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Dorsal scapular nerve (DSN) syndrome is often associated with sharp, dull, or aching pain in the upper extremity and back. The primary cause of pain is the entrapment of this nerve at the middle scalene muscle. Even though there is clinical evidence that DSN syndrome exists, it is often overlooked during clinical diagnosis. The purpose of this study is to locate the surface projection of the DSN relative to the middle scalene muscle while using the laryngeal prominence as a reference point. From 20 embalmed adult cadavers, 23 DSN were dissected and documented regarding its spinal root origins, anatomical route, and muscular innervations. A transverse plane through the laryngeal prominence was established to measure the distance of the DSN as it enters, crosses, and exits the middle scalene muscle. Approximately 70% of the DSNs originated from C5, 22% branched from C4, and 8% from C6. In regards to the route of the DSN in relation to the middle scalene muscle, 74% of the DSNs pierced this muscle, 13% crossed this muscle anteriorly, and 13% traveled posterior to this muscle. About 48% of the DSNs supplied the levator scapulae muscle only and 52% innervated the levator scapulae and both the rhomboid muscles. The average distances from a transverse plane of the laryngeal prominence to where the DSN entered, crossed, and exited the middle scalene muscle were 1.50 cm (±0.88 cm), 1.79cm (±0.89 cm), and 2.08 cm (±0.96 cm) respectively. Injection studies were performed on 10 un-dissected embalmed cadavers to verify the accuracy of our surface projection measurements of the DSN relative to the middle scalene muscle. These injections were performed at approximately 2.08 cm (~1 thumb interphalangeal joint width) from the transverse plane of the laryngeal prominence. Dissections at these injection sites revealed that the scalene muscles were consistently located. The middle scalene muscle was accurately located in approximately 50% of the injections. The goal of this research is to understand the variability in

DSN's anatomy as well as introduce a method that will assist clinicians to efficiently pinpoint and therefore treat patients with DSN entrapment.

A CADAVERIC INVESTIGATION OF THE

DORSAL SCAPULAR NERVE

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A CADAVERIC INVESTIGATION OF THE DORSAL SCAPULAR NERVE

DISSERTATION

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By

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CHAPTER I

INTRODUCTION

1.1 *Anatomical Background*

In standard anatomical textbooks and atlases, the dorsal scapular nerve (DSN) is primarily a motor nerve that originates from the C5 root of the brachial plexus [1-11]. In addition to C5, this nerve occasionally receives contributions from C4 [12-15]. The DSN arises within the posterior cervical triangle and typically pierces the middle scalene muscle to provide innervation to the levator scapulae, rhomboid minor, and rhomboid major muscles [8, 13-18]. Because these muscles insert along the medial border of the scapula, collectively, they function to elevate and retract the scapula [2, 16]. Anatomical textbooks have also reported that the DSN sometimes innervates the levator scapulae muscle but primarily supplies the rhomboid minor and rhomboid major muscles [4, 5, 13, 19]. In addition to C5, the levator scapulae muscle, in particular, may be supplied by C3 and C4 [2, 17, 20]. The rhomboid muscles are predominantly innervated by C5 from the DSN, along with minor contributions from C4 or C6 [21].

In contrast, several anatomical studies in the primary literature indicate that the spinal root origins and muscle innervations of the DSN may vary (Appendix A). One study found that the DSN not only received contribution from C5 but also receive variable contributions anywhere from C4-T1 [22]. Lee et al. reported that nearly 25% of the DSN in their study originated from other spinal nerve roots aside from C5 [23]. Ballesteros' and Ramirez's study found that nearly 48% of the DSN originated from C5, whereas approximately 30% shared a trunk with the long thoracic nerve [24]. Shilal et al. (2015) also reported that the DSN shared a common trunk with the long thoracic nerve [55]. In contrast, Tubbs et al. reported that 95% of the DSN originated from C5, with 5% branching from the superior trunk of the brachial plexus [16].

In addition, there are varying reports regarding the muscles that the DSN innervates. For example, one case study from Japan reported that the DSN supplied the serratus posterior superior [25]. In Frank et al.'s study, they reported that the DSN innervated the levator scapulae muscle in only 11 out of 35 neck specimens [26]. Due to the variation in the reports regarding the spinal root origins and muscular innervations of the DSN, the overall anatomy of this nerve requires further investigation in order for rehabilitation professionals to properly diagnose and treat patients with pain from DSN impingement.

1.2 *Dorsal Scapular Nerve Syndrome*

Compression or entrapment of the dorsal scapular nerve (DSN) is associated with pain in the upper extremity and back. The typical symptoms documented in patients with this nerve impingement are dull, sharp, or aching pain along the medial border of the scapula that radiates to the lateral surface of the arm and forearm (Figure 1) [18, 32]. The compression of this nerve which causes these symptoms has been referred to as DSN syndrome [44, 54]. The entrapment of the DSN within the middle scalene muscle is the primary cause of pain. For example, Sultan et al. studied 55 patients with complaints of interscapular pain and observed that the impingement of the DSN at the middle scalene muscle was a frequent causative factor for their pain [33]. According to Kim et al. (2016), patients with DSN syndrome usually complain of a not well defined shoulder pain with different degrees of functional impairment [54]. Occupations which involve raising the arms over long periods of time, such as painters and electricians, make these particular individuals more likely to develop DSN entrapment [34]. There are also reports of DSN injury among athletes [35]. Jerosch et al. (1990) reported that, along with injury to the long thoracic nerve, the DSN was also injured as a result of an anterior shoulder dislocation during judo [36]. Another report described an isolated DSN entrapment in a body builder using anabolic steroids. It was thought that his middle scalene muscle was injured due to repetitive stretching during exercises of neck flexion and forceful repetitive shoulder shrugging [37]. Lastly, concurrent with injury to the suprascapular nerve, the DSN was also injured in two sibling volleyball players. According to Ravindran, the brother and sister were active volleyball players for over 6 years and had almost identical symptoms in that both developed right shoulder and scapular pain with particular wasting of the right infraspinatus muscles. Both siblings also had mild winging of the right scapula with weakness of the rhomboid muscles [38]. In addition to these sports- related DSN injuries, there are also case reports in which a lesion to or neuropathy of the DSN caused scapular winging [34, 39]. Because the DSN branches from the brachial plexus, clinicians often consider the impingement of this nerve to contribute to thoracic outlet syndrome [22].

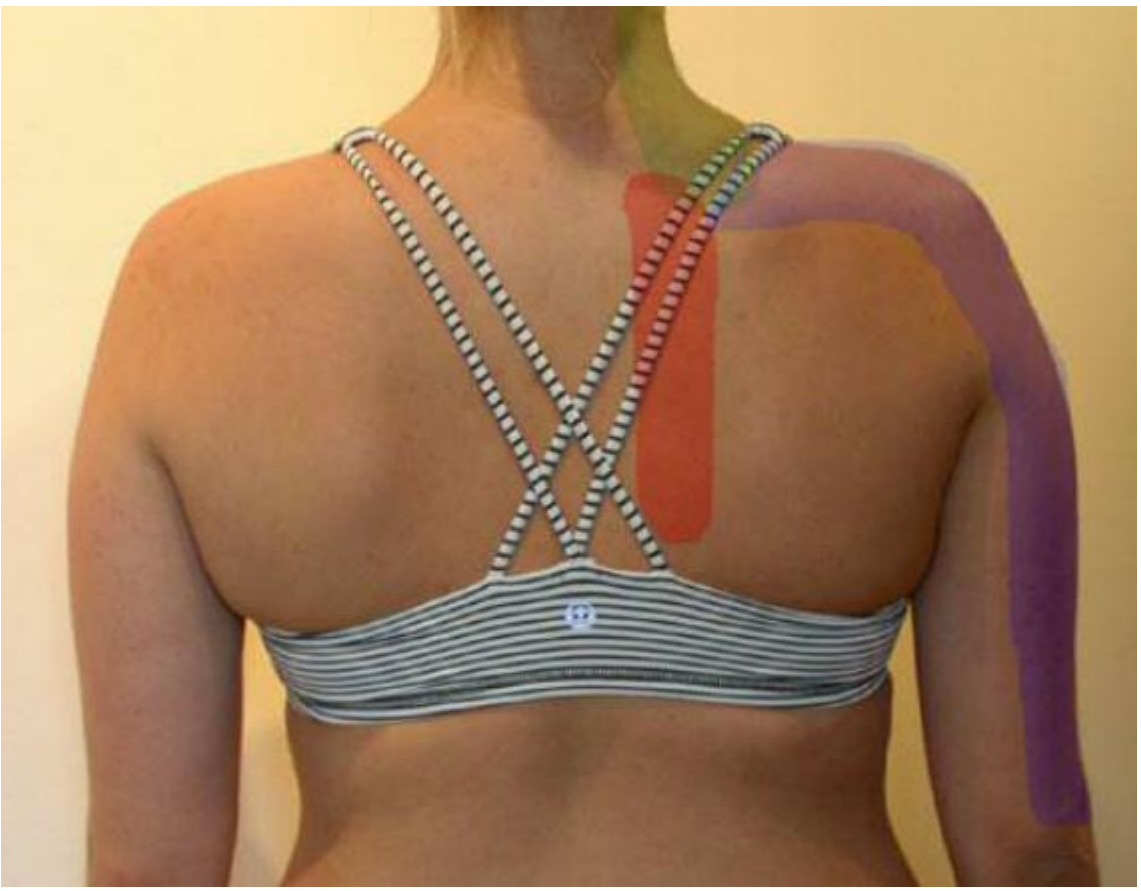

Figure 1. Pain pattern associated with dorsal scapular nerve entrapment. *Red* interscapular pain, *green* posterior neck and "levator" pain, *purple* lateral arm pain. Figure and image from *Dorsal Scapular Nerve Entrapment*, in *Peripheral Nerve Entrapments: Clinical Diagnosis and Management* by Andrea Trescot, MD [18].

1.3 *DSN Syndrome in Relation to Thoracic Outlet Syndrome*

Thoracic outlet syndrome (TOS) occurs when there is compression, injury, or irritation of the neurovascular bundle in the space between the clavicle and thoracic cage, resulting in numbness, pain, or paresthesia in the anterior chest, neck, shoulder, and anywhere else within the upper extremity [40, 41]. Approximately 95% of clinical cases of TOS is due compression of the brachial plexus, known as neurogenic TOS, whereas 4-5% are caused by compression of vascular structures [42]. According to a review article by Sanders et al. (2007), the causes of neurogenic TOS may be due to a fall or hyperextension neck injury due to whiplash from a motor vehicle accident. The next most common cause is repetitive work-related injury, such as sitting at a keyboard for long periods of time [40]. Overall, these neurovascular structures may be impinged in any of the three potential spaces in the thoracic outlet, which are the interscalene, costoclavicular, and subpectoralis minor spaces [43]. Specifically, the entrapment of the DSN affects the interscalene space [44]. The interscalene space is located at the base of the neck, superior to the first rib, and posterior to the clavicle. This space is bounded anteriorly by the anterior scalene muscle, posteriorly by the middle scalene muscle, and inferiorly by the clavicle between the insertions of these two muscles. Enclosed in this interscalene space are the trunks of the brachial plexus and the subclavian artery [45]. Currently, meaningful epidemiological figures of TOS are difficult to obtain due to debate among clinicians with regard to its exact definition, diagnosis, and treatment [46, 47]. As a result, some experts believe that TOS may be underdiagnosed or misdiagnosed [40, 48, 49]. The incidence of TOS has been broadly estimated to range from 0.3% to 8% of the United States population [41, 46] and the most commonly affected age range is between 20-50 years old [50]. Because the DSN lacks sensory branches, clinicians often overlook the entrapment of this nerve during differential diagnosis of back pain [33].

