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Mapping the course of long thoracic nerve

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Abstract

Long thoracic nerve (LTN) injury has been reported after radiotherapy, trauma, patient's position, transaxillary breast augmentation, implantation of transvenous leads, anaesthetic nerve block and transaxillary incision. Denervation of the serratus anterior muscle at LTN injury results in loss of scapular stabilization or winged scapula. LTN injury results in prolonged disability and impact on quality of life for patient and potential medicolegal concerns for the physician.

The purposes of this study is to map the course of LTN relative to the scapula and sternum, thereby developing guidelines to aid in the prevention of LTN injuries.

The course of the long thoracic nerve were investigated in 15 adult Turkish cadavers. Each cadaver was placed in the transaxillary thoracotomy positions. The LTN was exposed bilaterally in its course from axilla to its penetration into serratus anterior muscle.

The nerve courses vertically, gets progressively closer to the anterior border of the scapula. The length of the LTN was measured as 201.4 ± 20.7 mm on the right and 208.6 ± 17 mm on the left. The distance from main trunk to clavicle was 28.8 ± 6.3 mm on the right and 29.8 ± 3.6 mm on the left side. The distance from sternal angle to LTN was measured as 212.4 ± 21 mm on the right and 220.5 ± 27.5 mm on the left. The distance between xiphoid process was 246.5 ± 21.8 mm on the right and 242.8 ± 27.9 mm on the left. The distance from scapular rim to LTN was 61.9 ± 10.7 mm on the right and 57.6 ± 13 mm on the left.

The length of thickest branch of LTN was 22.6 ± 10.4 mm on the right and 31.4 ± 28.1 mm on the left. The diameter of the thickest branch was 1.6 ± 0.59 mm on the right and 1.63 ± 0.85 mm on the left. The number of side branches was 6.44 ± 2.06 ones on the right and 6.45 ± 2.77 ones on the left side. Bifurcation number of terminal branch of LTN was 2.55 ± 0.72 ones on the right and 2.54 ± 0.68 ones on the left.

By using these anatomical guidelines, we believe that the incidence of iatrogenic long thoracic nerve injury can be minimized.

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Key words: [long thoracic nerve] [serratus anterior muscle] [injury] [thoracotomy]

Introduction

Long thoracic nerve (LTN) injury has been reported after radiotherapy, trauma, patient's position, transaxillary breast augmentation, implantation of transvenous leads, anesthetic nerve block and transaxillary incision [1–7]. For thoracic surgeon, the LTN is at risk for proximal injury during transaxillary thoracotomy for lung surgery, video thoracoscopy port insertion, first rib resection and chest tube placement [8–12]. Denervation of the serratus anterior muscle at LTN injury results in loss of scapular stabilization or winged scapula. LTN injury results in prolonged disability and impact on quality of life for patient and potential medicolegal concerns for the physician.

The serratus anterior muscle arises from the first through ninth to tenth ribs medial to the anterior axillary line and inserts to the ventral vertebral border of the scapula, forming the medial wall of the axilla [13]. Classically, serratus anterior is distinguished in three portions; upper, middle and lower portions. The upper two-thirds of the muscle forms a flat sheet attaching the first five ribs to the superior aspect of the medial scapular border, fixing the scapula to allow elevation of the arm above the shoulder [10, 14–16]. The lower third of the muscle forms a radiating of four to five muscle slips from the sixth to the ninth ribs, inserting to the lower angle of the scapula [17]. Only the last two are of interest in thoracotomy, especially the last which is also known in French surgical anatomy as the "faisceau de ponte" [18, 19].

Innervation to the serratus anterior muscle is supplied by the LTN (C5-C7). The serratus anterior muscle is important in normal shoulder functioning and its actions may be divided into three categories. Firstly, it fixes the scapula to the chest wall pushing, punching and deep breathing with the aid of pectoralis minor. Secondly, the muscle actively protracts the scapula over the thoracic cage and brings the entire shoulder forward by an action at the sternoclavicular joint, such as in reaching forward. Together with trapezius and possibly also pectoralis minor, it rotates the scapula in the second stage of arm abduction [20–22]. In a related action the muscle counters the rotational force transmitted to the scapula by the biceps and coracobrachialis tendons when the arm is held extended or abducted [15]. The ingenious mechanisms which the scapulothoracic joint requires almost continual modulating of serratus anterior activity [22].

