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Anatomy of the Thoracic Recurrent Laryngeal Nerves from a Surgeon's Perspective

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Abstract

There is a need for a fresh understanding of the course of the recurrent laryngeal nerves (RLN) in the chest. Thoracic surgeons avoid dissection around the nerves altogether to avoid its injury. This is impacting on how comprehensive nodal dissection can be in lung cancer surgery. It's imperative to understand the anatomy of the course of the nerves in extreme details before having the confidence to preserve the motor branch. In the chest the course of the right RLN is short and the thoracic surgeon is unlikely to cut it inadvertently. The left RLN is more complex and requires in-depth understanding. Absolute mastery of the RLN anatomy is the best way to preserve it, and we strongly believe that 'the best way to avoid injuring the RLN is to expose it and note the course of its motor branch'. By improving exposure of the RLN and armed with the knowledge of detailed anatomy it was possible to point out a safe way to harvest nodes in stations 3p, 2-4R, 5-6L, 4L and 2L. RLN palsy should be an historical event for the thoracic surgeon.

Keywords: Video-assisted thoracic surgery; Recurrent laryngeal nerve; Vocal cord palsy; Systematic nodal dissection; Mediastinum

Introduction

Neck and chest surgeons have profound interest in the recurrent laryngeal nerve (RLN). The importance of its course is appreciated in the neck during thyroid, parathyroid, carotid vascular, anterior cervical spinal and laryngeal surgery [1-3]. In thoracic surgery, the RLN comes into focus during thymic, mediastinal, tracheal, cardiac, aortic, oesophageal and lung cancer surgery [4-10]. Reputable anatomy books describe the RLN in cadavers, and this doesn't pay a great service to the surgical practice on living humans [11,12]. This paper attempts to re-describe in extreme detail the anatomy of this nerve in the right and left chests, as seen through the eyes of a thoracic surgeon. It might seem a daring step to re-describe the anatomy of an old nerve such as the RLN, however; there is no systematic research or published descriptive account that addresses this subject in the chest. When appropriate; caveats are highlighted to avoid injury to the nerves, with special reference to mediastinal nodal dissection for lung cancer surgery. The information should prove valuable across the different specialities and surgical disciplines.

Methods

This account has been collected by a single thoracic surgeon's firm at Southampton the UK between 2007-2017. We routinely practice systematic nodal dissection (SND) during Video-Assisted Thoracoscopic (VATS) major pulmonary resections (MPR) for Non-Small Cell Lung Cancer (NSCLC). Nodal groups that put the RLN at risk of damage are #2 and 4R (high and low right paratracheal) and #3p (right retrotracheal), #4L (low left paratracheal and tracheobronchial), #2L (high left paratracheal) and #5-6L (sub aortic and pre-aortic) on the left. This account was based on 600 VATS-MPR for lung cancer, during which SND was routinely performed.

Our knowledge of the RLN anatomy was bolstered by dissecting a freshly embalmed cadaver at the All India Institute of Medical Sciences (AIIMS) in January 2017. A detailed description of the structure and course of the left RLN was obtained by transecting the aortic arch just below the origin of the ligamentum arteriosum. This gave excellent views of the course under the aortic arch, within the tracheo-oesophageal grove, which was hitherto enigmatic to the general thoracic surgeon.

Evolution of the RLN

The course of RLN in mammals is thought to be an extreme detour, about 4.6 meters (15 ft) in the case of the giraffe [13]. The nerve avoids the direct route between brain and throat and instead descends into the chest, then makes a U-turn around the Aorta, and returns to the larynx. That makes it seven times longer than it needs to be. This unnecessary stretch down to the chest and the sudden change of direction to ascend to the larynx is considered by evolution scientists as 'evidence of poor design'. But is the model defective? This remains debatable [14]. Similar examples exist in the human model. The phrenic nerve, for example, arises from high cervical nerves (C3-5) and descends within the chest all the way down to the diaphragm. It would have been more straightforward course if it obtained its nerve supply from segmental spinal nerves at the level of T10-12. In this case, the nerve descended with the septum transversum structures, which were in the neck area of the early embryo. Apart from the motor nerves to the larynx the recurrent laryngeal nerves supply plethora of 'autonomic' and 'sensory' nerves on its way down and up and these must have some value ascribed to their sensory autonomic feedback to the brain. Despite the large discrepancy in the course of right and left RLN, they work in perfect harmony to produce a well-coordinated 'voice'.