1.4 *Current Treatments of Dorsal Scapular Nerve Entrapment*

Current treatments used by clinicians in relieving patients with DSN entrapment may involve conservative and/or surgical approaches. According to Walther, soft tissue manipulation is commonly performed by passively extending the patient's neck in order to specifically stretch the middle scalene muscle on the affected side [51]. Another form of conservative management is directly anesthetizing the DSN. In this method, a nerve block (typically guided via ultrasound) is administered in order to relieve patients of their symptoms [52-54]. Although rare, surgical intervention, such as lesion of the middle scalene muscle, has also been reported to relieve patients from their pain [22]. In either case, the location and route of the nerve as it passes anterior, through, or posterior to the middle scalene muscle is important to know. In addition, it is imperative for rehabilitation professionals to be aware of other important anatomical structures surrounding the scalene muscles, such as the contents of the carotid triangle, the phrenic nerve, as well as the roots and trunks of the brachial plexus in order to safely treat their patients.

1.5 *Purpose of Research and Specific Aims*

Even though there is clinical evidence that DSN impingement exists, entrapment of this nerve is still easily missed during clinical diagnosis of back pain [33]. In addition, mixed reports regarding the DSN's spinal root origin(s) and muscular innervations indicate that further investigation in the overall anatomy of this nerve is needed in order for clinicians to implement proper diagnosis and treatment for patients with possible DSN impingement. Therefore, the entire anatomy of the DSN from its spinal root origins through its anatomical route relative to the middle scalene muscle and muscular innervations were investigated in this study. In addition, we developed a novel method for locating the surface projection of the DSN as it relates to the middle scalene muscle because the entrapment of the DSN typically occurs at this muscle [16]. The laryngeal prominence was chosen as the anatomical landmark in order to measure the oblique course of the DSN as it enters, crosses, and exits the middle scalene muscle. We believe that this method will provide a convenient and efficient mechanism for rehabilitation professionals to pinpoint where DSN entrapment may occur, so that appropriate management can be implemented. Our hypothesis is as follows:

We hypothesize the surface location of the DSN can be determined using measurements at the transverse plane of the laryngeal prominence to create a model of the nerve's path in relation to the middle scalene muscle.

In order to address our hypothesis, the specific aims of this project are:

1. <u>Determine the spinal root origin(s), anatomical route, and muscular innervations of the dorsal scapular nerve.</u> This aim was accomplished by dissecting 20 embalmed adult cadaveric necks and backs. The dissection was initially approached at the interscalene space in order to locate the superior trunk (C5, C6) of the brachial plexus. The DSN's spinal root origin(s), as well as its route in relation to the scalene muscles was documented. The route was then traced to its targeted muscles and also recorded (Appendix B). By investigating the overall anatomy of the DSN, we also documented any anatomical variations that may contribute to DSN compression.

2. Determine the distances of the dorsal scapular nerve as it enters, crosses, and exits the middle scalene muscle using the laryngeal prominence as the anatomical landmark. This specific aim was accomplished by establishing a transverse plane from the laryngeal prominence on embalmed adult cadavers in order to measure the distances of the DSN from this plane as it enters, crosses, and exits the middle scalene muscle. Average values of these triplicate measurements in centimeters and standard deviations were calculated. The purpose of this aim is to use these measurements to investigate the surface anatomy of the DSN's path in relation to the middle scalene muscle.
3. Determine the accuracy of the surface projection measurements of the dorsal scapular nerve in relation to the middle scalene muscle. A resin dye injection was performed on un-dissected embalmed cadavers in order to verify the accuracy of our measurements. The overall purpose of this aim is to pinpoint the surface location of the dorsal scapular nerve by using the laryngeal prominence and the posterior border of the sternocleidomastoid muscle as reference points, so that clinicians could potentially treat and manipulate the nerve at its site of entrapment.

1.6 SIGNIFICANCE

This research study is innovative because the anatomy of the dorsal scapular nerve was thoroughly investigated in order to develop a novel method for identifying the approximate location of the surface projection of this nerve as it relates to its typical site of impingement at the middle scalene muscle. Our study is the first to document the route of the DSN relative to the middle scalene muscle. The laryngeal prominence and the posterior border of the sternocleidomastoid muscle were chosen as anatomical landmarks for studying the surface projection of the DSN. Because the laryngeal prominence is palpable and easy to identify, it provided a convenient landmark through which a transverse plane could be established to take measurements of the route of the DSN in relation to the middle scalene muscle. The goal of this project is to improve a clinician's ability to accurately and efficiently locate the area of DSN entrapment so that proper diagnosis and treatment can be performed. This research will also assist rehabilitation professionals by becoming aware of potential variations in the overall anatomy of the dorsal scapular nerve so that during diagnosis, the impingement of this nerve is less likely to become overlooked.

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A Cadaveric Investigation of the Dorsal Scapular Nerve*

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ABSTRACT

Compression of the dorsal scapular nerve (DSN) is associated with pain in the upper extremity and back. Even though entrapment of the DSN within the middle scalene muscle is typically the primary cause of pain, it's still easily missed during diagnosis. The purpose of this study was to document the DSN's anatomy and measure the oblique course it takes with regards to the middle scalene muscle. From 20 embalmed adult cadavers, 23 DSN were documented regarding its spinal root origins, anatomical route, and muscular innervations. A transverse plane through the laryngeal prominence was established to measure the distance of the DSN from this plane as it enters, crosses, and exits the middle scalene muscle. Approximately 70% of the DSNs originated from C5, with 74% piercing the middle scalene muscle. About 48% of the DSNs supplied the levator scapulae muscle only and 52% innervated both the levator scapulae and rhomboid muscles. The average distances from a transverse plane at the laryngeal prominence where the DSN entered, crossed, and exited the middle scalene muscle were 1.50cm, 1.79cm, and 2.08cm respectively. Our goal is to help improve clinicians' ability to locate the site of DSN entrapment so that appropriate management can be implemented.

1. INTRODUCTION

In standard anatomical textbooks and atlases, the dorsal scapular nerve (DSN) is documented as a motor nerve originating from the ventral ramus of spinal nerve root C5, from the superior trunk of the brachial plexus [1-3, 7]. In addition to C5, various texts have also documented the DSN to occasionally receive contributions from C4 [12-15, 17]. This nerve typically pierces the middle scalene muscle and travels posteroinferiorly to innervate the levator scapulae, rhomboid minor, and rhomboid major muscles [8, 13-17]. Collectively, these muscles function to elevate and retract the scapula [7, 12, 13].

In contrast, several anatomical studies in the primary literature indicated that the spinal root origins and muscle innervations of the DSN may vary. One study found that the DSN not only receives contribution from C5 but also may receive variable contributions anywhere from C4-T1 [22]. Ballesteros' and Ramirez's study found that nearly 48% of the DSN originated from C5 whereas approximately 30% shared a trunk with the long thoracic nerve [24]. Lee et al. (1992) reported that nearly 25% of the DSNs in their study originated from other spinal nerve roots aside from C5 [23] whereas Tubbs et al. (2005) reported that 95% of the DSN originated from C5 and 5% branched from C5 and C6. A recent study by Shilal et al. (2015) also documented that the DSN arose from C5 and C6 and receives communications with the long thoracic nerve [55]. In addition, there are varying reports regarding the muscles that DSN innervates. For example, one case study from Japan reported that the DSN innervated the serratus posterior superior muscle [25]. In a study by Frank et al. (1997), they reported that the DSN innervated the levator scapulae muscle in only 11 out of 35 neck specimens [26].

The entrapment of the DSN is often located at the middle scalene muscle, because the nerve often pierces this muscle [33]. This nerve impingement or entrapment often leads to pain in the upper extremity and back. Patients typically experience sharp or aching pain along the medial border of their scapula that can radiate to the lateral aspect of their arm and forearm [32]. In addition, patients also report pain in their neck and back, as well as dysfunction of their shoulders [22]. Occupations which involve raising the arms over long periods of time, such as painters and electricians, make these particular individuals more likely to develop DSN entrapment [34]. There are also reports of DSN injury among athletes [35]. For example, Jerosch et al. (1990) reported that, along with injury to the long thoracic nerve, the DSN was also injured as a result of an anterior shoulder dislocation during judo [36]. Another report described an isolated DSN entrapment in a body builder using anabolic steroids. It was thought that the middle scalene muscle was injured due to repetitive stretching during exercises of neck flexion and forceful repetitive shoulder shrugging [37]. Lastly, concurrent with injury to the suprascapular nerve, the DSN was also injured in two sibling volleyball players. According to Ravindran, the brother and sister were active volleyball players for over 6 years and interestingly, had almost identical symptoms in that both developed right shoulder and scapular pain with particular wasting of the right infraspinatus muscles. Both siblings also had mild winging of the right scapula with weakness of the rhomboid muscles [38]. In addition to these DSN injuries in sports, there are also case reports in which a lesion to or neuropathy of the DSN caused scapular winging [34, 39]. Because the DSN branches from the brachial plexus, clinicians often describe the impingement of this nerve as contributing to thoracic outlet syndrome (TOS). Specifically, the impingement of the DSN affects the interscalene space in TOS [22, 44, 45]. Meaningful epidemiological figures of this syndrome are difficult to obtain due to debate among clinicians with regard to the exact definition, diagnosis, and treatment of TOS [46]. As a result, some experts believe that TOS may be under diagnosed or misdiagnosed [40, 48, 49]. The incidence of TOS has been broadly estimated to range from 0.3% to 8% in the US population [41, 46] and the most commonly affected age range is between 20-50 years old [49].

Current treatments used by clinicians in relieving patients from DSN entrapment may involve either conservative and/or surgical treatments. Conservative treatments beyond physical rehabilitation may involve administering a local nerve block injection, which is commonly guided via ultrasound, in order to relieve patients of their symptoms [44, 56, 57]. It is very important for health care providers to have good working knowledge of the area around the scalene muscles in the neck, especially if they are going to apply nerve block injections in this area. They must be aware of other important neurological structures such as the roots and trunks of the brachial plexus and the phrenic nerve. Surgical treatments for DSN entrapment typically involves lesion of the muscle that is impinging the DSN, most often the middle scalene muscle [22]. In either case, the location and route of the nerve as it passes anterior, through, or posterior to the middle scalene muscle is important to know.

The purpose of this study is to undertake a more extensive investigation and description of the anatomy of the DSN in order to gain a better understanding of the spinal root origins, anatomical route, and muscular innervations of this nerve. In addition, we created a model of the DSN's path in relation to the middle scalene muscle by using measurements established at the transverse plane of the laryngeal prominence. The measurements for the DSNs in this study will assist clinicians with efficiency in pinpointing the surface location of this nerve in their patients for the purpose of diagnosis and treatment of possible nerve entrapment.

2. MATERIALS AND METHODS

The dorsal scapular nerve was dissected and examined in 20 embalmed adult cadavers (12 females and 8 males) obtained through the Willed Body Program, Center for Anatomical Sciences, at the University of North Texas Health Science Center (UNTHSC) in Fort Worth, Texas. The age of the donors span from 52-93 years old with a mean age of 75 years. The self-reported ethnicities of the donors are 95% Caucasian and 5% African American. The cadavers are individually wrapped in cotton shrouds with Maryland State Wetting agent (Hydrol Chemical Company, Yeadon, PA) and are stored in metal tanks located in the UNTHSC gross anatomy laboratory.