We concluded that understanding the anatomical course of LTN will help to increase the surgical success rate and decrease the damage of the nerve which happens due to various reasons, leading to problem of chronic nature and deteriorating the life quality of patients. Although not studied in detail, the growing trend for using the LTN as a nerve graft during recent years have enhanced the importance of this study. There have been no reports mapping the course of LTN in detail, with respect to scapula and sternum. The purposes of this study was to map the course of LTN relative to the scapula, thereby developing guidelines to aid in the prevention of LTN injuries.

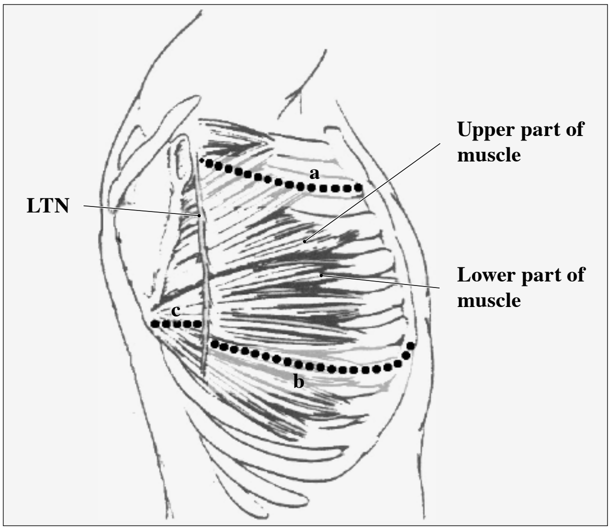

Figure 1. Distances that define the topographic location of the long thoracic nerve (LTN). Distance of the LTN to sternal angle (**a**) and xiphoid process (**b**) and inferior angle of scapula (**c**) were measured.

Figure 2. Origin of LTN was examined except one, all cases seemed to be sourced from C5, C6 or C7.

Figure 3. In one case we discovered a variation in subscapular artery passing between C5-C6 and C7.

Material and Methods

The axillary region dissections were performed on 15 adult male Turkish cadavers. To facilitate the dissection, each cadaver was placed in supine position with the shoulder abducted to 90 degrees. Bilateral comparative dissections were performed. The proximal incision was at with the axillary fold and was extended down to the level of the eight or ninth rib, and 2 cm anterior to the lateral edge of the latissimus dorsi muscle. The incision was deepened, and superior point of the cervical region and the anterior edge of the latissimus and inferior edge of the serratus anterior were identified. The LTN was exposed bilaterally on its course from axilla to its penetration into serratus anterior muscle. The scapular tip and anterior border were identified but not skeletonized, thus preserving normal anatomical relationships.

The cervical spinal nerve roots which LTN was sourced from, the depth measured from clavicula to the main trunk of LTN made up of C5 and C6, diameter of the main trunk, the length of the nerve, number of branches throughout its course, type of terminal branching, the length and diameter of the thickest branch were evaluated. Additionally, the distance of the nerve from sternal angle and xiphoid process were investigated. The distance from the inferior angle of scapula was also measured in order to define the topographic location of the nerve (Figure 1). The distance from the scapular tip to the LTN was measured. All measurements were tabulated, the means and standard deviations were assessed. The cases were photographed.

Results

The results of our study had been briefed in Table 1. The serratus anterior muscle is supplied by LTN, which takes its origin from the fifth, sixth and seventh cervical spinal roots. The fifth and sixth cervical roots, along with the dorsal scapular nerve, pass through the substance of scalenus medius muscle, and join with the root of C7 (Figure 2). Except one case, all of the LTN were emerging from C5, C6, and C7. In one case C7 had not contributed to LTN structure and nerve had originated from C5 and C6. The source roots were above the subscapular artery. In one case we discovered a variation in subscapular artery passing between C5-C6 and C7 (Figure 3).