Khalid Amer (2017) The Recurrent Laryngeal Nerves and The thoracic Surgeon. Available: https://www.youtube.com/watch?v=gOcSaWRmZFA&feature=youtu.be.

Function

Voice control is quite a sophisticated physiology that is controlled by the Vagus and RLN, both arising directly from the brain rather than segmentally from the spinal cord. The RLN supply all the intrinsic muscles of the larynx (voice box), with the exception of the Cricothyroid muscles (CT). The latter is supplied by the superior laryngeal nerve (SLN), a direct branch of the Vagus given in the neck. The vocal cords are made of an intrinsic muscle called Thyroarytenoid (TA) wrapped inside a thin layer of mucosa. The Posterior Cricoarytenoid (PCA) muscles open or abduct the vocal cords, whereas the lateral Cricoarytenoid muscles (LCA) adduct or close the vocal cords. The RLN also supplies laryngeal sensation below the level of the vocal cords, and the superior laryngeal nerve supplies sensation above the cords. The TA muscle does not work in isolation but in harmony with all other intrinsic muscles to control the voice. Unilateral injury to the RLN causes ipsilateral vocal cord paralysis. According to Wagner & Grossman hypothesis (1897) the vocal cord lies in the adducted position because the intact cricothyroid muscle adducts the cord (supplied by the intact superior laryngeal nerve) [15-17]. If the superior laryngeal nerve is also paralysed the cord will assume an intermediate or paramedian (slightly off the median line) position because of the loss of adductive force. Impairment of swallowing is an accompanying symptom to dysphonia in roughly 60% of patients.

The RLN, has a strong propensity for regeneration and re-innervation of muscles after transection injury, however; functional recovery is usually poor. Direct re-anastomosis of severed RLN does not restore the voice. Even if the nerve was not fully repaired there is almost always nerve regeneration and muscle re-innervation to some extent. The commonly held conviction in thoracic surgery is that the commonest cause of dysfunction is thermal or traction injury, rather than denervation (disconnection). This is caused by the use of monopolar diathermy or ultrasonic energy devices close to the nerve at high risk zones. The paramedian position of the vocal cords results in a normal but weak voice. Alternatively, the voice could be hoarse with ineffective cough and choking fits. Unilateral paralysis can improve spontaneously due to compensation by the normal cord, which crosses the midline to meet the paralysed one. The incidence of spontaneous recovery is roughly 25%, and therefore generally, no treatment is required. Usually, 6 months is an adequate time to wait for spontaneous recovery. Early involvement of the Ear Nose and Throat (ENT) specialist is recommended, as the risk of aspiration may put the patient at high risk. Laryngeal medialisation procedures are very effective in restoring voice quality and swallowing function back to normal. Bilateral injuries to both RLN cause stridor and complete loss of voice as well as difficulty with spontaneous breathing. The airways are functionally obstructed by the two paralysed cords, which lie in median or paramedian position due to unopposed action of CT muscles. An urgent tracheostomy might be needed to allow spontaneous breathing.

The right recurrent laryngeal nerve [1]