The cadavers used in this project were initially dissected by first year medical students enrolled in the school's gross anatomy course. Once the medical students were finished with their dissections, the final preparation of the cadavers for this study began. The sternocleidomastoid muscles were detached from their origin and reflected laterally. The superior trunk of the brachial plexus (C5 and C6) was identified between the anterior and middle scalene muscles and any fascia overlying these muscles were removed. The DSN was first identified in relation to the scalene muscles, and then the route to the muscles that it innervates was traced. If the DSN or the scalene muscles on the cadaver were damaged (left or right side), then the DSN data on that side was excluded from the study. The majority of the DSN dissection in this study remained intact on the left side of the neck region compared to the right. On the right side of the neck, an incision was made to access vasculature for the embalming of our cadavers. Therefore, important structures such as the scalene muscles and the DSN were often damaged on that side.

A transverse plane through the laryngeal prominence was established using a 90º-angled ruler to create a reference site for three points of measurement to document the oblique route the

DSN takes in relation to the middle scalene muscle. The points were derived measuring the distance of the DSN from this transverse plane as the nerve enters, crosses, and exits the middle scalene muscle. The point at which the DSN "enters" the middle scalene muscle is defined as where the nerve initially contacts the medial border of the middle scalene muscle. The point at which the DSN "exits" the middle scalene muscle is defined as where the nerve contacts the lateral border of the middle scalene muscle. Finally, the point where the DSN "crosses" the middle scalene muscle is defined as the midpoint where the nerve contacts the medial (enters) and lateral (exits) border of the muscle. Yellow pins were placed to delineate the transverse plane (white dotted lines) of the laryngeal prominence (Figure 1a). The distances of the DSN from this plane as it enters, crosses, and exits the middle scalene muscle were measured using an electronic sliding caliper (Mitutoyo Corp.); three repeated measurements were made for each observation from this plane (Figure 1b). Average values and standard deviations were calculated from these measurements. In order to test the reliability (consistency) of these measurements, the Crohnbach's alpha test was conducted through the Statistical Package for Social Sciences (SPSS) software (IBM Corp 2015. IBM SPSS Statistics for Windows, Version 23.0, Armonk, NY: IBM Corp.). Dissection images were taken with a digital camera (Nikon Coolpix AW110).

3. RESULTS

The DSN was dissected from 20 embalmed adult cadavers that were previously dissected by first year medical students for classroom study. From these 20 cadavers, a total of 23 DSNs were examined. As indicated in Table 1, 70% of the DSNs originated from the spinal nerve roots of C5, whereas 22% arose from C4, and 8% from C6. With regard to the route of the DSN in relation to the middle scalene muscle, 74% pierced the muscle, whereas 13% of the DSNs traveled anterior to the middle scalene muscle, and 13% traveled posterior to the muscle. In addition, we observed that 52% of the DSNs provided innervation to the levator scapulae, rhomboid minor, and rhomboid major muscles combined. Furthermore, we observed that in 48% of the cadavers in our study, the DSN supplied only the levator scapulae muscle. Figures 2a and 2b are examples of a dissection of the DSN followed from its spinal root origins, anatomical route in relation to the middle scalene muscle, and muscular innervations in a 90-year-old female cadaver in the supine and prone position, respectively.

Measurements were taken of the DSN as it courses obliquely from the medial to lateral border of the middle scalene muscles. From the transverse plane of the laryngeal prominence, the mean distances at which the DSN enters (medial border) the middle scalene muscle was 1.50 cm with a standard deviation of 0.88 cm, the DSN crosses (midpoint) the middle scalene muscle at 1.79 cm (±0.89 cm) and exits (lateral border) this muscle at a mean distance of 2.08 cm (± 0.96 cm). These mean values and standard deviations were calculated from the 23 DSNs dissected and documented in this study (N=23). The Cronbach's alpha value was 0.999 which indicates very high consistency of the triplicate measurements conducted in this study.

4. DISCUSSION

In this study, we report the percentage of cases in which the spinal root of the DSN arose from C5 (70%) to be very similar to that reported by Lee et al. (1992) where the DSN arose from C5 approximately 75.8%. Similar to our data, almost 25% of the DSN in that study originated from spinal root origins other than C5, such as from the superior trunk of the brachial plexus (C5 and C6), C4 and C5, and C6 alone [23]. In terms of the muscular innervations, almost half of the DSNs in our study supplied the levator scapulae muscles only. Interestingly, Frank et al. (1997)

reported that although the DSN consistently pierced the middle scalene muscle, the muscular innervations of this nerve were highly variable. Their study documented that the DSN innervated the levator scapulae in only 11 out of 35 neck specimens [26]. These reports and our current data suggest that the anatomy of the DSN is variable and may be a possible reason in which clinicians often overlook the impingement of this nerve during differential back diagnosis [33].

5. CONCLUSION

Our research will assist clinicians in becoming aware of potential variations in the overall anatomy of the DSN in terms of its spinal root origins, anatomical route, and muscular innervations. No prior study has measured the oblique route of the DSN as it crosses the middle scalene muscle relative to the transverse plane of the laryngeal prominence. For future studies, these measurements will allow us to evaluate the surface projection of the DSN relative to its typical site of impingement (the middle scalene muscle) while using the transverse plane of the laryngeal prominence as a reference point. The long-term goal of this study is to provide data to assist clinicians and therapists to accurately and efficiently pinpoint the location of this nerve in patients with possible DSN impingement.

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CONFLICT OF INTEREST DISCLOSURE

The authors declare that there is no conflict of interest regarding the publication of this paper.

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TABLES

Table 1. Variation in the spinal roots and innervations of the DSN

Origin	**N and Percentage**
C4	5 (22%)
C5	16 (70%)
C6	2 (8%)
Route	
Anterior to middle scalene m.	3 (13%)
Pierces middle scalene m.	17 (74%)
Posterior to middle scalene m.	3 (13%)
Muscles Innervated	
Levator scapulae m. only	11 (48%)
Levator scapulae m. & Rhomboid mm.	12 (52%)
Total N	**23**

Cadaver number (N) and percentage for specific spinal root origins, route, and muscles innervated for the DSN.

FIGURES

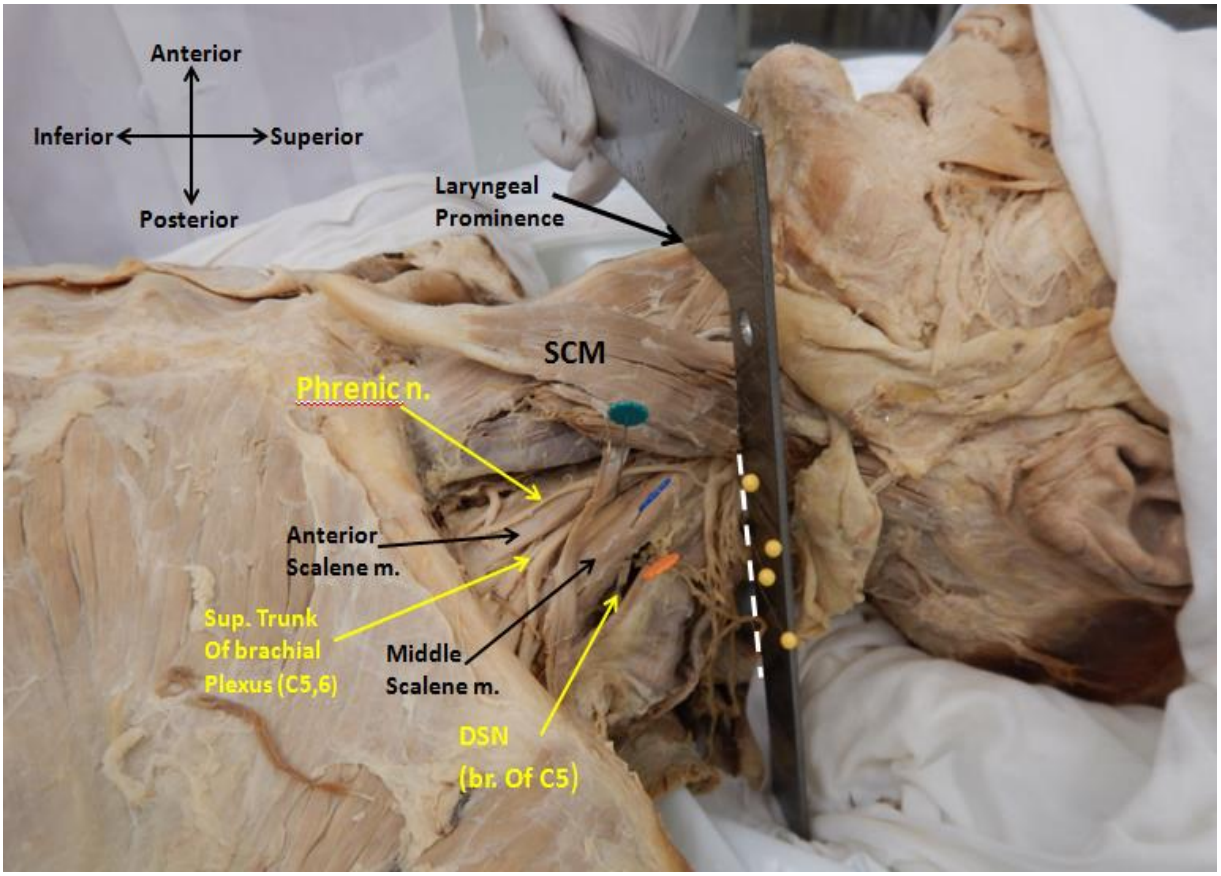

Figure 1a. A 90º-angled ruler was placed directly on top of the laryngeal prominence creating a transverse plane as denoted by the yellow pins. The DSN branches from C5 and pierces the middle scalene muscle.

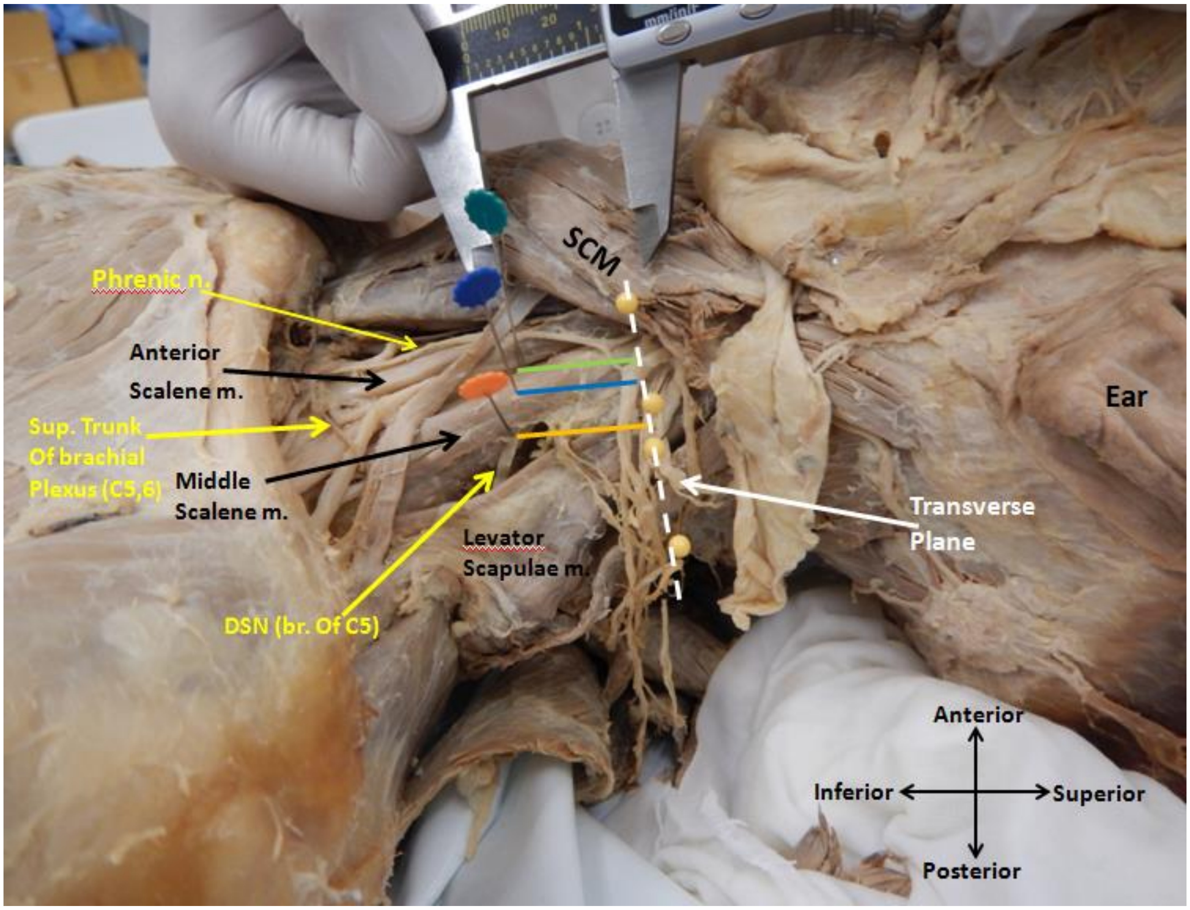

Figure 1b. An electronic sliding caliper was used to measure the distances (cm) from the transverse plane (white dotted line) of the laryngeal prominence to the DSN as it enters the middle scalene muscle (green pin), crosses this muscle (blue pin), and exits the middle scalene muscle (orange pin). SCM= sternocleidomastoid muscle.