The LTN travelled beneath the brachial plexus and clavicle to pass over the first rib. The nerve descended along the lateral aspect of the chest wall and crossed the outer border of the first rib to reach outer of serratus. On its course it passed dorsal to axillary artery and brachial

Table 1. Some measurements of LTN

Measurements	**Unit**	**Right**		**Left**	
		Mean ± SD	Minimum – Maximum	Mean ± SD	Minimum – Maximum
Length of LTN	mm	201.4 ± 20.7	182 – 235	208.6 ± 17	168 – 238
Diameter of main trunk (C5-C6)	mm	2.26 ± 0.83	1 – 3.56	2.47 ± 0.85	1.60 – 3.79
Distance between main trunk to clavicle	mm	28.14 ± 6.30	21 – 38	29.8 ± 3.60	21 – 38
Distance between sternal angle to LTN	mm	212.4 ± 21	184 – 238	220.5 ± 27.5	189 – 290
Distance between xiphoid process to LTN	mm	246.5 ± 21.8	217 – 270	242.8 ± 27.9	213 – 290
Distance between Scapula rim to LTN	mm	61.9 ± 10.7	40 – 75	57.6 ± 13	40 – 73
Length of thickest branch	mm	22.6 ± 10.4	21 – 43	31.4 ± 28.1	15 – 27
Diameter of thickest branch	mm	1.60 ± 0.59	0.88 – 2.56	1.63 ± 0.85	1 – 3.20
The number of side branches	–	6.44 ± 2.06	2 – 10	6.45 ± 2.77	2 – 10
Bifurcation number of terminal braches	–	2.55 ± 0.72	2 – 4	2.54 ± 0.68	2 – 4

plexus. Main trunk diameter was 2.26 ± 0.83 mm on the right and 2.47 ± 0.85 mm on the left. The distance from main trunk and clavicle was 28.8 ± 6.3 mm on the right; while it was 29.8 ± 3.6 mm on the left side.

LTN length was 201.4 ± 20.7 mm on the right and 208.6 ± 17 mm on the left. The nerve coursed vertically, gets progressively closer to the anterior border of the scapula. The LTN was unique in that it runs superficially

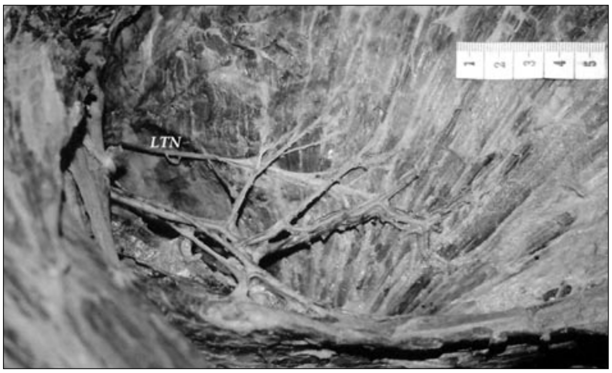

Figure 4. The vessels above the long thoracic nerve (LTN) were excised during dissection.

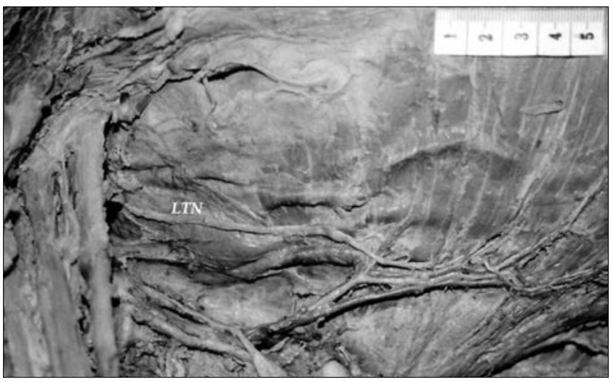

Figure 5. The long thoracic nerve (LTN) is visualized just anterior to the vascular pedicle.

to the serratus anterior muscle over its entire course. The LTN which descended along the junction of the middle and posterior thirds in the fascia of the lower serratus slips to join the thoracodorsal vascular pedicle at the level of the fifth rib. At this level the nerve laid anterior and deep to the vascular pedicle and usually divided into two fascicles of approximately equal size, which can easily be split into a separate nerve trunk to the lowest three or four muscle slips (Figures 4–5). The nerve can split off the proximal trunk for several centimetres to preserve the fascicles. This separate axial innervation allowed isolation of the lower slips to be reinnervated as a functional free transfer.

The distance from sternal angle to LTN was measured as 212.4 ± 21 mm on the right and 220.5 ± 27.5 mm on the left. The distance between xiphoid process and LTN was 246.5 ± 21.8 mm on the right and 242.8 ± 27.9 mm on the left. The distance from scapula rim to LTN was 61.9 ± 10.7 mm on the right and 57.6 ± 13 mm on the left.