The right and left nerves are not symmetrical. The right RLN is shorter and makes a quick entry and exit at the apex of the right chest. To understand the course of the right RLN one has to understand the course of the right Vagus nerve first. The latter originates from cell bodies in the Nucleus Ambiguus, Dorsal Motor Nucleus and Inferior Ganglion in the brain. It has central connections to Tractus Solitarius and its peripheral distribution influences speech, swallowing, heart beating, gastrointestinal motility, digestion, taste and sensations. The vagus [wandering] nerve is so named because it has the most extensive distribution and longest course of all cranial nerves, innervating structures in head, neck, chest and abdomen. The Vagal Trunk exits the base of the skull via the jugular foramen, lateral to the carotid artery. It passes vertically down the neck within the carotid sheath, lying between the internal jugular vein and internal carotid artery down to the thoracic inlet. In the neck, the vagus gives sensory and motor pharyngeal and superior laryngeal branches. It also gives the superior cardiac branch, and technically the RLN. At the origin of the common carotid artery from the brachiocephalic artery, the nerve crosses lateral to the subclavian artery, and descends over the anterolateral part of the main stem trachea, from anteromedial to posterolateral, proceeding under the Azygos arch, and descending behind the hilum of the lung. It gives vagal bronchial branches as part of the pulmonary plexus in its infra-Azygos course. It then comes to lie lateral to the oesophagus, and between the ascending part of the Azygos vein and bronchus intermedius. It is usually easily seen by the surgeon under the investing pleural coverage, on the lateral wall of the oesophagus. At the level of the inferior pulmonary ligament it breaks down into the oesophageal plexus, and reassembles joining similar branches from the left vagus to form the anterior and posterior vagal nerves. Throughout its course in the chest the vagus remains in an extrapleural position.

In the neck, the right RLN separates off the Vagus at a variable point in its course but remains within its sheath (two bananas in one skin). It descends parallel to the Vagus, all the way to the origin of the right common carotid and subclavian arteries. These two arteries are the terminal division of the brachiocephalic artery. The RLN is closely tucked around the subclavian artery, separate from the Vagus at this location. Anatomy books describe this looping point around the origin of the right subclavian artery [11,12]. Technically this is correct, but this description is not helpful, as the thoracic surgeon does not relate to the subclavian artery readily. The subclavian artery is the natural continuation of the brachiocephalic artery, and the view from the chest could hardly differentiate one from the other. The point of origin of the right common carotid artery is concealed from the thoracic surgeon, and practically lies in the neck. The chest surgeon has to extend the dissection above the first rib into the neck to expose this origin (Figure 1a and 1b). It is therefore practical to re-describe the nerve as "looping around the distal end of the brachiocephalic artery".

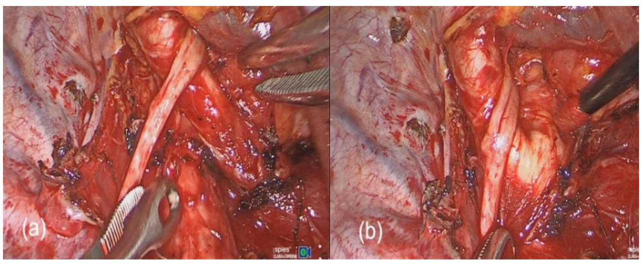

Figure 1: (a) The right subclavian artery is seen as a continuum of the brachiocephalic artery. (b) Further neck dissection reveals the origin of the subclavian off the brachiocephalic trunk.

The recurrent laryngeal nerve gets its name from this looping, [re curr] a Latin word meaning running in the opposite direction (to the Vagus nerve from which it branches). In 0.5%-1% of population a non-recurring right RLN exists [18]. A non-recurrent Laryngeal Nerve is

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rare but has been described in right-sided Aortic Arch or retropharyngeal left subclavian artery [19].

As mentioned above the right RLN makes a quick entry and exit in and out of the chest. Behind the bifurcation, the right RLN re-enters the neck and heads up towards the groove between trachea and oesophagus (tracheo-oesophageal groove). It reaches the groove at the level of the thyroid cartilage. Because the RLN is literally tucked to the brachiocephalic artery at the point of reflection, it is unusual for it to be disconnected by cutting or diathermy before causing some serious bleeding. The commonest cause for RLN palsy is thermal damage due to spray of energy (monopolar diathermy or ultrasonic sealing devices) close to the bifurcation of the brachiocephalic artery. The incidence of injury is proportional to the intensity of energy used and how close it is to the nerve. The thoracic surgeon is advised to avoid monopolar diathermy/ultrasonic energy devices in this area altogether.