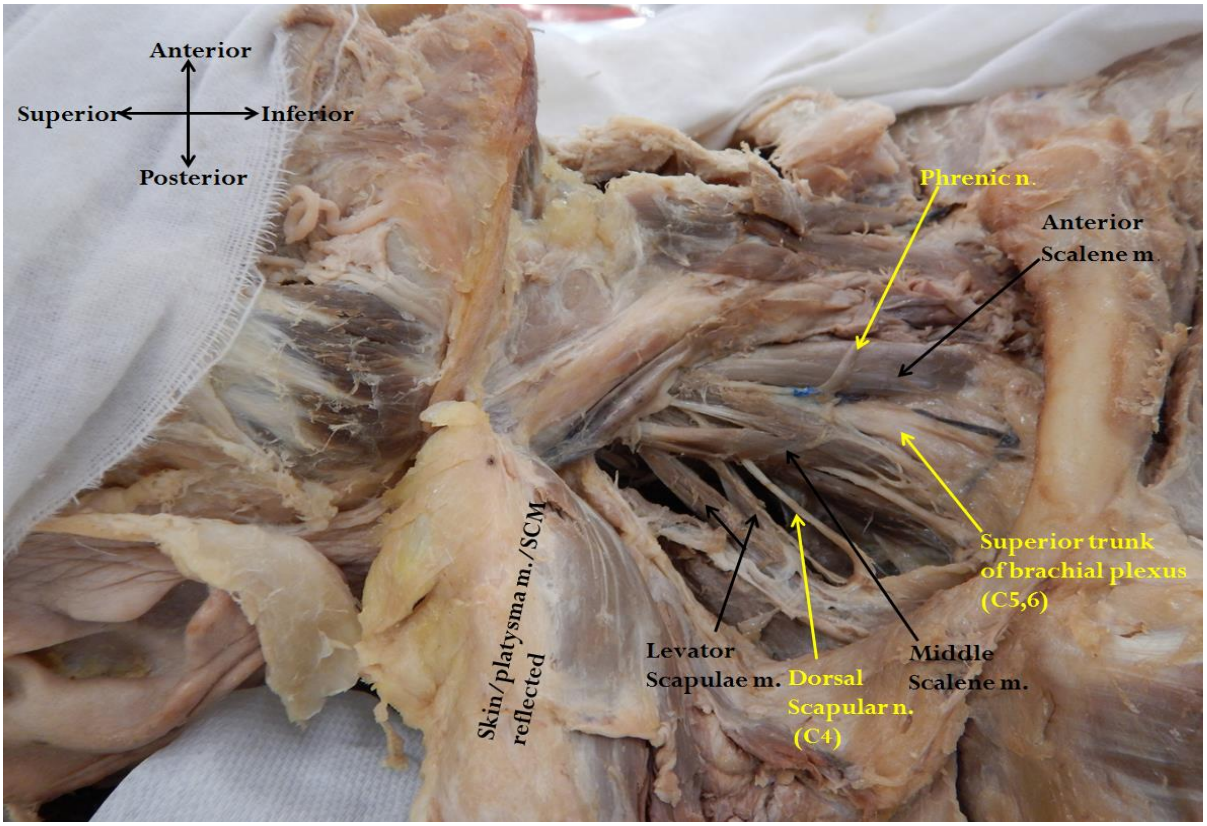

Figure 2a. An antero-lateral view of the right neck region of a 90-year-old female cadaver in the supine position. The DSN branches from C4 and pierces the middle scalene muscle.

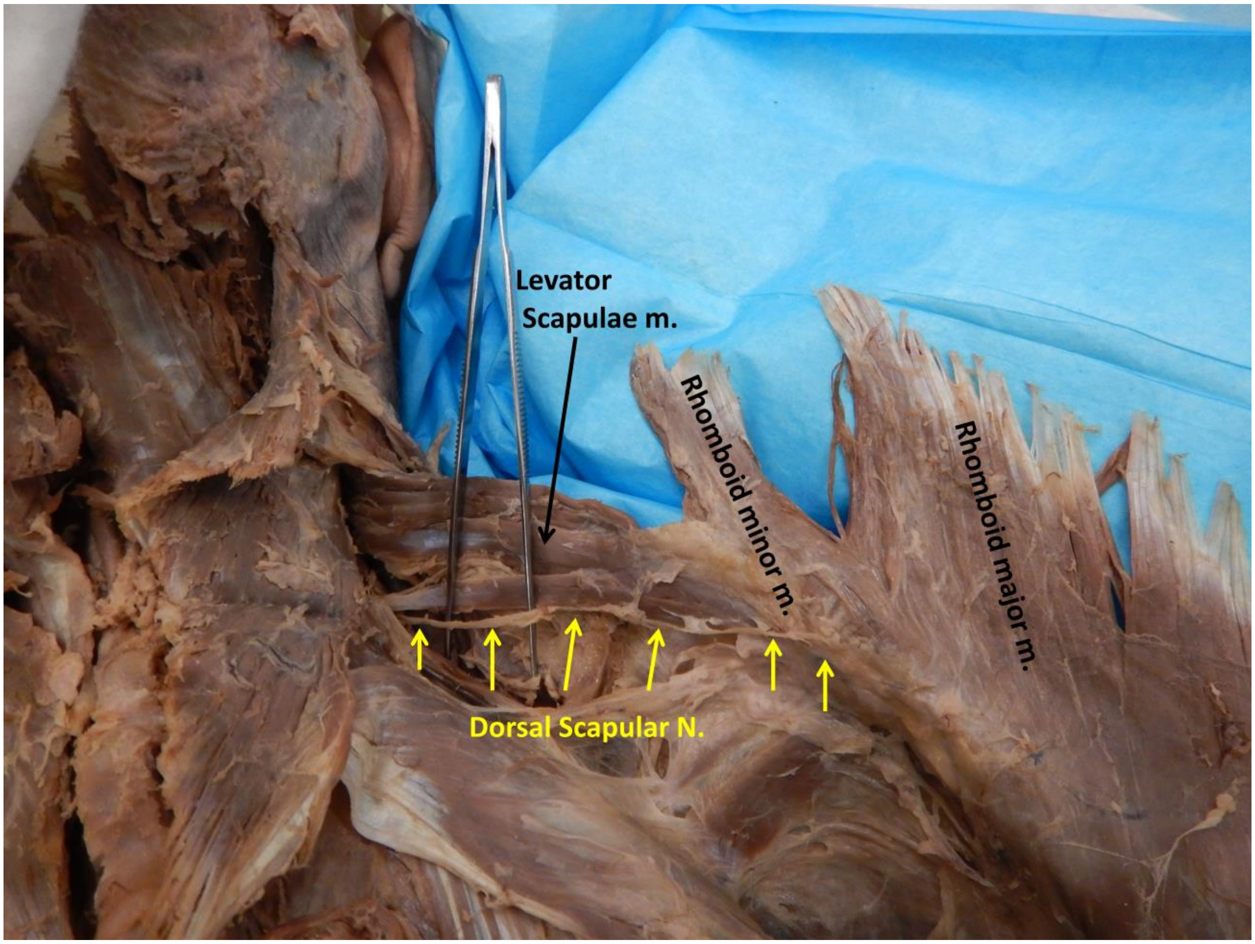

Figure 2b. In the prone position, the DSN travels postero-inferiorly after piercing the middle scalene muscle to supply the levator scapulae, rhomboid minor, and rhomboid major muscles. The rhomboid muscles are reflected laterally from their origin to show the route of the DSN.

CHAPTER III

The following manuscript was submitted to the *International Journal of Physical Therapy and Rehabilitation.*

MANUSCRIPT TITLE:

A Cadaveric Study on the Surface Projection of the Dorsal Scapular Nerve

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ABSTRACT

Background: Dorsal scapular nerve (DSN) syndrome is often associated by dull or aching pain along the medial border of the scapula that can radiate to the lateral aspect of the upper limb. The primary cause of this syndrome is due to the impingement or entrapment of this nerve at the middle scalene muscle. The purpose of this study is to identify the surface projection of the DSN relative to the middle scalene muscle by using the transverse plane of the laryngeal prominence and the posterior border of the sternocleidomastoid (SCM) muscle as reference points along with approximating the nerve's location using thumb interphalangeal joint (IPJ) width. **Methods:** The surface location of the DSN was examined in 10 embalmed adult cadavers. The posterior border of the SCM muscle was palpated and outlined along with the transverse plane of the laryngeal prominence. A resin dye was injected at a distance of 2.08 cm (~ 1 thumb IPJ width) medial to the intersection of the posterior border of the SCM and the transverse plane of the laryngeal prominence. Dissections were performed to reveal and record the location of the dye. The distance between the location of the dye to the DSN was also measured. **Results:** The overall accuracy of the injection study revealed that the scalene muscles were consistently located. Specifically, 50% of the injections were found at the middle scalene muscle, 20% was between the anterior and middle scalene muscles, 10% at the anterior scalene muscle, 10% between the middle and posterior scalene muscles, and 10% was located at the posterior scalene muscle. **Conclusion:** This investigation will provide clinicians a useful and convenient method to determine the surface projection of the DSN at its entrapment site for the purpose of diagnosis and therapeutic treatment.

Keywords: dorsal scapular nerve, entrapment, impingement, middle scalene muscle, scapular pain, levator scapulae, rhomboid minor, rhomboid major

BACKGROUND/ INTRODUCTION

The dorsal scapular nerve (DSN) is a motor nerve that primarily originates from the fifth cervical spinal nerve root in the brachial plexus [1-6]. Occasionally, in addition to C5, the DSN may also receive contributions from C4 [7-10]. The DSN arises within the posterior cervical triangle deep to the prevertebral fascia [11] and typically pierces the middle scalene muscle where it travels posteriorly between the posterior scalene and the serratus posterior superior muscles to provide motor innervation to the levator scapulae, rhomboid minor, and rhomboid major muscles. Collectively, all three of these muscles act to elevate and retract the scapula [12-17].