Along its course, the nerve divided into small branches parallel to the main trunk, several centimetres prior to diverging at right angles and entering the superior aspect of individual muscle slips (Figure 6). It laid anteromedially and ran obliquely to the vascular pedicle to intersect with the most inferior serratus branch artery at the crow's foot landmark.

The largest branches entering into the serratus anterior muscle had a length of 15–41 mm and an average diameter of 0.5 mm on entering the muscle. The length of thickest branch of LTN was 22.6 ± 10.4 mm on the right and 31.4 ± 28.1 mm on the left. The diameter of the thickest branch was 1.60 ± 0.59 mm on the right and 1.63 ± 0.85 mm on the left.

Along the course of the LTN, it gave off six to ten branches to the upper, middle and lower segments of the serratus anterior muscle. The number of side branches was 6.44 ± 2.06 on the right and 6.45 ± 2.77 on the left side. LTN sparsely innervated the upper serratus through

Figure 6. Along course of the LTN divided itself into small branches diverging at right angles and entering the superior aspect of individual muscle slips.

Figure 7. LTN gave off two or three terminal branches (arrow) to the middle and lower segments of the serratus anterior muscle.

small branches and then arborized more extensively to innervate the lower serratus. In 96% of the cases, the LTN gave off two or three terminal branches to the middle and lower segments of the serratus anterior muscle (Figures 6–7). Bifurcation number of terminal branch of LTN was 2.55 ± 0.72 on the right and 2.54 ± 0.68 on the left. There were no statistically significant differences in our measurements between two sides. In 25% of cadaver specimens, the lower digitations of the serratus anterior were innervated by intercostal nerves.

Discussion

The LTN has been for a long, concern for surgeons who have always tried to safeguard it during thoracoplasty, mastectomy and resection of the first rib. It is only recently that some writers have focused attention on the benefits of avoiding its injury in routine thoracotomy. There is high frequency of upper division of the LTN associated with various surgical procedures: 10.5% in radical mastectomy and 1.1% in simple mastectomy [18, 23].

The LTN palsy presents typically by severe burning, aching or stabbing shoulder or arm pain that usually subsides only to be followed by evidence of weakness [24]. Weakness of the serratus anterior results in the classical angel wing deformity as the scapula is translated medially and superiorly. The inferior angle rotates toward the midline and the vertebral border of the scapula becomes prominent as it is no longer opposed to the thoracic cage. The winging is more prominent as the patient attempts to push forward against resistance. Over the long term, however, shoulder area pain may occur from myofascial-type palsy triggered by overuse of the other periscapular muscles as the attempt to compensate for the weak serratus [25, 26]. All patients were found to have painful scapular winging characterized by prominence of the inferior angle of the scapula and loss of protraction of the scapula during shoulder and in periscapular region [27].

Further observation for scapular winging, patients in whom both C5 and C6 roots have been traumatically avulsed may have a functional serratus anterior [28]. Hester et al. [29] explained the causes of the LTN palsy. They found in all specimens a tight fascial band of tissue arose from the inferior aspect of the brachial plexus, extended just superior to the scalenus medius insertion on the first rib, and presented a digitation that extended to the proximal aspect of the serratus anterior muscle. They showed that with progressive manual abduction and external rotation, the LTN was found to bow-string across the fascial band. Medial and upward migration of the superior aspect of the scapula was found to further compress the LTN.

The prognosis for LTN palsy is generally good with a recovery period of 6 months to 2 years [30, 31]. In cases of a proximal laceration or when the level of the injury cannot be identified, as it occurs in a closed traction injury or a brachial plexus neuritis, surgical reconstruction options to restore serratus anterior muscle function are limited. Although most patients with symptomatic scapular winging will improve with non operative care, including periscapular splinting and muscle strengthening, some may require surgical treatment to stabilize the scapulothoracic articulation. The reported surgical reconstructions include late reconstructions that use muscle, tendon, or fascial flap reconstruction to restrict winging of the inferior angle the scapula [22, 32].