Just beyond the point of reflection the Vagus and its recurring branch behave in a predictable chaotic manner. It is mainly the Vagus, but also the RLN, that contributes to a multitude of sensory and autonomic twigs to the surrounding structures such as the main trachea, oesophagus, Arch of the aorta and its major branches and the nearby fibro-fatty-nodal block. These twigs act like guy ropes that fix the vagus and its RLN at the point of reflection. Nodes especially those of station 3p (retro-tracheal) are trapped within these twigs, akin to fish trapped in a fisherman's net. Interestingly the same arrangement exists on the left side at the same point of reflection. There is no doubt that these chaotic sprouting twigs are the main cause of confusion surrounding the anatomy of the RLN. The motor laryngeal branch should remain the sole concern of the thoracic surgeon, and the remaining sensory twigs could be cut with impunity.

Surgical exposure of the right RLN

There is some similarity in the surgical strategy of exposing the right and left RLN. On the right exposure is made clearer after complete clearance of station 2&4R nodal pack. On the left exposure of the RLN is made safer after harvesting stations 5&6L nodal pack. Both nodal packs are usually harvested en-block, and both lie within a 'Superior Triangle' bounded by the phrenic and vagus nerves. On the right, the base of this triangle is made by the Azygos vein, whereas on the left it is based on the main pulmonary artery (Figure 2a and 2b). One constant large branch of the Vagus is worthwhile mentioning, the Inferior Cardiac nerve. This is relatively large and seen in the right and left superior triangles (Figure 3a and 3b). It originates from the vagal trunk beyond the reflection point, traverses the triangle from superolateral to anteromedial, heading towards the Arch of aorta on the right, and the main pulmonary artery on the left. This branch can be cut with impunity when dissecting nodes.

Early surgical exposure of the RLN safeguards against inadvertent injury. We now routinely use a bipolar device for dissection close to the RLN. To expose the 2&4R nodal pack a trap door is opened in the medial mediastinal pleura at the junction of vena Azygos and Superior Vena Cava (SVC). The incision is extended up just parallel to the SVC and cursing above the Azygos Arch laterally to the chest wall. Only the pleura must be included within the jaws of the bipolar device. When the pleural trap-door is retracted laterally, the vagus could be seen over the lateral wall of the main stem trachea. It's important to identify the vagus, as it is a good landmark for the lateral border of the nodal pack. The lateral border of the nodal pack is cleared and separated from the vagus. This allows the pack to be gripped using a Rampley sponge holder and pulled away from the SVC. Attention is then paid to dissecting the medial border of the pack.

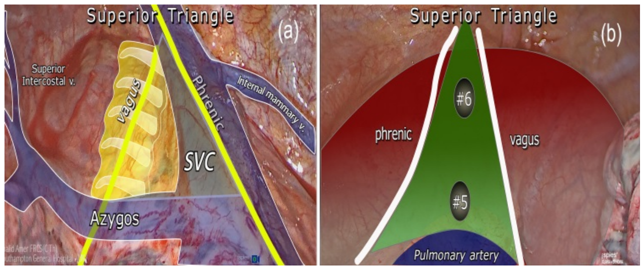

Figure 2: (a) The right superior triangle harbouring stations 2&4r nodes (b). The left superior triangle harbouring station 5&6 nodes.

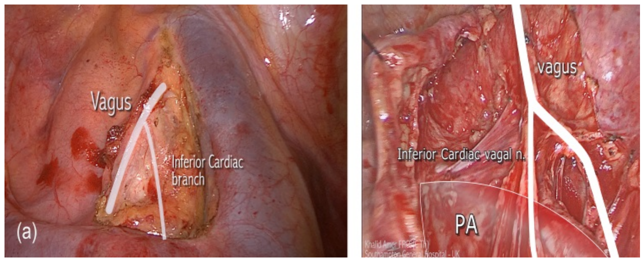

Figure 3: (a) The inferior cardiac branch of the right vagus nerve. (b) The inferior cardiac branch of the left vagus nerve.

