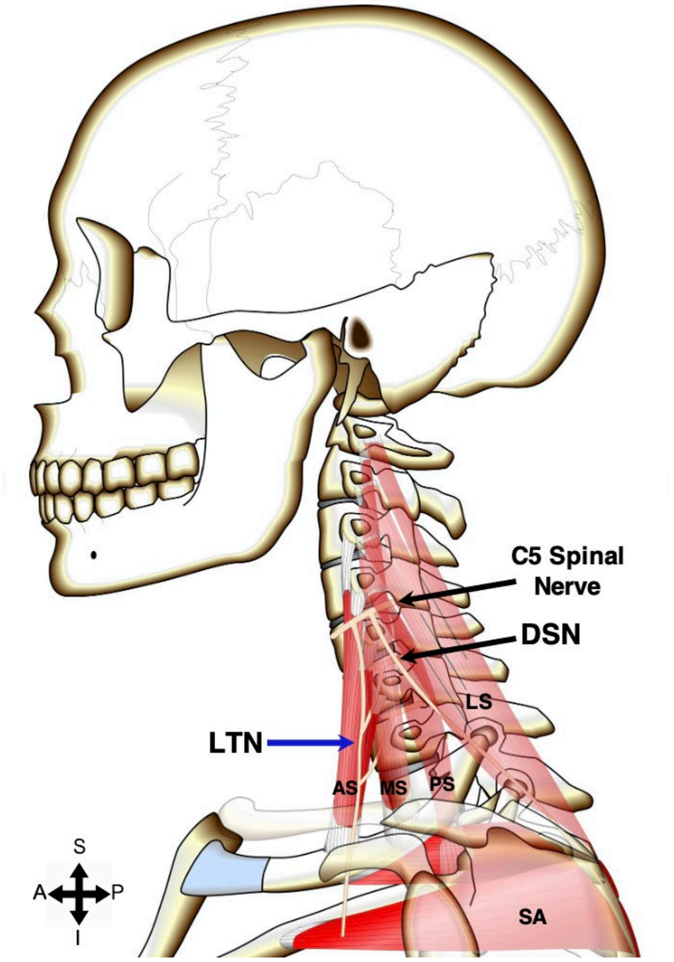

Figure 1. (**a**) image showcasing the classical anatomy of the dorsal scapular nerve and long thoracic nerve. Symbols: black arrows: dorsal scapular nerve, blue arrows: long thoracic nerve. Abbreviations: LS: levator scapulae muscle, MS: middle scalene muscle, AS: anterior scalene muscle, PS: posterior scalene muscle, SA: serratus anterior muscle, C5: 5th cervical spinal nerve, A: anterior, P: posterior, S: superior, I: inferior.

DSN neuropathy is an often misdiagnosed condition, presenting with nonspecific thoracic back pain [14,15]. DSN neuropathy often presents with nonspecific thoracic pain, and therefore is commonly misdiagnosed as myofascial pain of the rhomboid muscle, dorsal back strain, and thoracic facet syndrome [15]. Its clinical recognition is complicated by the DSNs classification as a motor nerve, lacking sensory fibers, and the lack of a clear pain pattern indicative of nerve injury. The pain associated with DSN neuropathy arises from a complex mechanism that can involve stretching of nearby sensory cutaneous fibers or inflammation of the dorsal scapular nerve sheath [15]. Entrapment of the DSN by the middle scalene muscle is a common mechanism underlying DSN neuropathy [7,8,10,15]. In an anatomical study by Chen et al. (1995), severance of the anterior or middle scalene led to relief of DSN neuropathy symptoms, highlighting the role of the scalene muscles in DSN injury. Several case reports have identified DSN neuropathy as a cause of scapular winging in a subset of patients [16–19]. These findings challenge the traditional attribution of isolated LTN injury being the etiology of scapular winging [12]. To explain these findings, further investigation is needed to explore the connections between the DSN and LTN.

The surgical anatomy of the proximal DSN is critical during procedures involving the middle scalene muscle and rhomboid musculature. For instance, interscalene nerve blocks, performed through the middle scalene muscle, provide access to the brachial plexus but increase the risk of injury to the DSN and LTN [20,21]. Similarly, surgical interventions for vascular or neurogenic

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thoracic outlet syndrome necessitate detailed knowledge of these nerves within the scalene muscle region to prevent complications [8,22,23].

