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BASIC SCIENCE

The surgical anatomy of the dorsal scapular nerve: a triple-tendon transfer perspective

Martim C. Pinto, MD[a], John L. Johnson, BS[a], Harshadkumar A. Patel, MD[a], Eva J. Lehtonen, BS[a], Amit M. Momaya, MD[a], William S. Brooks, PhD[b], Eugene W. Brabston, MD[a,*], Brent A. Ponce, MD[a]

[a]*Department of Orthopedic Surgery, University of Alabama at Birmingham, Birmingham, AL, USA*
[b]*Cell, Developmental and Integrative Biology, University of Alabama at Birmingham, Birmingham, AL, USA*

Background: Iatrogenic or traumatic injury to the spinal accessory nerve is a rare but debilitating injury. An effective treatment, known as the Eden-Lange modification triple-tendon transfer procedure, involves the transfer of the rhomboid major (RM), rhomboid minor (Rm), and levator scapulae (LS). Careful detachment of their insertions is necessary to avoid injury of the dorsal scapular nerve (DSN). This study evaluated the surgical anatomy and safety of the DSN relative to this procedure.
Methods: The study used 12 cadavers (22 shoulders). The RM, Rm, and LS were detached from their insertions, and the DSN was dissected. Measurements were taken to evaluate the anatomy of each relative to the triple-tendon transfer procedure. Additional measurements were taken to identify "danger zones" for DSN injury, regarding detachment of RM, Rm, and LS from their respective insertions.
Results: Measurements of the 22 shoulders included in the study showed wide variation in anatomy. The minimum distance between the scapula and the DSN at the vertebral scapular border was 0.7 cm, suggesting that care and precision are needed to perform this technique. The region where the DSN crosses the superior border of the Rm was shown to be the greatest "danger zone" of this technique, with a mean distance to the scapula of 1.61 ± 0.53 cm
Conclusions: This study provides insight into the surgical anatomy of the DSN relative to a rare but successful procedure used to treat trapezius paralysis. The results of this study can inform the surgeon regarding potential anatomic considerations when performing the triple-tendon transfer.
Level of evidence: Anatomy Study; Cadaver Dissection

Keywords: Eden-Lange; triple-tendon transfer; spinal accessory nerve lesion; dorsal scapular nerve; surgical anatomy; danger zone; scapula

Injury to the spinal accessory nerve (CN XI) resulting in trapezius paralysis is a rare but debilitating injury that can cause pain and disruption of scapular motion after lymph node biopsy or tumor resection.[2,24] Due to limited success with conservative management and difficultly associated with CN XI repair, tendon transfer is considered an effective treatment for restoring function.[8,23]

Traditional tendon transfer for spinal accessory nerve injury is accomplished with the Eden-Lange procedure, which entails transferring the levator scapulae (LS) to the acromion and the rhomboid major (RM) and minor (Rm) to the infraspinatus fossa.[19] This procedure has reported variable success.[1,2,10,11,19-21]

*Reprint requests: Eugene W. Brabston, MD, UAB, Department of Orthopedic Surgery, 1313 13th St S, Ste 207, Birmingham, AL 35205, USA.
E-mail address: ebrabston@uabmc.edu (E.W. Brabston).

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Recently, Elhassan et al[8] modified the Eden-Lange technique, designing it as the triple-tendon (T3) transfer. The T3 transfer improves the Eden-Lange procedure biomechanically by transferring the Rm and RM to the spine of the scapula, just medial to the LS transfer, leading to re-creation of the line of pull of the inferior portion of trapezius muscle fibers. This modification has resulted in symptomatic and clinical improvement with high rates of patient satisfaction.[8]

The dorsal scapular nerve (DSN) is crucial to the T3 transfer procedure; it most often innervates all 3 muscles involved in the tendon transfer: RM, Rm, and LS. In some cases (0%-29%), the LS has an alternate innervation, as reported in other cadaveric studies.[9,17,22] Thus, great care must be taken to identify and preserve the DSN to maintain function after the tendon transfer. The DSN trajectory is such that the detachment and splitting of the RM, Rm, and LS make the nerve susceptible to injury.