This is done initially by pushing the SVC away from the pack using a peanut swab. Care is taken not to injure a constant short vein that drains directly from the nodal pack to the back of the SVC, equidistant to its length. This vein was never officially reported before, therefore; it merits the name 'the Amer Vein' (Figure 4). The apex of the nodal pack is then dissected down and the pack is removed en-block. This exposes the base of the 'superior triangle', which is made of the arch of aorta and the brachiocephalic trunk. The key to exposure of the right RLN is the Vagus nerve. It should be followed above the Azygos vein, upwards towards the apex until it meets the brachiocephalic artery (Figure 5). The motor branch of the RLN will be found tucked to the subclavian artery at this point. Should the need arise the sensory twigs are cut using bipolar diathermy as distal as possible close to their targets. This will minimise the spread of energy to the motor branch. Nevertheless; it is perfectly safe to use the bipolar device up to 1 millimeter away from the motor RLN. The latter should be kept under vision at all times. The voice will not be affected if the motor branch is spared. The secret to identifying what and what not to cut lies in the large calibre of the motor nerve relative to the sensory twigs and to the fact that the motor branch is never seen more than 1-2 mm away from the brachiocephalic artery (or subclavian).

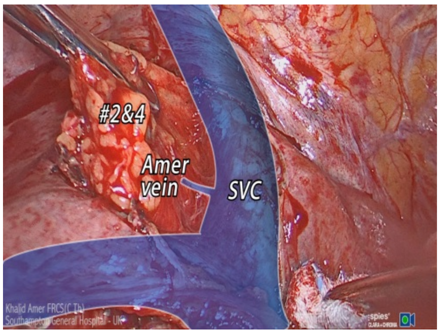

Figure 4: The Amer vein draining the nodal pack 2&4R directly to the superior vena cava.

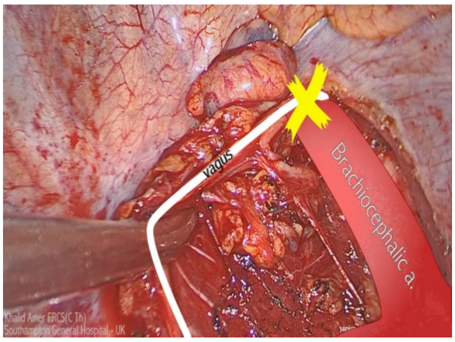

Figure 5: Landmarks for systematic identification of the right RLN.

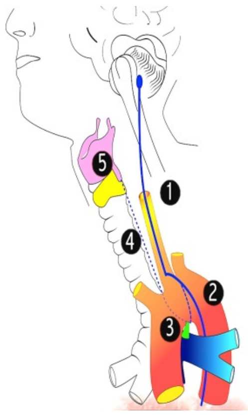

Figure 6: Anatomical zones of the left Recurrent Laryngeal Nerve.

The left recurrent laryngeal nerve [2]

The left RLN is longer than the right and its route is more complex. The journey of the left Vagus and its RLN in the chest can be described in 5 zones (Figure 6): Zone 1: Descending part from base of the skull to the Aortic Arch. Zone 2: Over the Arch of Aorta. Zone 3: Under the Arch of Aorta. Zone 4: Ascending part above the Arch of Aorta within the tracheo-oesophageal groove. Zone 5: Laryngeal part or target zone.

The left vagal nerve leaves the base of the skull and attains a position lateral to the carotid artery, similar to the right arrangement.

In zone 1 the descending first part of the nerve carries both the descending vagal trunk and the descending RLN (two bananas in one skin). Entering the thoracic inlet the left Vagal Trunk runs between the left subclavian artery and vein, and lateral to the left common carotid artery. Below the pleura, this space is occupied by fibro-fatty-nodal tissue, and the trunk of the Vagus is not readily identifiable. Dissection for station 2L nodes in this position should avoid inadvertent transection of the vagal trunk, as this will result in RLN palsy. To expose the vagal trunk in this position, it is best to cut the superior intercostal vein over the visible vagus and follow it retrogradely into zone 1. There is an overlap between zone 1 and zone 4 in this location, but it is to be noted that the ascending branch of the RLN in zone 4 is deeper than the left common carotid artery in this position, and lies within the tracheo-oesophageal groove.