Distally, the DSNs anatomical relationship with the rhomboid musculature is imperative in procedures such as the Eden-Lange procedure, which transfers the levator scapulae and rhomboid muscles for spinal accessory nerve injury treatment [24]. Preservation of the DSN is crucial during this procedure, as the function of these muscles depends on the nerve remaining uninjured and functional. Additionally, the distal course of the DSN has shown conflicting data regarding its distance from the medial border of the scapula as it traverses the rhomboid musculature [24,25].

While various studies describe DSN anatomy, significant gaps remain concerning its relationships, variations, and clinical implications. Limited research still exists on the common connections between the DSN and LTN. This study aims to provide a comprehensive analysis of the DSNs proximal and distal anatomy to address these gaps in knowledge.

2. Materials and Methods

The bilateral cervical regions of 32 formalin-embalmed donors (64 sides), comprising both male and female donors, were dissected to examine the DSN and LTN. The donors ranged in age from 47 to 97 years, with a mean age of 75.22 years and an average height of 167.09 cm. Donors were obtained through the Kansas City University Gift Body Donation Program in Kansas City, Missouri, USA. All donors had provided written consent for anatomical research during their lifetime. Ethnicity data was not included in the biographical information available for this study.

Initial dissections were performed by medical students as part of a gross anatomy course. Donors were excluded from the dataset if the DSN, LTN, or associated musculature was not intact or had been inadvertently damaged during the dissection process (Figure 2).

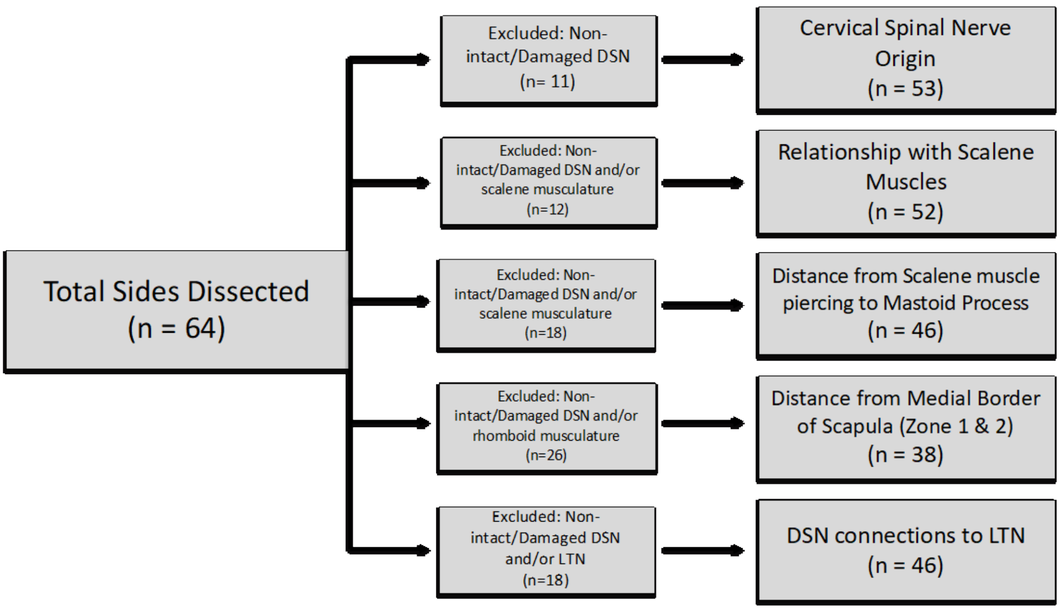

Figure 2. Process of exclusion criteria during data collection of this study. Abbreviations: n: sample size.

Each donor was placed in the supine position, and blunt dissection was utilized to expose the DSN and LTN within the scalene musculature using a lateral approach. While in the supine position, the DSNs relationship with the scalene musculature, the cervical spinal nerve origin of the DSN, connections between the DSN and LTN, and the piercing type of the LTN were recorded. Cervical spinal nerve contributions of the LTN that traveled through a scalene muscle were classified as piercing, while those passing between two scalene muscles were classified as non-piercing. The longest distance from the DSNs scalene piercing point to the mastoid process was recorded, following