Several anatomical studies in the primary literature have indicated the variability of the DSN in terms of its spinal root origins and muscular innervations. For example, Shilal et al. (2015) reported that the DSN not only receive contributions from C5 and C6 but also communicated with branches from the long thoracic nerve [18]. Similarly, Ballestero's and Ramirez's study reported that nearly 48% of the DSNs branched from C5 while nearly 30% shared a trunk with the long thoracic nerve [19]. A recent cadaveric study by Nguyen et al. (2016) found that approximately 70% of the DSN originated from C5 while 22% arose from C4 and 8% branched from C6 [13]. Chen et al. (1995) also reported that in addition to C5, the DSN received variable contributions throughout C4-T1 [20]. In addition, there are varying reports regarding the muscular innervations of the DSN. For example, a case study in Japan reported that the DSN innervated the serratus posterior superior muscle [21]. In a study by Frank et al. (1997), they reported that the DSN innervated the levator scapulae muscle in only 11 out of 35 neck specimens [22]. Similarly, Nguyen et al.'s study also found that 48% of the DSN supplied the levator scapulae muscle only whereas 52% of the nerve supplied the levator scapulae as well as the rhomboid major and minor muscles.

DSN syndrome is characterized by general symptoms of sharp, dull, or aching pain along the medial border of the scapula that radiates to the lateral surface of the arm and forearm [23]. Patients also report dysfunction of their shoulders as well as pain in their neck and back region [20]. DSN syndrome is often caused by the entrapment or impingement of this nerve at the middle scalene muscle, because the DSN often pierces this muscle [13, 24-26]. However, because the DSN lacks sensory branches, the entrapment of this nerve is often overlooked during clinical diagnosis of back and interscapular pain [17, 24]. In addition, the variability in the anatomy of the DSN in terms of its spinal root origins and muscular innervations may also be another factor in which DSN impingement is frequently missed [13]. Occupations that require overhead work, such as painters and electricians, make these particular individuals more susceptible to DSN impingement [17]. There are also documented injuries of the DSN amongst athletes such as volleyball and basketball players, judo, and body builders [24, 27-29]. For example, along with injury to the suprascapular nerve, the DSN was also injured in two sibling volleyball players. Both siblings reported pain in their right shoulders and scapular region as well as mild winging of their right scapulas with weakness of the rhomboid muscles [30]. There are also case reports in which a lesion to or neuropathy of the DSN caused scapular winging [31-33]. For example, Akgun et al. (2008) reported a 51-year-old man who damaged his DSN after lifting a heavy box overhead. As a result from this lesion, he developed right shoulder pain as well as weakness of arm abduction and winging of his right scapula [17].

Current treatments to help resolve patients of their pain from DSN syndrome include muscle manipulation at the scalene muscles and/ or nerve block injection [13, 20, 34]. According to Walther, soft tissue manipulation can be performed by passively extending the patient's neck in order to specifically stretch their middle scalene muscle of the affected side [35]. Another form of conservative treatment is directly anesthetizing the DSN. In this method, a nerve block injection that is typically guided via ultrasound, is administered in order to relieve patients of their symptoms [16, 25, 36, 37]. Although rare, surgical intervention such as lesion of the middle scalene muscle have also been reported to relieve patients from their pain [20]. In both types of these conservative and surgical treatments, it is imperative for rehabilitation professionals to be aware of other important anatomical structures surrounding the scalene muscles of the neck such as the phrenic nerve as well as the roots and trunks of the brachial plexus in order to reduce the risk of injuring these structures.

Our previous study of the DSN investigated the relationship of this nerve as it crosses the middle scalene muscle relative to the transverse plane of the laryngeal prominence [13]. Average distances from the transverse plane of the laryngeal prominence to where the DSN entered, crossed, and exited the middle scalene muscle were reported. We used data from our previous study, then added to those anatomical data by presenting thumb interphalangeal joint (IPJ) width to approximate and predict the surface projection of the DSN. This was done relative to its site of entrapment (the middle scalene muscle) while using the transverse plane of the laryngeal prominence and the posterior border of the SCM muscle as anatomical landmarks. According to Liu et al. (2009), thumb width is a convenient measurement tool commonly used by clinicians such as physical therapists to measure the distance from the location of pain to a given body landmark [38]. Injection studies were performed to test the accuracy of using thumb IPJ width to locate the site of DSN entrapment at the middle scalene muscle.

The overall purpose of this study is to provide a convenient method for rehabilitation professionals to examine, diagnose, and treat patients with possible DSN impingement through the use of thumb IPJ width while using the transverse plane of the laryngeal prominence and the posterior border of the SCM as reference points. This method will assist clinicians in evaluating and implementing appropriate therapeutic treatments to patients who may exhibit symptoms of DSN syndrome.

MATERIALS & METHODS

The surface projection of the dorsal scapular nerve was examined in 10 embalmed adult cadavers (6 males and 4 females) obtained through the Willed Body Program, Center for Anatomical Sciences, at the University of North Texas Health Science Center (UNTHSC) in Fort Worth, Texas. The age of the donors span from 68 to 92 years with a mean age of 80 years. The self-reported ethnicities of the donors are Caucasian. The cadavers are individually wrapped in cotton shrouds with Maryland State Wetting agent (Hydrol Chemical Company, Yeadon, PA.) and are stored in metal tanks located in the UNTHSC Gross Anatomy Laboratory.

The cadavers used in this study have not been previously dissected and therefore, all skin in the neck region remained intact. The posterior border of the sternocleidomastoid (SCM) muscle was first identified and palpated. A transverse plane through the laryngeal prominence was established using a 90º-angled ruler. A grease pencil was used to outline the posterior border of the SCM muscle as well as mark the transverse plane of the laryngeal prominence to create reference points. An injection was made at approximately 2.08 cm medial from the intersection of the posterior border of the SCM and the transverse plane of the laryngeal prominence (Figure

1(a)). This value is the average distance at which the DSN exited the middle scalene muscle from the transverse plane of the laryngeal prominence as reported from our previous research [13]. In addition, 2.08 cm is equivalent to approximately one thumb IPJ width as reported from Liu et al.'s study in which average thumb IPJ width is approximately 2.0 ± 0.4 cm [38]. For injection, a polyurethane resin (PU4ii) with a proprietary blue dye was prepared following the manufacturer's instructions (vasQtec, Zürich, Switzerland). Approximately 0.1 ml of the resin dye was injected at a depth of 1 cm using a 1 ml syringe with a 22 gauge needle. The polyurethane resin was allowed to solidify for 24 hours post-injection. Dissections were then made along the posterior border of the SCM to reveal the location of the injection site as indicated by the blue dye. The distance of the dye to the DSN was measured using an electronic sliding caliper (Carrera Precision Corp.). All injections and dissections were performed on the left side of the neck region. On the right side of the neck, a previous incision was made to access vasculature for the embalming of our cadavers. Therefore, important structures such as the scalene muscles and the DSN were often damaged on that side. Dissection images were taken with a digital camera (Nikon Coolpix S6200).

RESULTS

The surface projection of the DSN was investigated in 10 embalmed adult cadavers. Measurements were also taken between the site of injection and the actual location of the DSN at the midpoint of the middle scalene muscle. The results of the injection study revealed that in 5 cadavers, the resin dye was located directly at the middle scalene muscle as the DSN either pierces or crosses anteriorly to this muscle. On one cadaver, the dye was located at the anterior scalene muscle and the distance between the location of the dye to the DSN was 0.683 cm. On two cadavers, the dye was located between the anterior and middle scalene muscles. The average distances between the location of the dye and the DSN at these injections was approximately 1.40 cm. On another cadaver, the dye was between the middle and posterior scalene muscles and the distance between the location of this injection to the DSN was about 0.676 cm. On the last cadaver, the dye was found at the posterior scalene muscle and the distance between this injection site and the DSN was 0.832 cm. Figure 1 is an example of our injection study showing the blue dye at the middle scalene muscle and the DSN crosses anteriorly to this muscle. It was also observed that in relation to the middle scalene muscle, 50% of the DSN pierced this muscle whereas 40% of the DSN crossed anterior to the middle scalene muscle and 10% of the nerve traveled posterior to the middle scalene muscle.

DISCUSSION

We used previous data from Nguyen et al. (2016) in order to estimate the surface projection of the DSN relative to the middle scalene muscle. The average distance, 2.08 cm (± 0.96 cm), was chosen from our previous research as the distance for the injection site from the intersection of the transverse plane of the laryngeal prominence and the posterior border of the SCM muscle [13]. This distance for the injection site was chosen for several reasons. Because 2.08 cm is the measurement at which the DSN exited the middle scalene muscle, this value is located at the most lateral border of this muscle. Therefore, important anatomical structures such as the phrenic nerve and the superior trunk of the brachial plexus would be farthest away from the injection site. This information is especially important for rehabilitation professionals in order to avoid injuring these anatomical structures during a nerve block injection. In addition, for therapists and clinicians, 2.08 cm is approximately 1 thumb IPJ width which makes this measurement clinically useful in pinpointing the surface projection of the DSN while using the reference points of the posterior border of the SCM muscle and the transverse plane of the laryngeal prominence.

The results of our investigation revealed that the surface location of the anterior, middle, and posterior scalene muscles were consistently identified when approximating the surface projection of the DSN using 1 thumb IPJ width medial to the intersection of the posterior border of the SCM muscle and transverse plane of the laryngeal prominence. Although we accurately identified the surface location of the DSN at its typical entrapment site (the middle scalene muscle) in 50% of the injections performed, the distances between the dye at other sites within the scalene muscles to the actual location of the DSN were measured. In those measurements, the average distance between the injected dye and the DSN was less than 1.0 cm which is less than half the distance of 1 thumb IJP width. Clinically, rehabilitation professionals could use these measurements as a radius to approximate the area of a circle at or very near to the DSN's position at the middle scalene muscle. This would allow professionals to treat patients with DSN syndrome by performing circular tissue manipulations within the surface projection of the middle scalene muscle.

CONCLUSION

Because the surface projection of the DSN has not been previously reported, the overall significance of this research is to provide easily identifiable reference points for clinicians to locate the nerve. Utilizing the posterior border of the SCM muscle as well as the transverse plane of the laryngeal prominence, clinicians' ability to accurately and efficiently locate the site of DSN entrapment will improve. In addition, using these reference points combined with a simple

1 thumb IPJ width measurement, this method may prove to be very useful for rehabilitation professionals to examine, diagnose, and conservatively treat patients with DSN impingement. Future studies in investigating the effectiveness of our method in a patient population along with locating the DSN via ultrasound could be beneficial in validating our proposed method.

COMPETING INTERESTS

The authors declare that there is no conflict of interests regarding the publication of this paper.