Although various surgical treatments have been described for chronic scapulothoracic winging, the most commonly used is transferring the sternal head of the pectoralis major tendon to the inferior of scapula reinforced with fascia or tendon auto graft. This procedure is reliable for restoration of scapular stability but has the potential disadvantage of requiring a large incision. Bracing is often poorly tolerated. Patients with severe symptoms in whom 12 months of conservative treatment have failed, may benefit from surgical reconstruction [11, 20, 22].

In support of the theory that the anatomical course of the LTN made it specially vulnerable, Horwitz and Tocantins [33] dissected the nerve in 100 cadavers. In the majority, the contributions from the cervical roots which combined to form the main trunk transversed the scalenus medius and emerged from its lateral side. They suggested that spasm of this muscle might interrupt conduction of these nerve roots, so causing the paralysis.

Angulation of the nerve trunk as it crossed the second rib emerged as a possibility. Distraction of the shoulder from the neck tightened the nerve, but since nerve is long (its length averages 24 centimetres) it may tolerate a reasonable amount of stretching without any damage; this is born out by the fact that traction injuries of the brachial plexus are not invariably accompanied by injury to the LTN. The same authors went to suggest that, if the scapula is forced medially, the nerve might be compressed between the coracoid process and second rib, particularly in cases where the nerve roots emerged from the posterior border of the scalene muscle.

Lesions of the C5, C6 and C7 root are common and cause a readily recognised neurological syndrome. Recognition is essential to differentiate C5, C6 and C7 root lesions from lesions of brachial plexus and peripheral nerves. The authors reported cases of C5, C6, and C7 radiculopathy in which weakness of the serratus anterior was present in addition to the usual findings [34]. The serratus anterior, like the diaphragm, is an example of a muscle which migrates during embryogenesis, taking its nerve supply with it [34]. Motor neurons extend from its ancestral spinal level to the muscle's final position via LTN. A review of several sources reveals the spinal root contributions to be C5, C6 and C7 in most instances [35, 36]. Some authors would minimise C5 contributions or include a minor contribution from C8. Hortwitz and Tocantis found that in 92% of cases a major C7 contribution was present, which usually joined the nerve only after C5 and C6 twigs had passed through the scalenus medius, after branches to the upper two and three digitations had already arisen. Furthermore, in one instance the C7 contribution proceeded independently to the lower digitations of the muscle, never joining up with the lower twigs [34].

The LTN courses vertically, the nerve gets progressively closer to the anterior border of scapula. The relationship of nerve and scapula forms a triangular-shaped region within the proximal nerve is situated, and therefore is at risk for injury. Salazar et al. [23] show that LTN is located at the greatest distance from the scapula at its tip. The size of triangular shape varies with arm positioning. With the arm flexed forward, the scapula moves anteriorly closer to the position of which remains unchanged. As the arm is extended posteriorly, the scapula moves further from the nerve, exposing more of the nerve for potential injury [18, 37].

Schultes et al. [38] reported that the length of the dissected LTN was 12.1 cm on average (range 8 to 14 cm). The largest branches leading to the serratus muscle had an average length of 2.4 cm. Nguyen et al. reported in their study that in lateral thoracotomies, the safe length of section dissociation of the serratus anterior which should stop before reaching the nerve is about 10 cm. They also said that the approach must be extended either anteriorly, by section or disinsertion of the pectorals, or posteriorly, by detaching the intercostal muscles along the upper edges of the ribs, after having carefully elevated serrato-rhomboides.

On the basis of our data, we suggest that the incisions should be at least 7.5 cm and 6.0 cm anterior to the scapular rim and scapular tip respectively.

Conclusion

This study confirms previous studies on the innervation to the serratus anterior muscle. Thoracic surgeons now have a range of incisional options to choose, including standard and muscle-sparing thoracotomy, thoracoscopy, video-assisted thoracic surgical techniques, and mini thoracotomies. Thoracotomy incisions cephalad to the scapular tip, including port sides, are at risk for iatrogenic proximal LTN injury and winged scapula. The objective of this study was to develop clinically applicable guidelines to aid in the prevention of iatrogenic LTN injuries. We believe that we have developed a quick and clinically useful method to minimize the risk of LTN injury, by mapping the course of the LTN relative to the scapula and sternum, the landmark most commonly used to orient standard thoracotomy incisions.

By using these anatomical guidelines, we believe that the incidence of iatrogenic LTN injury can be minimized.

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