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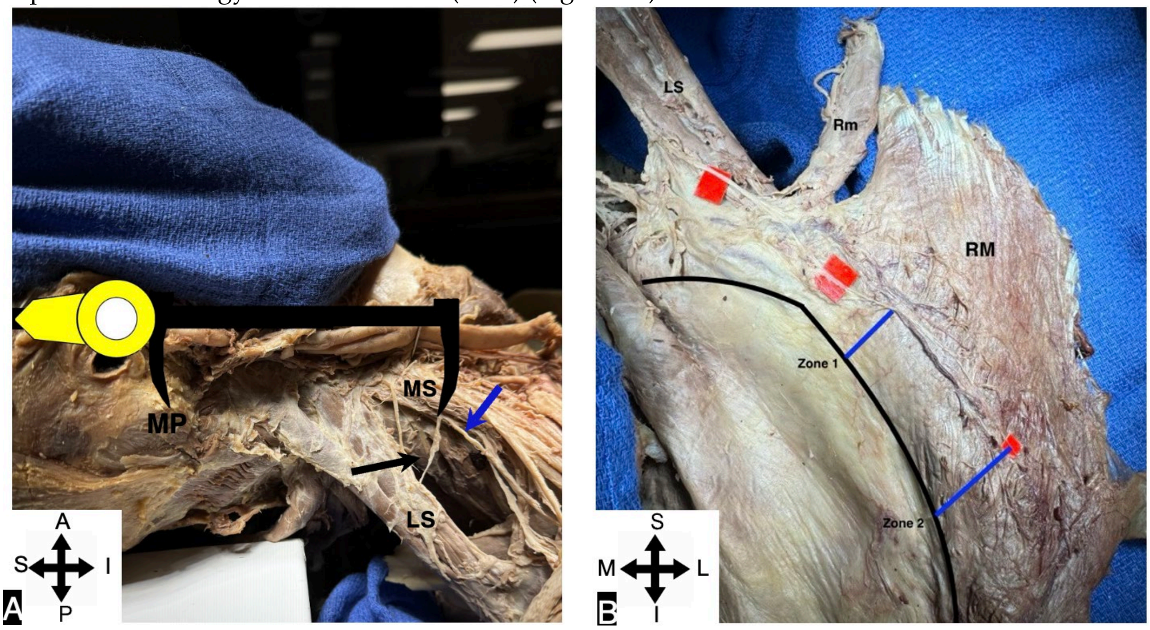
the methodology described in a previous study by Çelikgün et al. (2023) (Figure 3a). This measurement was performed three times by the same researcher, and the mean value was recorded.

In the prone position, the undisturbed DSN was carefully exposed on the anterior surface of the rhomboid musculature using blunt instruments to determine its position relative to the medial border of the scapula. Care was taken to preserve the position of the DSN by ensuring that the deepest fascia overlying both the rhomboid major muscle and the DSN were not disturbed. The distance of the DSN from the medial border of the scapula was measured at two locations: zone 1, at the scapular spine (SS), and zone 2, at the midpoint between the SS and the inferior angle (IA) of the scapula, using an adapted methodology from Pinto et al. (2019) (Figure 3b).



(**a**) (**b**)

Figure 3. (**a**) digital caliper demonstrating the distance between the point where the dorsal scapular nerve pierces the scalene muscles and the mastoid process. Symbols: black arrow: dorsal scapular nerve, blue arrow: long thoracic nerve. Abbreviations: MP: mastoid process, MS: middle scalene muscle, LS: levator scapulae muscle, A: anterior, P: posterior, S: superior, I: inferior.; (**b**) demonstration of the distance between the dorsal scapular nerve and the medial border of the scapula at the scapular spine (zone 1) and the measured midpoint between the scapular spine and the inferior angle of the scapula (zone 2) in a laterally reflected right-sided scapula, positioning the medial surface of the scapula and the rhomboid musculature to face laterally. Symbols: solid black lines: outline of the medial border of the scapula, solid blue lines: the dorsal scapular nerve distance from the medial border of the scapula. Abbreviations: LS: levator scapulae muscle, Rm: rhomboid minor muscle, RM: rhomboid major muscle, S: superior, I: inferior, M: medial, and L: lateral.

All numerical measurements were recorded in millimeters (mm) and performed bilaterally utilizing a digital caliper. Statistical analysis was conducted using Excel 2023 for Mac. A two-tailed t-test assuming unequal variances was used for comparisons between two groups and a regression analysis was used to examine correlation between two variables. Results were evaluated at a 95% confidence interval, with significance defined as $p < 0.05$. Ethical approval for this study was provided by the Institutional Review Board of Kansas City University (IBC-2195821-1; Approved 06/20/2024).

3. Results

3.1. The Proximal Dorsal Scapular Nerve

A total of four distinct types of DSN cervical spinal nerve origins were observed across 53 dissections, with 26 on the left and 27 on the right. Of these, 21 were found in male donors and 32 in female donors. Consistent with classical anatomical descriptions, 86.79% of the DSNs originated from

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the C5 spinal nerve root. Other origins included C4/5 in 9.43%, C4 in 1.89%, and C5/6 in 1.89% (Figure 4a-e).