AUTHOR'S CONTRIBUTION

1. Vuvi Nguyen: contributed to the concept and design, data acquisition, data analysis and interpretation, and writing of manuscript.
2. Hao (Howe) Liu: contributed to the concept and design, data interpretation, and manuscript editing
3. Armando Rosales: contributed to data interpretation and manuscript editing
4. Rustin Reeves: contributed to the concept and design, data analysis and interpretation, and manuscript editing for final approval

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FIGURES

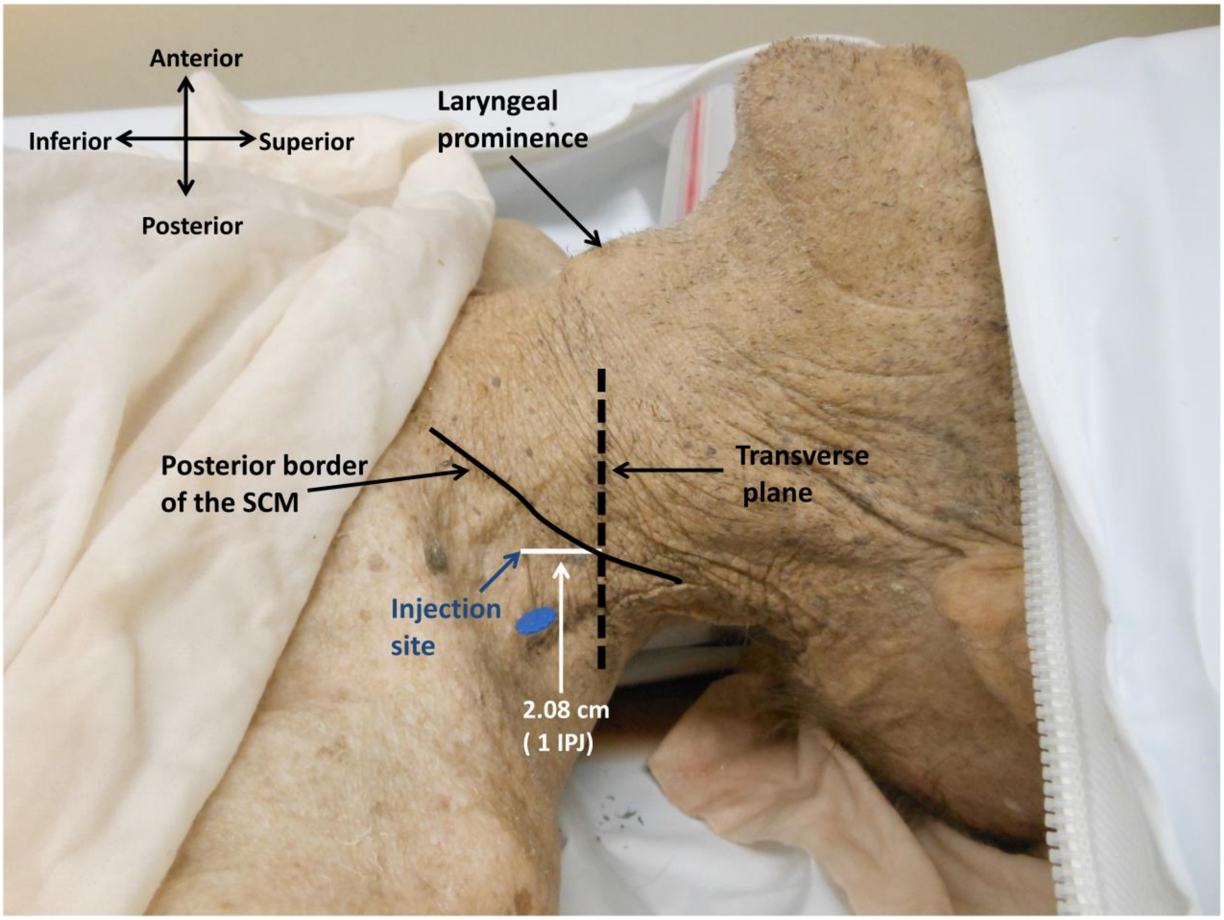

Figure 1a. The surface anatomy of the left neck region of an 81-year-old male cadaver in the supine position. The black dashed lines represents the transverse plane of the laryngeal prominence. The black solid line indicates the posterior border of the sternocleidomastoid (SCM) muscle. The white solid line represents the distance of 2.08 cm (~1 thumb IPJ width) at which the injection was performed. The blue pin indicates the injection site.

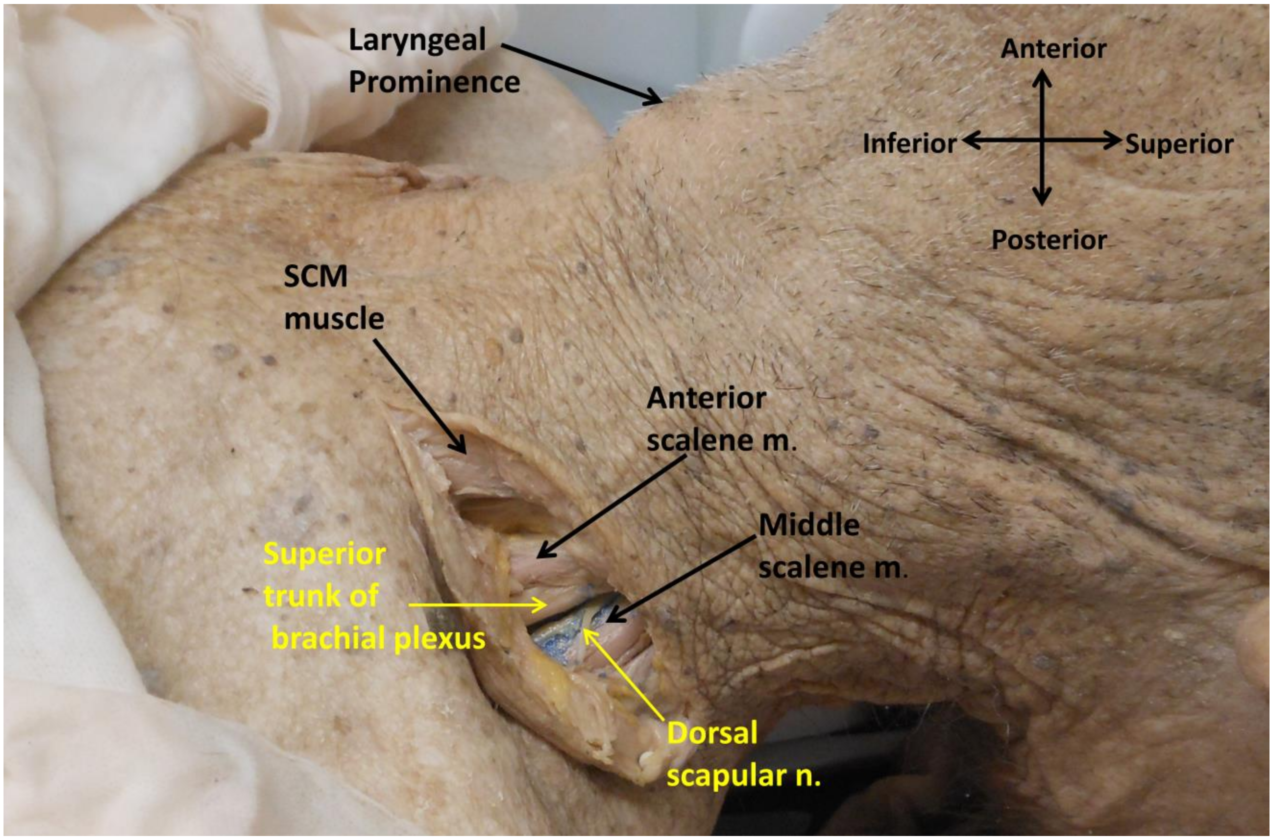

Figure 1b. The dissection revealed the location of the injection site as indicated by the blue stain on the middle scalene muscle as the DSN crosses anterior to this muscle.

CHAPTER IV

RESEARCH LIMITATIONS

There were a few limitations encountered during the course of our cadaveric investigation of the dorsal scapular nerve. These limitations included the fragile dissection of this nerve along with its targeted muscles which may have limited the sample size of this project. For the injection study, not all of the body donors had a distinguishable surface anatomy of the laryngeal prominence and palpable posterior border of the SCM muscle. As a result, this may have affected our accuracy in consistently pinpointing the surface projection of the DSN at the middle scalene muscle. Lastly, the medical histories of the cadavers used in this study were unavailable for us to correlate certain anomalies of the DSN reported in our study that may contribute to DSN impingement.

The cadavers used in this project were previously dissected by first year medical students for classroom study which may contribute to our limitation in the sample size of this research. The anatomy of the DSN is typically not exposed to students during lab dissection. Therefore, this fragile nerve can often be torn by students who are unaware of DSN's anatomical route to its targeted muscles in the neck and superior back region. In addition, the levator scapulae, rhomboid minor, and rhomboid major muscles were sometimes also torn during these dissections and therefore, the DSN would often be torn as well. As a result, data for the DSN for these particular bodies would be excluded. Another contribution to the limitation of our sample size would be the embalming site that was performed previously in these cadavers. The majority of the DSN dissected in this study remained intact on the left site of the neck region compared to the right one. On the right side of the neck, an incision was made to access vasculature for the embalming of our cadavers. Therefore, important structures such as the scalene muscles and the

DSN were often damaged on that side. As a result, the DSN was often not observed in both the left and right sides of the same donor.

Another limitation encountered during this research was that in some bodies, the surface anatomy of the laryngeal prominence and the posterior border of the DSN were not prominent and at times difficult to identify. As a result, during the pilot study of our injections, the SCM muscle was often penetrated and the scalene muscles were missed because the posterior border of the SCM were not clearly defined in bodies with an increase amount of fascia in the neck region. Therefore, the injection studies performed in our research were limited to bodies in which the surface anatomy of the laryngeal prominence and the posterior border of the SCM muscle were clearly identifiable.

The last limitation is that the medical histories of the body donors are unknown. As a result, it is difficult to be certain which of the varying anomalies of the DSN that we reported in our study correlate to the likelihood that these body donors may have exhibited symptoms of DSN syndrome in their lifetime. Therefore, the clinical correlations that we can ascertain with our DSN data would be through previous publications of patients who exhibited DSN entrapment.

CHAPTER V

SUMMARY AND DISCUSSION

The purpose of this project was to investigate the overall anatomy of the dorsal scapular nerve regarding its spinal root origins, anatomical route, and muscular innervations. The results of this study revealed that in our sample size of 20 cadavers, approximately 70% of the DSN originated from C5, 22% originated from C4, and 8% branched from C6. In terms of the anatomical route of the DSN relative to the middle scalene muscle, 74% of the DSN pierced this muscle, 13% crossed the middle scalene muscle anteriorly, and 13% traveled posterior to this muscle. For the muscular innervations, nearly half of the DSN innervated the levator scapulae muscle only, whereas the rest innervated the levator scapulae along with the rhomboid minor and rhomboid major muscles. Interestingly, our results were similar with previous research on the DSN. For example, Lee et al. (1992) reported that 75% of the DSN originated from C5 and about 25% of the DSN originated from other spinal root origins, such as from C4 and C5, C5 and C6, and C6 alone [1]. In terms of the anatomical route of the DSN, previous research as well as various anatomical textbooks in the primary literature have only reported the nerve piercing through the middle scalene muscle [2-8]. Our research is the first to observe and document the route of the DSN relative to the middle scalene muscle. The significance in understanding the route of the DSN will assist clinicians in becoming aware of its variability relative to the middle scalene muscle, especially if conservative and/ or surgical treatments are performed in patients with DSN impingement. In terms of the muscular innervations of the DSN, our observation in which this nerve only innervated the levator scapulae muscle was also reported by Frank et al. (1997) in which they noted that the DSN innervated the levator scapulae muscle in only 11 out of

35 neck specimens [9].

Our investigation in the overall anatomy of the DSN has led us to create a model of the DSN's path in relation to the site of impingement (the middle scalene muscle) by using measurements established at the transverse plane of the laryngeal prominence. Measurements were taken of the DSN as it courses obliquely from the medial to lateral border of the middle scalene muscle from the transverse plane of the laryngeal prominence. The mean distances at which the DSN enters (medial border) the middle scalene muscle was 1.50 cm (±0.88 cm), crosses the middle scalene muscle at 1.79 cm (±0.89 cm), and exits (lateral border) the middle scalene muscle at 2.08 cm (±0.96 cm). Our measurements allowed us to evaluate the surface projection of the DSN relative to the middle scalene muscle for specific aim 3.