Despite previous studies on the DSN and its neurovascular bundle,[9,17,22] its surgical anatomy distal to the LS and its relationship to nearby structures have not yet been well established in the literature. More data are needed to improve understanding of its anatomy and to minimize surgical risk of nerve injury. This cadaveric study was conducted to (1) describe the anatomy of the muscles involved in the T3 transfer procedure, (2) describe the DSN and its anatomic relationships, and (3) identify the presence of "danger zones" when detaching the RM, Rm, and LS from the scapula.

Materials and methods

The institution provided 12 human cadavers (4 women and 8 men). Their self-reported ethnicity was white for 11 and black for the remaining deceased donor. The donors were embalmed using a formaldehyde-free protocol, composed of Freedom Art, Metaflow, and Rectifiant (Dodge, Billerica, MA, USA), covered in cloth, placed in a body bag, and stored in a thermal shelter at 4°C.

Two of the authors (M.P. and H.P.) dissected 24 shoulders to define the anatomy of RM, Rm, and LS, and the DSN. All dissections were performed with the cadavers placed prone and the arms at the side in neutral rotation. Two specimens were used for methodology improvement, leading to the analysis of 22 shoulders from 12 cadavers.

A wide cruciate-shaped incision was made horizontally from the left to the right acromion and vertically from the occipital protuberance to T12. Skin and subcutaneous tissue were reflected laterally, exposing the superficial plane of the back musculature. The C7 vertebral spinous process was identified by palpation and marked with a needle to be used as a reference. The trapezius muscle was identified and released from deeper planes using the index finger (Fig. 1), detached from its origin at the vertebral spinous processes, and reflected superolaterally, allowing for better visualization and exposure of the muscles of interest, RM, Rm, and LS (Fig. 2).

The first set of measurements was made to describe the anatomy. The edges of measurement points were pierced with 18-gauge needles, and the distances between needles were measured using a Vernier Caliper (Fowler High Precision, Auburndale, MA, USA). All measurements were taken to the nearest millimeter. The measurements performed were origin length and spinous process levels of the RM (Fig. 3, line C) and Rm (Fig. 3, line B), insertion lengths of the RM (Fig. 3, line E), Rm (Fig. 3, line D), and LS (Fig. 3, line A), medial scapular border length (Fig. 3, line G), and distance from the inferior angle of scapula to the inferior border of the RM insertion (Fig. 3, line F).

A second set of measurements was made to assess "danger zones" during detachment of the RM, Rm, and LS during a T3 transfer. The RM and Rm were released from their origins at the spinous process, and the DSN was carefully dissected without detaching it from the anterior surface of the RM, Rm, and LS and preserving its native course (Fig. 4). The DSN pathway was tracked with 18-gauge needles, piercing from posterior to anterior as described by Omid et al.[18] The following points were located and pierced: (1) intersection between the DSN pathway and the superior border of the

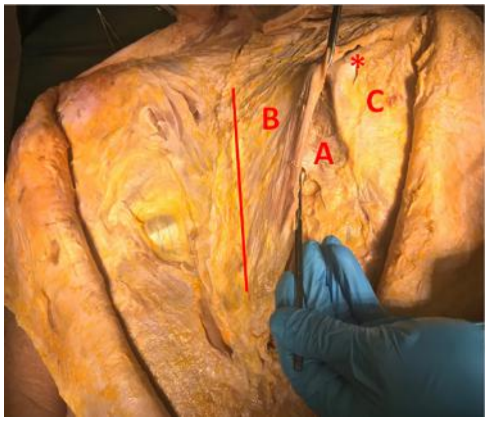

Figure 1 Posterior view of the cadaver in prone position after reflecting the skin and subcutaneous tissue. *A*, rhomboid major; *B*, trapezius, *C*, scapula; *trapezius footprint on the scapular spine; *red line*, midline relative to spinous process.