Five distinct variations of DSN piercing patterns were identified across 52 dissections, with 28 on the left and 24 on the right. Of these, 22 were from male donors and 30 from female donors. The majority, 75%, followed the classical anatomical description, piercing the middle scalene muscle. In 2%, the DSN pierced the posterior scalene muscle. 13% exhibited a non-piercing DSN arising posterior to the middle scalene muscle, while 6% exhibited a non-piercing DSN anterior to the middle scalene muscle. 4% originating from the C4/5 spinal nerve roots displayed a dual non-piercing pattern, with the C4 branch anterior to the middle scalene muscle and the C5 branch posterior to the middle scalene muscle (Figure 4a-e).

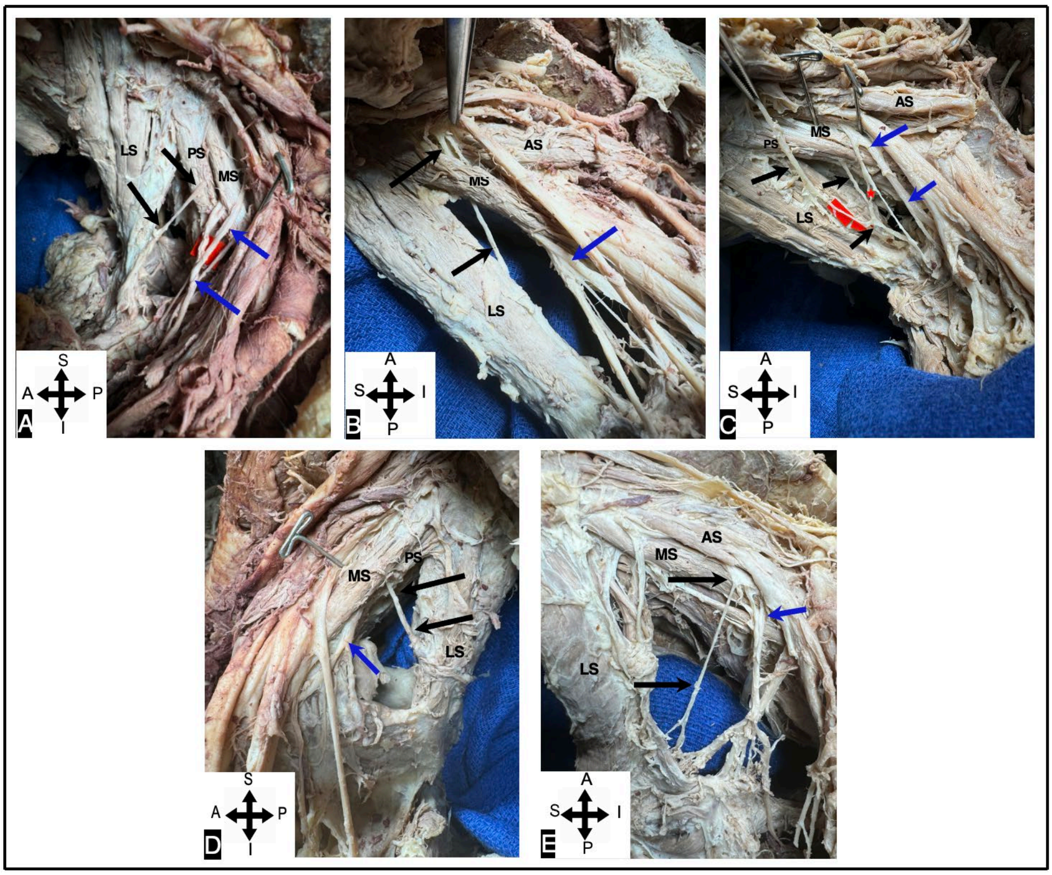

Figure 4. (a) DSN arising from the 5th cervical spinal nerve root and piercing the posterior scalene muscle. **(b)** DSN arising from the 5th cervical spinal nerve root and piercing the middle scalene muscle. **(c)** DSN formed by the 4th cervical spinal nerve root anterior to the middle scalene muscle and the 5th cervical spinal nerve root traveling posterior to the middle scalene muscle. This DSN also displays a small connection with the LTN. **(d)** DSN arising from the C5 spinal nerve root and traveling posterior to the middle scalene muscle. **(e)** DSN arising from C5 and traveling anterior to the middle scalene muscle. Symbols: black arrows: dorsal scapular nerve, blue arrows: long thoracic nerve, red star: DSN to LTN connection. Abbreviations: AS: anterior scalene muscle, MS: middle scalene muscle, PS: posterior scalene muscle, LS: levator scapulae muscle, A: anterior, P: posterior, S: superior, I: inferior.