We created a resin dye injection study in order to verify our predicted location of the DSN at the middle scalene muscle while using the transverse plane of the laryngeal prominence and the posterior border of the sternocleidomastoid muscle as reference points. The average measurements of the DSN as it crossed (1.79 cm) and exited (2.08 cm) the middle scalene muscle were evaluated and we decided to perform our injection site at 2.08 cm from the transverse plane of the laryngeal prominence. Since this value represented the DSN at the most lateral border of the middle scalene muscle, the injection site would be farthest away from important structures, such as the phrenic nerve and the superior trunk of the brachial plexus. Reducing the risk in injuring these structures would be very important for rehabilitation professionals in their approach for treating patients with DSN syndrome. In addition, the statistical differences between 1.79 cm and 2.08 cm along with their standard deviations were quantified using Cohen's d effect size formula. This formula was used to show that these two values are relatively similar in size and that our choice in performing the injections at 2.08 cm instead of 1.79 cm will not have a major difference in the outcome of the injections. By using the formula, the d value between these averages is 0.3, which indicates a small size difference in accordance with Cohen's general guidelines which defined effect sizes as "small, d=0.2," "medium, d=0.5," and "large, d=0.8" [10].

In order for our measurements in predicting the surface location of the DSN to be clinically useful, we correlated the average value of 2.08 cm to the number of thumb interphalangeal joint (IPJ) widths against the transverse plane of the laryngeal prominence. According to Liu et al. (2009), thumb width is a convenient measurement tool commonly used by clinicians to measure the distance from the location of pain to a given body landmark [11]. In their study, average thumb IPJ width is approximately 2.0 ± 0.4 cm which is equivalent to about 1 thumb IPJ width in our study, when measuring 2.08 cm from the transverse plane of the laryngeal prominence.

Injection studies using a blue resin dye were performed on 10 undissected embalmed adult cadavers to verify and reveal the accuracy of using thumb IPJ width to locate the site of DSN entrapment at the middle scalene muscle. Based on the location of the dye, which signifies the injection site, the results of our study revealed that in 50% of the injections performed, the blue dye was located on the middle scalene muscle in which the DSN either pierced or crossed anteriorly to this muscle. In 20% of the injections, the dye was found in between the anterior and middle scalene muscles. In 10% of the injections, the dye was located on the anterior scalene muscle whereas in another 10%, the dye was found in between the middle and posterior scalene muscles. In the last injection, the dye was located on the posterior scalene muscle. Our results indicated that the scalene muscles were consistently pinpointed when using the laryngeal prominence and the posterior border of the sternocleidomastoid muscle as reference points. Even though 50% of the injections were located at sites other than the middle scalene muscle, the average distances between those sites and the actual location of the DSN was less than 1 thumb IPJ width. In a clinical setting, rehabilitation professionals could use these measurements to approximate the distances to implement circular motions via tissue manipulations on patients with possible DSN entrapment at or very near the surface projection of their middle scalene muscle. The laryngeal prominence and the posterior border of the sternocleidomastoid muscles are easily identifiable landmarks that will help clinicians to quickly estimate the projected surface anatomy of the DSN at the site of impingement for the purpose diagnosing and treating patients with DSN syndrome.

CHAPTER VI

CONCLUSION AND FUTURE DIRECTIONS

The long term goal of our cadaveric research on the DSN is to assist rehabilitation professionals, such as physical therapists and osteopathic physicians, in treating patients with possible DSN syndrome. Currently, conservative treatments such as muscle manipulation at the middle scalene muscle or ultrasound-guided DSN block have been commonly performed to relieve patients from their interscapular and/or upper extremity pain [12-15]. Prior to this study, the overall investigation of the surface projection of the DSN has not been previously documented. Therefore, our novel and innovative method of investigating the surface location of this nerve using the laryngeal prominence and the posterior border of the sternocleidomastoid (SCM) muscle as reference points may prove to be useful in assisting clinicians to accurately, efficiently diagnose, and implement conservative treatments to patients who suffer from interscapular and back pain. In addition, our thorough documentation in the overall anatomy of the DSN will help rehabilitation professionals become aware of the anatomical variations of this nerve in terms of its spinal root origins, route in relation to the middle scalene muscle, and muscular innervations, so that DSN impingement is less likely to be overlooked during diagnosis.

For future directions, applying our method in a clinical setting could be used to evaluate the effectiveness by which physicians can pinpoint the site of DSN impingement in treating patients. In addition, the surface anatomy of the DSN could be further confirmed through the use of ultrasound. Even though ultrasound is often used to locate the DSN in patients, it has been documented that in some cases, this nerve may not be visible in ultrasound due to its anatomical variability [14]. Therefore, the results of our study in identifying variations in DSN anatomy can assist clinicians in locating this nerve by ultrasound along with using our designated anatomical landmarks as reference points. The overall results of this research may have a major impact on rehabilitation professionals in accurately diagnosing, effectively treating, and improving the lives of patients with DSN syndrome.

APPENDICES

APPENDIX A:

TABLE OF VARIATIONS ON DORSAL SCAPULAR NERVE'S ANATOMY CITED FROM VARIOUS ANATOMICAL TEXTBOOKS, ATLASES, AND PEER REVIEWED JOURNALS

APENDIX A

TABLE 1: Dorsal Scapular Nerve's Anatomy References from Various Textbooks and Atlases

Textbook	Spinal Root Origins	Anatomical Route	Muscular Innervations
Clinically Oriented Anatomy 6th Ed. by Moore et al [13] (p. 701)	Posterior aspect of anterior ramus of C5 with a frequent contribution from C4	Pierces middle scalene muscle; descends deep to target muscles.	Rhomboid minor/major- DSN (C4,5) Occasionally levator scapulae- innervated by DSN (C5) and cervical nerves (C3,4)
Gray's Basic Anatomy by Drake et al [2] (p. 363)	Originates from the C5 root of the brachial plexus	Passes posteriorly, often piercing the middle scalene muscle in the neck, to reach and travel along the medial border of scapula and innervates the rhomboid muscles from their deep surfaces.	Levator scapulae- branches directly from anterior rami of C3 and C4 spinal nerves and by branches [C5] from the DSN. Rhomboid minor and major- DSN [C4,5]
Atlas of Clinical Gross Anatomy 2nd Ed. by Moses et al [17] (pp. 149 & 184)	DSN arises from the anterior ramus of C5	Pierces (and innervates) the middle scalene muscle, descends deep to the targeted muscles.	Levator scapulae Rhomboid minor and major
Netter's Clinical Anatomy 3rd Ed. by John Hansen [12] (p. 360)	DSN C4,5	Not mentioned	Levator scapulae and Rhomboid muscles
Human Anatomy Color Atlas and Textbook 6th Ed. by Gosling et al[20] (p. 101)	C5	Not mentioned	Supplies the rhomboids and may innervate levator scapulae, which is also supplied by branches from the cervical plexus (C3&4)
Crash Course Anatomy 4th Ed. by Granger [27] (p. 39)	C5	Not mentioned	Distributes to levator scapulae, rhomboid minor/major muscles

Dorland's Gray's Pocket Atlas of Anatomy by Drake et al [4]. (p.308)	C5	Not mentioned	Distributes to rhomboid muscles and occasionally levator scapulae
Anatomy An Essential Textbook by Gilroy [15] (p. 255)	C4,5	Not mentioned	Levator scapulae and rhomboids
Clinical Atlas of Human Anatomy 7th Ed. by Abrahams et al. (p. 31)	C5	Pierce middle scalene muscle	Levator scapulae and rhomboids
Clinical Anatomy for Medical Students 6th Ed. by Snell et al [1] (p. 49-410 and 422)	C4,5	Not mentioned	Levator scapulae- DSN (C5) and C3,4 Rhomboids- DSN (C5)
Anatomy & Physiology From Science to Life 3rd Ed. by Jenkins and Tortora (p. 474)	C5	Not mentioned	Distributes to levator scapulae and rhomboid minor and major muscles.
Essential Clinical Anatomy 3rd Ed. by Moore and Agur[19] (p. 430)	Posterior aspect of anterior ramus of C5 with a frequent contribution from C4	Pierces middle scalene; descends deep to levator scapulae and rhomboids	Rhomboid muscles; occasionally levator scapulae
Anatomy A Regional Atlas of the Human Body 5th Ed. by Carmine D. Clemente [9] (p. 334)	C5	Not mentioned	Levator scapulae- C3,C4 and the DSN (C5) Rhomboid minor and major- DSN (C5)
Board Review Series Gross Anatomy by Kyung Won Chung[28] (p. 265)	Originates from C5 behind the scalenus anterior	Runs through the scalenus medius and then deep to the trapezius. Passes deep to or through the levator scapulae and descends along with the DSN on the deep surface of the rhomboids along with the medial border of the scapula	Supplies the levator scapulae and rhomboid muscles
Fundamental Anatomy by Walter Hartwig[5] (p. 354)	C5	Not mentioned	Rhomboid minor and major- DSN (C5) Levator scapulae- DSN (C5) and ventral rami C3,C4

USMLE Road Map: Gross Anatomy by James S. White (p. 142)	Arises from the C5 ventral ramus of plexus	Courses through the substance of the scalenus medius muscle and courses the posterior triangle of the neck. Passes deep to the vertebral border of the scapula.	Supplies the levator scapulae, rhomboid minor, and rhomboid major muscles.
Atlas of Human Anatomy 4th Ed by Frank Netter [7] (plate 430)	Shown as a branch from C5	Not mentioned	Not mentioned
Gross Anatomy in the Practice of Medicine by Frank J. Slaby, Susan K. McCune, and Robert W. Summers[10] (pp. 67 and 92)	Arises from C5	Not mentioned	Levator scapulae- DSN (C5) and fibers from spinal nerves C3,C4 Rhomboid muscles- DSN (C5)
Functional Human Anatomy by James E. Crouch 2nd Edition[29] (1972) (pp. 266-272)	Not explicitly stated	Not mentioned	Levator scapulae (C3,4,5)- DSN Rhomboids- DSN
Textbook of Anatomy by A.W. Rogers [30] (1992) (pp.251-252)	C5	Not mentioned	Levator scapulae- supplied from the anterior primary ramus of C5 and also has fibers from C3,C4 Rhomboids- supplied by the anterior primary ramus C5
Grant's Atlas of Anatomy by James E. Anderson[31] (1978) 7th Edition	C5	Not mentioned	Levator scapulae- C3,4 Rhomboids- C5
Anatomy: development, function, clinical correlation By William J. Larsen (2002) (p. 524) [11]	C5	Not mentioned	Levator scapulae, rhomboid minor, rhomboid major muscles

TABLE 2: Dorsal Scapular Nerve's Anatomical Variations Cited from Peer-Reviewed Journals

Literature	Sample size	Sex and Age	Ethnicity	Comments about DSN
Damage of the long thoracic and dorsal scapular nerve after traumatic shoulder dislocation: Case report and review of the literature by Jerosch et al. (1990)	1 patient	19 years old- female	not mentioned	Right anterior shoulder dislocation while practicing judo. Humeral head dislocated anteriorly each time she abducted and externally rotated her shoulder. 1 year later- weakness and atrophy of shoulder muscles. Winged scapula and atrophy of serratus anterior and rhomboids
Variations of the Ventral Rami of the Brachial Plexus by Lee et al. (1992)	77	46 males and 31 females 20-88 years old	Korean	C5= 75.8%; C5,6= 9.0% C4,5= 7.6%; C6= 7.6% DSN pierced the middle and posterior scalene m. in 7 cases No mention of muscles innervated
The human superior posterior scalene muscle supplied b both intercostal and dorsal scapular nerve by Kida and Tani (1993)	1	1 male 67 years old	Japanese	C5; innervated serratus posterior superior muscle (no picture provided; article in Japanese)
Dorsal Scapular Nerve Compression of Atypical Thoracic Outlet Syndrome by Chen et al. (1995)	10 formalin fixed cadavers and 2 fresh	Not provided	Likely Chinese but not stated explicitly	7 Cadavers- C5,6,7 4 Cadavers- C5 1 Cadaver- C3,4 No mention of muscles innervated or photographs