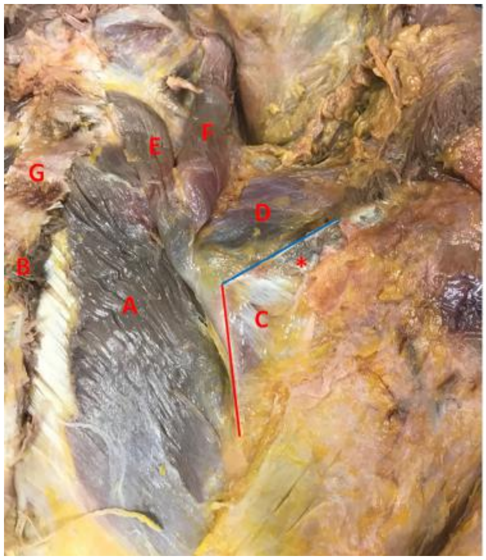

Figure 2 Posterior view of the right scapula in prone position after lateral reflection of the trapezius: *A*, rhomboid major; *B*, medial border of trapezius detachment; *C*, infraspinatus; *D*, supraspinatus; *E*, rhomboid minor; *F*, levator scapulae; *G*, spinous process; *trapezius footprint on the scapular spine; *red line*, medial border of the scapula; *blue line*, scapular spine.

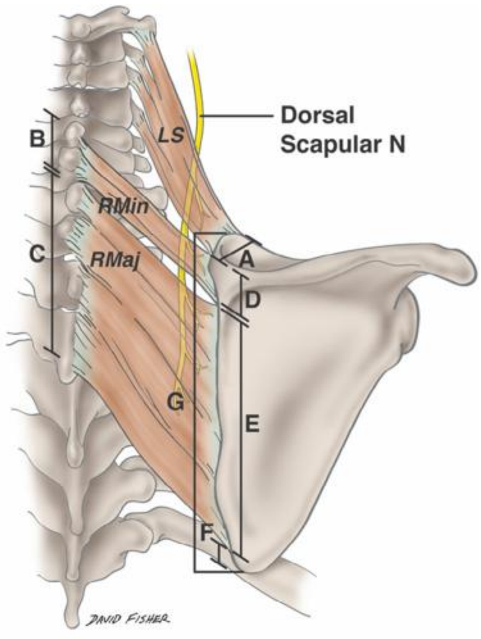

Figure 3 Measurements of relevant anatomy for tendon transfer. *A*, levator scapulae (*LS*) footprint; *B*, rhomboid minor (*RMin*) spinal footprint; *C*, rhomboid major (*RMaj*) spinal footprint; *D*, rhomboid minor insertion footprint; *E*, rhomboid major insertion footprint; *F*, distance from the inferior angle of the scapula to the inferior border of the rhomboid major; *G*, medial scapular border; *N*, nerve.

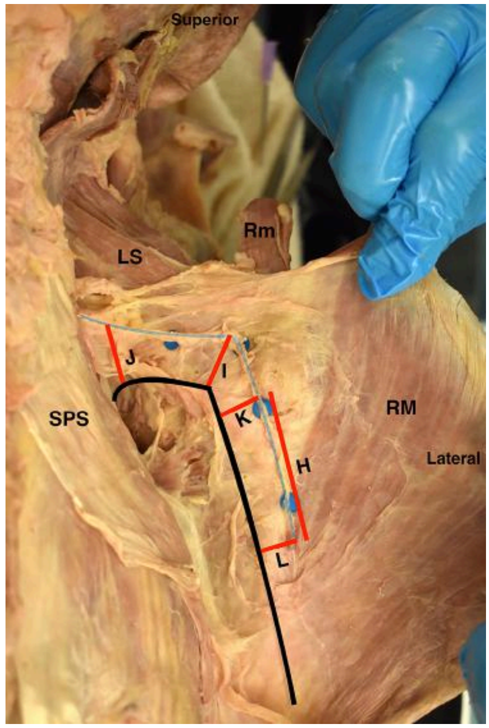

Figure 4 View of the dorsal scapular nerve trajectory (*light blue line*) on the deep surface of the rhomboid major (*RM*) and rhomboid minor (*Rm*) and the levator scapulae (*LS*), after the rhomboids have been detached from their medial insertion and reflected laterally. *SPS*, serratus posterior superior muscle; *black line*, projection of the scapular border (anterior/deep surface view); *H-L,* see Fig. 5 legend.