The mean distance from the DSN scalene piercing point to the mastoid process was 94.87 ± 10.09 mm (Table 1). The mean distance for DSNs that pierced a scalene muscle was 94.63 ± 1.19 mm while DSNs that did not pierce a scalene muscle had a mean distance of 96.36 ± 1.06 mm, with no statistically significant difference between groups. For DSNs originating from the C4/5 spinal nerve roots (mean, 97.21 ± 2.51 mm; N = 3), the distance was significantly greater than those originating from the C5 spinal nerve root (mean, 91.50 ± 8.63 mm; N = 20; $p = 0.035$). Males exhibited a significantly greater

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distance than females ($p < 0.001$). No significant correlation was found between body height and this DSN distance. Additionally, there was no significant difference between the right and left sides.

Table 1. Measurements of the dorsal scapular nerve.

Measurement	Total	Male	Female
DSN distance from the medial border of the scapula (zone 1) (mm)	(N= 38) Mean: 18.51 ± 6.19 Range: 5.8-29.11	(N= 13) 19.17 ± 5.60 -	(N= 25) 17.85 ± 6.47 -
DSN distance from the medial border of the scapula (zone 2) (mm)	(N=38) Mean: 27.99 ± 8.75 Range: 13.29-57.05	(N= 13) 29.75 ± 7.41 -	(N= 25) 25.26 ± 9.23 -
DSN distance from the scalene muscles to the mastoid process (mm)	(N= 46) Mean: 94.87 ± 10.09 Range: 72.18-120.75	(N=19) 100.59 ± 9.82 -	(N= 27) 90.84 ± 8.28 -

*DSN: dorsal scapular nerve, mm: millimeters, N: sample size.

3.2. The Distal Dorsal Scapular Nerve

The average scapular length was 156.93 ± 13.86 mm. The mean distance from the SS to the IA of the scapula was 58.05 ± 5.98 mm. The average distance at the zone 1 was 18.51 ± 6.19 mm (Table 1). The average distance at zone 2 was 27.99 ± 8.75 mm. The DSN distance at zone 2 was found to be significantly different than zone 1 ($p < 0.001$). No significant differences were observed between sides or sexes in either zone 1 or zone 2. No DSNs crossed the medial border of the scapula, with the smallest distance being 5.8 mm.

3.3. The Relationship Between the Dorsal Scapular Nerve and Long Thoracic Nerve

A total of 65.2% of DSNs were found to have a connection with the LTN, with 15 occurring on the right and 15 on the left (Figure 5a-d). Of these, 14 connections were observed in male donors and 16 in female donors. The LTN piercing type was examined and compared to the prevalence of DSN to LTN connections. Among the 28 LTN piercing types, 82% exhibited a connection with the DSN. Of the 18 LTNs with a non-piercing type, 33% were connected to the DSN (Figure 6).