A cadaveric study of the motor nerves to the levator scapulae muscle. by Frank et al. (1997)	20 formalin fixed cadavers	13 males/7 females 63-95 years old	Not provided	DSN from C5; supplies levator scapulae in 11 of 35 necks (sides), pierce MS (no mention of which sides and which side DSN was found) *C3 and C4 consistently contributes to levator scapulae m.
Two cases of suprascapular neuropathy in a family. by M. Ravindran (2003)	2 patients (siblings)	35 year old male 27 year old female	Not provided	Both pts presents with right shoulder pain & wasting scapular muscles due to entrapment of suprascapular and DSN. Slight winging of scapular with weakness of rhomboid muscle
Surgical anatomy of the dorsal scapular nerve by Tubbs et al. (2005)	10 formalin fixed cadavers	6 males/ 4 females Ages not provided	Not provided	19 sides= C5; 1 side= C5,6 Pierce middle scalene m. Innervated levator scapulae and rhomboid muscles.
Variations of the origin of collateral branches emerging from the posterior aspect of the brachial plexus by Ballesteros et al. (2007)	57 cadavers	46 males/ 11 females 40-80 years old	Mixed race	DSN arose from C5= 48.3% DSN shared common trunk with long thoracic nerve (C5,6,7)= 30.4%
Selective blockage of the dorsal scapular nerve for scapular surgery by Auyong and Cababe (2014)	1 patient	31 year old female	Not provided	1 side= C5 Nerve block injection
Dorsal scapular nerve injury: a complication of ultrasound- guided interscalene block by A. Soparito (2013)	1 patient (ultrasound image)	Not mentioned	Not provided	DSN from C5, with possible contribution from C6; pierces middle scalene muscle and passing posteriorly, beneath levator scapulae and supplies rhomboids

Aberrant dual of the dorsal scapular nerve and its communication with long thoracic nerve: An unusual variation of the brachial plexus. by Shilal et al. (2015)	1 cadaver	Male Age not mentioned	Not provided	DSN from C5,6. The C5 component pierced the MS and divided into 2 branches within the muscle. Bigger branch supplied LSM while small branch continued downwards and joined with a branch arising from C6 root. 2 branches from C5,6 united and course down the main trunk of DSN. Communicates with the C7 part of long thoracic nerve. Muscle innervation not provided.

APPENDIX B:

DATA COLLECTION TABLE OF DORSAL SCAPULAR NERVE'S ANATOMY

APPENDIX B

TABLE 3: Data collection table of the Dorsal Scapular Nerve's Anatomy

				LEFT SIDE				RIGHT SIDE			
Date/ Tank #	**SAB # / Ethnicity**	**Age/ Sex**	**Cause Of Death**	**DSN roots**	**Course Traveled**	**Muscles Innervated**	**Comments**	**DSN roots**	**Course Traveled**	**Muscles Innervated**	**Comments**
			MS width in cm	**(enters MS: avg distance cm)**	**(cross MS)**	**(exits MS: avg distance)**		**(enters MS: avg distance)**	**(avg distance)**	**(exits MS: avg distance)**	
1.06.16	62328 Black	60/M	Met. Liver Cancer	C5	Crosses on top of middle scalene m.	Rhomboid muscles. DSN does not contribute to LSM.	Crosses anteriorly to MS instead piercing	C5 MS Width: 1.30cm	Pierces middle scalene m.	Levator scapulae and rhomboids m.	DSN takes different route on right and left sides
			1.34cm (MS width)	1) 2.19 1) 2.33 1) 2.41	2) 3.06 2) 3.09 2) 3.11	3) 4.01 3) 3.98 3) 3.96		1) 1.77 1) 1.80 1) 1.79	2) 2.43 2) 2.47 2) 2.55	3) 3.34 3) 3.27 3) 3.24	
1.06.16	56592 (P18) White	93/F	Cardiovasc collapse	C5	Pierces middle scalene m.	Levator scapulae m. & rhomboids	Usual route	n/a	n/a	n/a	Muscles and nerves torn
			1.34cm (MS Width)	1) 1.66 1) 1.74 1)1.59	2) 2.298 2) 2.35 2) 2.26	3) 2.847 3) 2.82 3) 2.81		n/a	n/a	n/a	
1.07.16	62497R Tank 6	90/F	Alzheimer's disease	C4	Pierce MS	LSM and rhomboids	Usual route	C4	Pierce MS	.LSM and rhomboids	Usual route,
			MS Width: .826cm	1) 0.616 1) 0.627 1) 0.628	2) 1.355 2) 1.288 2) 1.328	3) 1.928 3) 1.940 3) 1.972		1)0.626 1) 0.541 1) 0.528	2) 0.924 2) 0.854 2) 0.730	3) 1.441 3) 1.272 3) 1.231	

1.08.16	62473R Tank 3	54/F	Stroke	n/a	n/a	n/a	Nerve is cut/ muscles torn	C5 1) 2.357 1) 2.516 1) 2.667	Pierces MS 2) 2.403 2) 2.496 2) 2.637	LSM 3) 2.43 3) 2.528 3) 2.676	Rhomboids torn MS Width 1.1cm 32, 29, 30
1.11.16	Tank 7	70/M	COPD	n/a	n/a	n/a	Muscles torn	C5 MS 1.28cm 1) 2.92 1)2.81 1) 2.93	Travels in betwn mid& post .scalene 2) 2.913 2) 2.904 2) 2.96	LSM 3) 3.05 3) 3.12 3) 3.116	Did not see innervation to rhomboids
1.11.16	62494 Tank 10	80/M	Myocardial Infarction MS Width: 0.644cm	C4 1) 2.07 1) 2.108 1) 2.18	Pierces MS 2) 2.42 2) 2.38 2) 2.38	LSM and rhomboids 3) 2.556 3) 2.493 3) 2.508	Usual route	n/a	n/a	n/a	Torn nerve
1.14.16	65355 Tank 9	76/F	Cerebral-vascular disease MS Width: 1.171cm	C5 1) 1.243 1)1.218 1) 1.163	Pierces MS 2) 1.433 2) 1.438 2) 1.40	LSM 3) 1.586 3) 1.507 3) 1.486	Did not see contribut. to rhomboids	n/a	n/a	n/a	Muscles torn
1.18.16	65340 Tank 11	84/F	Unknown natural causes MS Width: 1.065cm	C6 1) 1.182 1)1.037 1) 1.11	Pieces MS 2) 1.349 2) 1.353 2) 1.294	LSM 3) 1.643 3) 1.587 3) 1.578	Did not see contrib to rhomboids	n/a	n/a	n/a	Muscles torn

1.20.16	65326R Tank 21	72/F	Alzheimers Disease MS Width 1.536	C5 1)0.720 1) 0.725 1) 0.747	Travels anterior to MS 2) 0.975 2) 0.871 2) 0.936	LSM 3) 1.217 3) 1.15 3) 1.181	Did not see branches to rhomboids	n/a	n/a	n/a	Torn nerve and muscles
1.21.16	65313R Tank 23	75/F	COPD MS Width: 1.46cm	C5 1) 1.655 1) 1.676 1) 1.74	Pierce MS 2) 1.840 2) 1.803 2)1.882	LSM (C4 also innervates LSM) 3) 1.842 3) 1.806 3) 1.884	Did not see branches to rhomboids	n/a	n/a	n/a	Torn nerve
1.25.16	65363R Tank 26	92/F	End stage debility MS Width: 0.86cm	C5 1) 1.92 1) 1.887 1) 1.919	Pierce MS 2) 1.983 2) 1.957 2) 1.964	LSM and rhomboids 3) 2.065 3) 2.021 3) 2.002		n/a	n/a	n/a	Torn muscles
1.25.16	65358 Tank 37	86/M	COPD MS Width: 1.326cm	C5 1) 0.738 1) 0.724 1) 0.707	Pierce MS 2) 0.879 2) 0.857 2) 0.887	LSM 3) 1.046 3) 1.129 3) 1.111	Did not see contribution to rhomboids	n/a	n/a	n/a	Torn muscles and nerve
1.26.16	65345R Tank 30	52/F	Multiple Organ Failure MS WIdth: 1.092cm	C5 1) 2.075 1) 2.068 1) 2.059	Pierce MS 2) 2.277 2) 2.341 2) 2.309	LSM and rhomboids 3) 2.505 3) 2.467 3) 2.548	Usual route	n/a	n/a	n/a	Torn nerve

2.1.16	65312R Tank 31	78/M	COPD MS Width 1.579	C5 1) 0.730 1) 0.708 1) 0.685	Pierce MS 2) 0.917 2) 0.891 2) 1.026	LSM 3) 1.13 3) 1.145 3) 1.226	Did not see contrib to rhomboids	n/a	n/a	n/a	Muscles torn
2.1.16	62477R Tank 32	89/M	Heart Failure from coronary artery disease	C5 1) 0.427 1) 0.470 1) 0.475	Pierce MS 2) 0.460 2) 0.518 2) 0.535	LSM and rhomboids 3) 0.566 3) 0.577 3) 0.573	MS Width 1.38cm	n/a	n/a	n/a	Scalene muscles torn on right side
2.1.16	65318R Tank 34	64/F	Met. Colon Cancer MS Width: 1.151cm	DSN br. from C4 (&possibly phrenic n) 1) 0.122 1) 0.226 1) 0.164	Pierce MS 2) 0.322 2) 0.338 2) 0.33	LSM (partially torn) 0.503 0.475 0.497	Rhomboids torn. did not see contrib.	n/a	n/a	n/a	Muscles torn
2.2.16	62474R Tank 35	58/M	Resp. failure due to malignant neoplasm of bone MS Width: 1.46cm	DSN br. from C6 1) 3.4 1) 3.225 1) 3.388	Travels between middle and posterior scalene m. 2) 3.531 2) 3.538 2) 3.526	LSM and rhomboids 3) 3.725 3)3.724 3) 3.724		n/a	n/a	n/a	Nerves and muscles torn

2.2.16	65341R Tank 36	87/F	Met Cancer MS Width 1.538cm	C5 1) 1.43 1) 1.476 1) 1.419	Pierce MS superf. 2) 1.79 2) 1.81 2) 1.77	LSM and rhomboid mm. 3) 2.2 3) 2.14 3) 2.17	Usual route	n/a	n/a	n/a	Scalene m. torns
10.19.15	62325 White (CAS/PA PT Prosectio n)	68/M	Coronary artery disease 1.29cm (MS width)	C5 0.746cm	Pierce MS 1.17cm	Levator Scapulae m. 1.39cm	DSN pierces MS but travels posterior relative to MS.	n/a	n/a	n/a	Nerve is cut
2.17.16	65370R Tank 38	85/M	Lung Cancer	C5 1) 1.472 1) 1.528 1) 1.497	Pierce MS 2) 1.882 2) 1.893 2) 1.843	LSM and Rhomboids 3) 2.357 3) 2.363 3) 2.367	Usual route	C5 1) 2.658 1) 2.604 1) 2.556	Pierce MS 2) 2.811 2) 2.774 2) 2.764	LSM and Rhomboids 3) 2.905 3) 2.838 3) 2.835	Usual route

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