LS (Fig. 5, line J), (2) superior border of the Rm (Fig. 5, line I), and (3) the Rm and RM transition (Fig. 5, line K). Next, the RM and Rm were stretched back to their origins, and the shortest distance from each of these points to the scapular medial border was measured. Finally, the distances from the point of termination of the DSN in the RM to the scapula (Fig. 5, line L) and to the intersection between the DSN and the RM border (Fig. 5, line H) were measured.

All statistics were performed using Excel 2011 software for Mac (version 14.4.0l; Microsoft, Redmond, WA, USA). Descriptive statistics were calculated for each measurement. For continuous variables in bilateral dissections, the percentage difference between sides was calculated as the absolute difference in measurements between a cadaver's left and right side as a percentage of the right-sided measurement.

Results

The study included 22 shoulders from 12 cadavers. The average age of cadavers was 82.4 years (range, 75-94 years). The shoulder anatomy 2 cadavers was compromised unilaterally (1 left, 1 right) such that no accurate measurements could be obtained. The DSN anatomy in 1 additional specimen was compromised bilaterally preventing the accurate measurement of H-L (Fig. 5). Demographic information of the included cadavers is summarized in Table I.

The DSN trajectory was variable between and within individuals. In 11 of 20 shoulders, the DSN was in closest to the scapula at the superior border of the Rm (distance I, in cm; mean, 1.61; standard deviation [SD], 0.53; range, 0.7-2.5). In 25% (5 of 20) of shoulders, the DSN was closest to the scapula at the level of the rhomboids transition (distance K, in cm; mean, 1.81; SD, 0.39; range, 1.2-2.8). In 15% (3 of 20) of shoulders, the DSN was nearest the scapula at the termination into the RM (distance L, in cm; mean, 2.29; SD, 0.69; range, 1.1-3.8). The DSN in 1 shoulder was equidistant at 2.1 cm from the scapula at all 3 of the aforementioned levels. Statistics of DSN measurements (H-L) are summarized in Table II.

Summary statistics of the musculoskeletal measurements (A-G) are reported in Table III. In general, there was wide variation in musculoskeletal anatomy between and within individuals. The greatest asymmetry, as determined by the percentage difference between left and right sides, was found in the distance from the inferior angle of the scapula to the inferior border of the RM (percentage difference in distance F; mean, 20%; SD, 21%; range, 0%-60%) and the length of the lateral footprint of the Rm (percentage difference in distance D; mean, 22%; SD, 14%; range, 6%-56%). The length of the vertebral scapular border (distance G) showed the least asymmetry, varying by no more than 2% between sides in any cadaver. The remaining measurements (A, B, C, and E) varied, on average, by 7% to 8% between sides. No reliable correlations were identified between any 2 measurements.

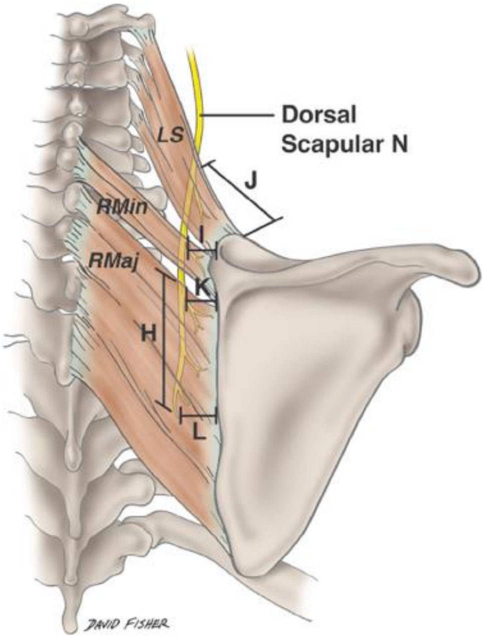

Figure 5 Dorsal scapular nerve (*N*) measurements. Distance from the medial scapular border to the dorsal scapular nerve at the following: *I*, superior border of the rhomboid minor (*RMin*); *J*, superior border of the levator scapulae (*LS*); *K*, gap between the rhomboid minor and rhomboid major; *L*, termination of the dorsal scapular nerve on the rhomboid major; *H*, distance traveled by the dorsal scapular nerve on the posterior surface of the rhomboid major.