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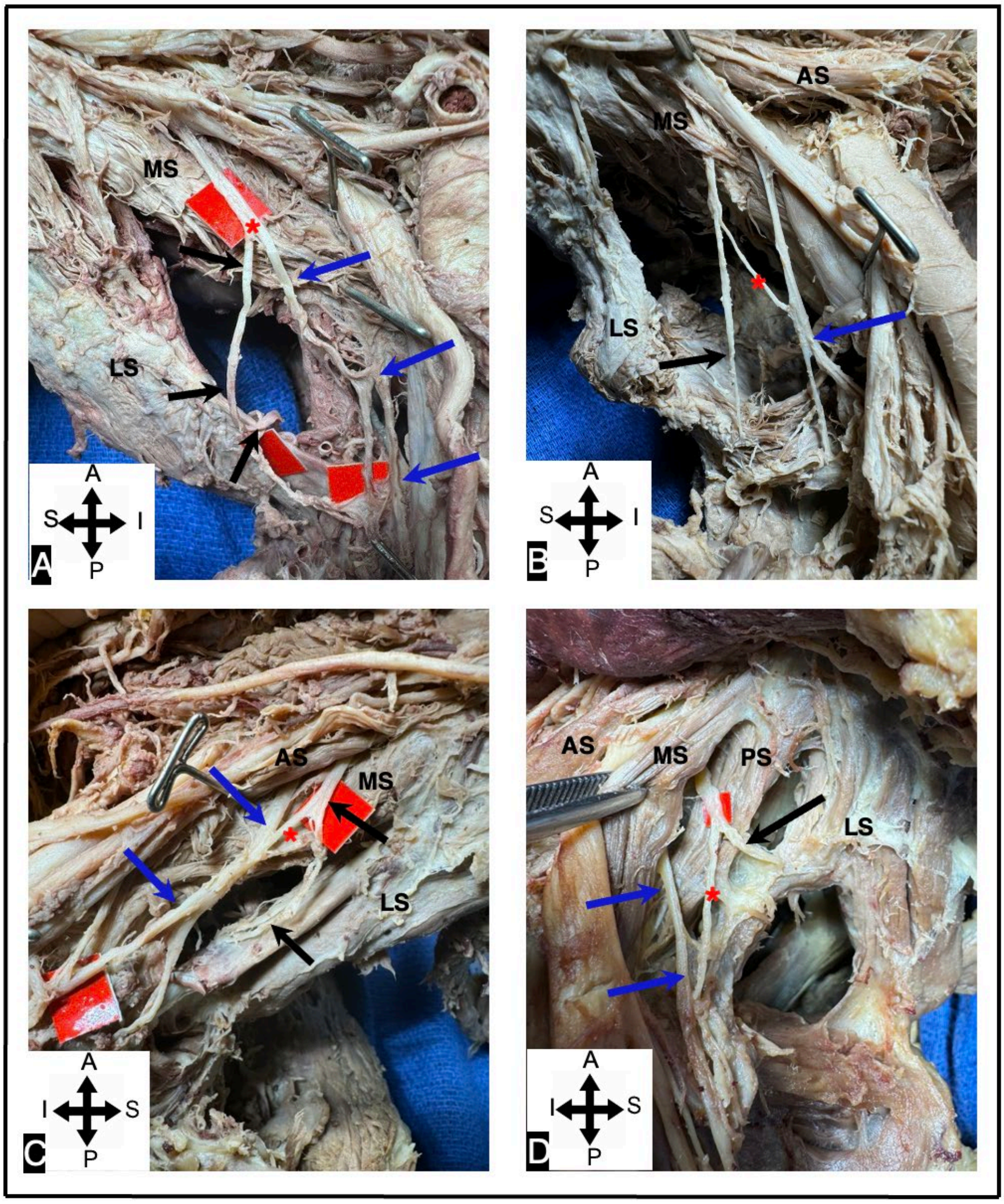

Figure 5. (a) Shared 5th cervical spinal nerve origin between the DSN and LTN. The DSN splits from this common origin to travel posterior to the levator scapulae muscle in route to target musculature while the LTN joins the other contributions to the LTN. A portion of the middle scalene muscle in this image was carefully removed to showcase this variation in more detail after data collection had taken place. **(b)** Shared distal branch between the DSN and LTN. **(c)** Common branch between a DSN that arose from the 5th cervical spinal nerve and the LTN. A portion of the middle scalene muscle in this image was carefully removed to showcase this variation in more detail after data collection had taken place. **(d)** Common branch between a DSN arising from the 5th cervical spinal nerve and the LTN. Symbols: black arrows: dorsal scapular nerve, blue arrows: long thoracic nerve, red star: DSN to LTN connection. Abbreviations: AS: anterior scalene muscle, MS: middle scalene muscle, PS: posterior scalene muscle, LS: levator scapulae muscle, A: anterior, P: posterior, S: superior, I: inferior.

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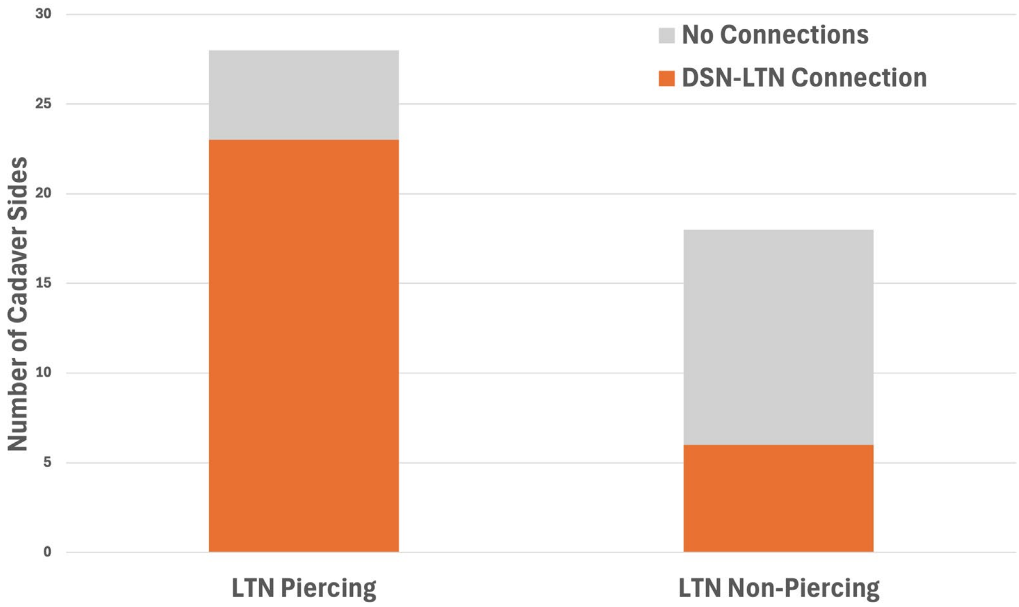

Figure 6. Long thoracic nerve (LTN) piercing patterns compared to the number of dorsal scapular nerve (DSN) to LTN (orange) and no DSN to LTN connections (grey).

The distance from the DSN to the medial border of the scapula at zone 1 was compared between sides with and without a LTN connection. In sides with a DSN to LTN connection (mean, 17.68 ± 6.38 mm; N = 21; p= 0.037), the DSN was significantly closer to the medial border of the scapula than in sides without a connection (mean, 21.97 ± 4.57 mm; N = 11; p = 0.037). No significant difference was observed between these groups in zone 2. Furthermore, no significant difference was found in the distance from the DSN scalene piercing point to the mastoid process between DSNs with (mean, 95.10 ± 12.07 mm; N = 22) and without (mean, 92.64 ± 8.53 mm; N = 15) LTN connections.

4. Discussion

Classical anatomical knowledge recognizes the DSN as originating from the C5 spinal nerve root [1,2]. Studies, however, suggest that contributions can vary from this typical spinal nerve origin. The findings in this study align with those of Çelikgün et al. (2023), who observed similar variation rates of the DSN spinal nerve origin. In contrast, literature has shown extensive variability in the cervical spinal nerve origin of the DSN. Jack et al. (2020) reported 100% of DSNs originating from the C5 spinal nerve root, Nguyen et al. (2016) reported the C5 spinal nerve origin in 70% of sides, whereas Ballesteros and Ramirez (2007) found the C5 spinal nerve origin in only 48.3% of cases.

Regarding the DSNs relationship with the scalene muscles, it is typically described as piercing the middle scalene [1,2]. The DSN was found to pierce the middle scalene muscle in 75% of the time, which is consistent with existing knowledge. 13% of DSNs were observed traveling posterior to the middle scalene muscle, a finding supported by Nguyen et al. (2016) and Williams and Smith (2020). Notably, a previously unreported variation was identified where the C4 and C5 spinal nerves contributed to the formation of the DSN. The C4 branch traveled anterior to the middle scalene muscle, while the C5 branch traveled posteriorly to the middle scalene muscle and eventually converged at the levator scapulae muscle. These variations may reflect population-based differences, as well as variations in donor sample size and sex distribution. A notable reflection of population-based differences affecting this variation is seen in the results of Tetsu et al. (2018), which reported 32.1% of DSNs traveling anterior to the middle scalene muscle. This increased incidence of an anterior DSN could be attributed to the high incidence of neck pain (katakori) among the Japanese population. Scalene muscle spasms or hypertrophy increase the susceptibility of entrapment for this anteriorly positioned DSN, resulting in higher rates of DSN neuropathy among this population [10].

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Çelikgün et al. (2023) was the first to measure the distance between the DSN scalene piercing point and the mastoid process. This measurement was replicated, yielding a mean distance of 94.87 ± 10.09 mm, compared to the mean distance of 88.53 ± 9.87 mm reported by Çelikgün et al. Notably, male donors had a mean distance of 100.59 ± 9.82 mm, which was greater than the mean distance of 86.9 ± 9.29 mm reported in Çelikgün et al.'s study. A significant difference was found between male and female donors, which was not observed in the study by Çelikgün et al. Height did not predict this distance, suggesting potential sex-based differences in the vertical positioning of the DSN. These discrepancies may be due to population-based differences, sex distribution, or sample size and warrant further investigation. Variation with this distance may have an impact when performing procedures in the neck region. In treatment of DSN neuropathy, interscalene nerve blocks may be used to alleviate symptoms, but caution is needed as these procedures may risk injury, particularly in cases of the typical middle scalene muscle piercing pattern [20,21]. Furthermore, variations in DSN anatomy should be carefully considered during thoracic outlet syndrome procedures in order to prevent injury [22,23].