Table I Demographic information of the cadavers

Variable	Data
Total number	
Cadavers	12
Shoulders	22
Side, No. (%)	
Bilateral	10 (83)
Right unilateral	1 (8)
Left unilateral	1 (8)
Sex, No. (%)	
Male	7 (58)
Female	5 (42)
Race, No. (%)	
White	11 (92)
Black	1 (8)
Cause of death, No. (%)	
Cardiac arrest or cardiopulmonary arrest	3 (25)
Dementia or Alzheimer dementia	3 (25)
Stroke or cerebrovascular accident	2 (17)
Chronic obstructive pulmonary disease	2 (17)
Coronary heart disease	1 (8)
Lung cancer	1 (8)
Height, cm	
Mean ± SD	169.98 ± 8.76
Range	154.94-182.88
Age, yr	
Mean ± SD	82.42 ± 6.02
Range	75 - 94

SD, standard deviation.

Table II Dorsal scapular nerve anatomy

Measurement	Distance, in cm		
	Mean ± SD	Median	Range
Distance J*	2.76 ± 0.91	2.40	1.50-4.80
Distance I†	1.61 ± 0.53	1.70	0.70-2.50
Distance K‡	1.81 ± 0.39	1.80	1.20-2.80
Distance L§	2.29 ± 0.69	2.20	1.10-3.80
Distance H‖	3.75 ± 2.70	2.70	1.00-0.10

SD, standard deviation.

* The intersection between the dorsal scapular nerve (DSN) pathway and the superior border of the levator scapulae (LS) to the scapular medial border (J on Fig. 4).

† The superior border of the rhomboid minor (Rm) to the scapular medial border (I on Fig. 4).

‡ The Rm and rhomboid major (RM) transition to the scapular medial border (K on Fig. 4).

§ The point of termination of the DSN in the RM to the scapula (L on Fig. 4).

‖ The point of termination of the DSN in the RM to the intersection between the DSN and the RM border (H on Fig. 4).

Discussion

The most common cause of spinal accessory nerve palsy is iatrogenic, with up to 71% being caused by head and neck operations, particularly those involving the posterior cervical triangle.[6] The rates of spinal accessory nerve injury vary depending on the degree of dissection, with rates near 50% in radical neck dissections[4,7,12] and 3% to 10% during lymph node biopsies, and it can still occur in up to 67% of patients undergoing neck dissections, even with nerve-sparing techniques.[3,15]

The T3 transfer is a modification of the Eden-Lange technique used to treat this type of injury. The T3 procedure adheres to principles of tendon transfers, including (1) similar line of pull, (2) similar tension, (3) similar excursion, (4) 1 transfer for 1 loss of function, and (5) normal or nearly normal strength of the donor muscle.[5] Favorable outcomes have been reported with the T3 transfer, which has an improved line of pull from the originally described Eden-Lange technique.[5,8] This modification of the Eden-Lange procedure allows the rhomboids to more closely replicate the direction of the anatomic inferior trapezius muscle fibers. Additional reports are pending to determine whether this modification will become the standard of care for treatment of winged scapula and trapezius dysfunction secondary to CN XI paralysis.

Given its innervation of the LS, RM, and Rm, protection of the DSN is critical to the success of the T3 transfer. We attempted to provide a more detailed description of DSN anatomy because previous reports have mainly focused on the nerve's trajectory in a limited window above the LS.[9,17,22] In our sample, the minimum distance between the scapula and the DSN at any height of the vertebral scapular border

Table III Musculoskeletal anatomy

Measurement	Distance, in cm			Percentage difference between sides	
	Mean ± SD	Median	Range	Mean	Range
Distance A*	3.75 ± 0.85	3.65	2.20-5.50	6.9	0.0-13.9
Distance B†	2.01 ± 0.63	1.80	1.40-3.90	8.0	0.0-18.2
B_{so}		C6	C6-C7		
B_{io}		C6	C6-T1		
Distance C‡	11.42 ± 2.89	12.45	6.10-15.40	8.3	0.0-36.1
C_{so}		C7	C6-T2		
C_{io}		T5	T2-T7		
Distance D§	1.87 ± 0.57	1.75	1.20-3.30	22.2	6.5-56.3
Distance E‖	10.66 ± 1.76	10.60	8.10-14.70	7.8	0.0-20.4
Distance F¶	1.32 ± 0.82	1.40	0.00-3.10	19.6	0.0-60.0
Distance G#	17.20 ± 1.88	17.75	14.00-20.00	1.2	0.0-2.2