The Eden-Lange procedure, which involves transferring the levator scapulae and rhomboid muscles from the scapula to the acromion and infraspinatus fossa, is used to address spinal accessory nerve injury [24]. It is crucial to preserve the DSN during this procedure to maintain proper function of these muscles post-operatively. The DSN was recorded to maintain a smaller distance to the medial border of the scapula at its proximal end near the SS, with increasing distance distally. This supports recommendations from Pinto et al. (2019) to remain close to the bony attachment of these muscles to avoid damaging the DSN. Interestingly, a study by Kang et al. (2022) using ultrasound on living humans reported that the DSN becomes progressively closer to the medial border of the scapula distally. This discrepancy may be due to differences between donor and living human anatomy, necessitating further investigation.

DSN neuropathy remains a challenging diagnosis, often overlooked or misdiagnosed. Sultan & Younis El-Tantawi (2013) examined 55 patients with a history of persistent upper back pain, finding that 29 of them had DSN neuropathy, which had been misdiagnosed. Many of these patients experienced mild, nonspecific pain radiating along the C5-6 dermatome or the medial border of the scapula [15]. In addition, several case reports have reported DSN neuropathy as the prospective cause for scapular winging in select patients rather than a traditional LTN injury [16–19]. The broadness of presentation and unexplained manifestations of DSN neuropathy underscores the importance for understanding the variations between the DSN and LTN. 65.2% of DSNs were found to connect with the LTN, a result consistent with recent studies such as Çelikgün et al. (2023), who reported a connection in 61.5% of cases. In a previous study from Williams and Smith (2020), the LTN was found to pierce through the scalene muscles in 55.4% of sides. This study aimed to examine the relationship between LTN piercing variants and DSN to LTN connections, an analysis not previously addressed in the literature. Piercing variants of the LTN were found to have the highest frequency of connections with the DSN. This may be due to both nerves favoring a piercing variation within the middle scalene muscle, increasing the likelihood of developing a connection due to their proximity. DSNs with a LTN connection maintained a smaller distance to the medial border of the scapula compared to DSNs that did not share a connection with the LTN. This provides additional insights into how the morphology and topography of the DSN may differ when it shares a connection with the LTN.

5. Limitations

While this study provides insights into the anatomical relationships of the DSN, several limitations should be acknowledged. Although care was taken to preserve the anatomical integrity of the DSN and its surrounding structures, some aspects of the dissection process may have affected the precise positioning of the nerve. While this study aimed to conduct measurements to maintain anatomical integrity, minor disruption to the surrounding fascia, particularly in the proximal portion of the DSN overlying the levator scapulae muscle may have influenced our results regarding the

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DSNs distance to the medical border of the scapula. To improved methodological rigor, future research should explore alternative measurement techniques to minimize tissue disruption.

6. Conclusions

This study provides more information about the origin of the DSN, the course of the DSN as it traverses proximal to distal, and the connections shared between the DSN and LTN. It is important to realize that this nerve may arise from cervical spinal nerves other than C5 and takes a variable course through or between the three scalene muscles. Additionally, there may be male and female differences in the vertical plane of where this nerve arises in the neck region, which is important to identify when performing procedures in this area. The DSN becomes increasingly distant from the medial border of the scapula as it travels distally, a finding that may be of critical importance during the Eden-Lange procedure. The DSN and LTN may also be highly connected providing insights for clinical manifestations such as scapular winging and thoracic back pain.

Author Contributions: Conceptualization, R.J.H. and S.S; Data curation, R.J.H.; Formal analysis, R.J.H.; Investigation, R.J.H. and S.S.; Methodology, R.J.H.; Supervision, S.S.; Writing – original draft, R.J.H.; Writing – review & editing, S.S.; R.J.H. gave final approval of the version of the article to be published; and R.J.H. agreed to be accountable for all aspects of the work ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of Kansas City University (IBC-2195821-1; Approved 06/20/2024).

Data Availability Statement: The data for this study is available from the corresponding author, R.J.H., upon reasonable request.

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Conflicts of Interest: The authors declare no conflicts of interest.

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