* The insertion of the levator scapulae (LS) on the scapula (A on Fig. 4).
† The origin of the rhomboid minor (Rm) (B on Fig. 4). B_{so}, superior spinous process level of Rm origin; B_{io}, inferior spinous process level of Rm origin.
‡ The origin of the rhomboid major (RM) (C on Fig. 4). C_{so}, superior spinous process level of RM origin; C_{io}, inferior spinous process level of RM origin.
§ The insertion of the Rm on the scapula (D on Fig. 4).
‖ The insertion of the RM on the scapula (E on Fig. 4).
¶ The inferior angle of the scapula to the inferior border of the RM insertion (F on Fig. 4).
\# The medial border of the scapula (G on Fig. 4).

was 0.7 cm, suggesting that care, accuracy, and precision are needed to perform this technique. Of note, the DSN did not cross the scapular border in any of our specimens. Thus, if the T3 transfer muscles were detached directly off their bony insertions, direct injury to the DSN would not have occurred in any of our samples, lending support for this technique.

Although direct visualization of the DSN has been recommended, our cadaveric dissection suggests that this may not be necessary if the LS, RM, and Rm are detached directly from their bony insertions.[5,8] Such information may be useful for surgeons not experienced in tendon transfers or nerve procedures to reduce the risk of iatrogenic injury to the DSN. Injury resulting in paralysis compromises the entire operation and increases patient morbidity. Harm to the DSN during the Eden-Lange or T3 procedures has not been identified in the literature, but if injury does occur, it may manifest clinically as a failed outcome of the T3, when it actually may be a nerve injury. A poorly or nonfunctioning DSN can lead to a complete disruption of the scapulothoracic rhythm, leading to further winging of the scapula, decreased shoulder range of motion, increased pain, and greater difficulties with activities of daily living.[13,16]

The potentially extreme consequences of surgical DSN injury warrant extensive knowledge of its anatomic relationships and potential danger zones to ensure that this does not become a complication. Our work helped to identify the region where the DSN crosses the superior border of the Rm as the greatest danger zone of this surgical technique, with the minimum distance to the scapula present in 55% of specimens. This is the point where the nerve had the smallest mean distance to the scapula (1.6 cm). However, the remainder of the nerve trajectory should not be overlooked, because it travels close to the scapular border with a mean distance of the DSN to the scapula of 1.9 cm after crossing the inferior border of the LS.

Our study is not without limitations. First, inherent inaccuracy exists due to manual measurement. To minimize this effect, a second observer confirmed each of the measurements.

Second, despite the formaldehyde-free embalming protocol used in this study, the preservation technique affected the pliability of the soft tissues, possibly altering native anatomy.

Third, the target population of tendon transfers is younger than our sample of specimens. From the age of our sample, we can estimate a rate of sarcopenia, the normal loss of muscle mass due to aging, as high as 29% to 33%, resulting in decreased muscle bulk and possible distortion of anatomic arrangements.[14] In addition, only direct injury to the DSN was addressed in this study. We did not account for the possibility of stretch injuries that may occur when tissues are stretched or moved. Tendon transfer techniques involve coharvesting of periosteum; however, this was not accounted for in our study because we considered it negligible. Instead, all distances were measured to the edge of existing bone. Finally, although T3 transfer is performed with the patient in a semilateral position with the affected arm facing upward, our dissections were performed with the cadaver prone and the arms at the side in a neutral position. This position was chosen because it was more stable and reproducible, leading to more consistency.

Conclusion

The T3 transfer is an effective treatment option for spinal accessory nerve injury, and this study offers insight into the surgical anatomy of the RM, Rm, LS, and DSN required for a successful tendon transfer. The DSN takes a variable path just medial to the scapular border along the deep surface of the RM, Rm, and LS, ranging from 0.7 to 4.8 cm from their harvested insertions. Surgeons performing this procedure should be familiar with the relevant anatomy, because a DSN injury while performing this procedure would lead to a failure in function of the transposed muscles.

Disclaimer

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