In zone 2 the Vagus reaches the origin of the carotid artery and climbs up the Aortic Arch, cursing underneath the superior intercostal vein, heading to the angle between Ligamentum Arteriosum and Aortic Arch (technically the beginning of the descending aorta, and a landmark for the reflection point). The RLN usually splits from the Vagus in this zone but runs very close and medial to it. Therefore; the thoracic surgeon should see two nerves side by side over the Arch of Aorta. The calibre of the RLN is about 1 mm, or half that of the Vagus, but sizable enough to distinguish it from the sensory twigs that arise from it and the vagus.

Throughout its course in the left chest, the Vagus nerve remains covered by mediastinal pleura. The surgical steps taken to expose the left RLN in our unit are more or less standardised. The 'superior triangle' is cleared of all stations 5-6L nodes en block. This triangle is bound by phrenic and vagus nerves and the main pulmonary artery (Figure 2b). Dissection is started by opening the investing medial mediastinal pleura over the triangle, extending cephalad towards the apex of the triangle, but taking care not to injure the phrenic nerve. Clearance of the nodes allows identification of the Ligamentum Arteriosum, which is crucial to identification of the motor RLN. At the point of origin of the Ligamentum, the Vagus continues to descend over the back of the hilum, anterior to the descending Aorta to reach a course lateral to the oesophagus and the inferior pulmonary ligament. It is at this point of reflection at the Ligamentum that the Vagus and its recurring branch give sensory and autonomic nerve twigs to the surrounding structures (main trachea, oesophagus, left main bronchus, cardiac branches, main pulmonary artery and nodal pack). This is a replica of the organised chaos seen on the right side, exactly at the same point of reflection (Figure 7b). These twigs work like guy ropes that fix the Vagus and the RLN to the point of reflection. They weave up a mesh that traps lymph nodes like fish trapped in a fisherman's net. The main motor branch is what the thoracic surgeon should be concerned about. The latter continues under the Arch of the aorta into zone 3, retaining the same calibre seen over the Arch, in contradistinction to the sensory guy ropes, which are considerably smaller in size. Similar to the right side arrangement, it is these guy ropes that cause confusion and fear of iatrogenic injury. The course of the nerve from the Ligamentum to the point where the nerve reaches the tracheo-oesophageal groove is only a few millimeters but completely unfamiliar to the thoracic surgeon. Knowledge of what is

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going on in these few millimeters is the key to confidence in preserving the motor RLN.

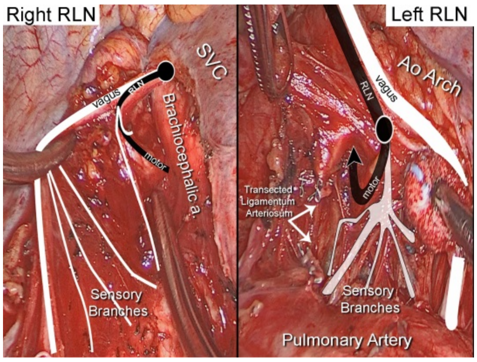

Figure 7: (a) Sensory twigs given by vagus and RLN at right point of reflection. (b) Same guy ropes at left point of reflection.

Contrary to common belief, the motor nerve does not ascend to the left-hand side but to the right side of the reflection point to reach the tracheo-oesophageal groove (viewed from a left lateral thoracotomy or VATS view). Figure 8 shows a cadaveric transected aorta at the point of origin of the Ligamentum Arteriosum. The Vagus nerve was slung using a suture material. The course of the motor RLN into zone 3 is shown clearly, and the difference in calibre compared to the sensory twigs is worthwhile noting. Deliberate cutting of these sensory twigs could facilitate dissection of nodes at stations 4L and 5L. It is perfectly safe to do so, with no consequences to normal voice. The trick is to identify the motor branch and make sure it is intact at all times.

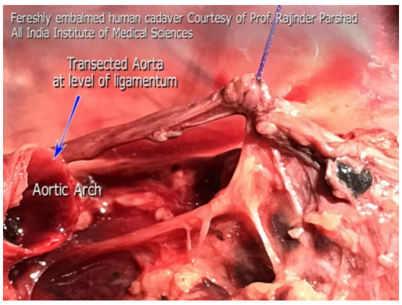

Figure 8: Freshly embalmed human cadaver. The aorta was transected at the origin of the Ligamentum Arteriosum to expose the motor branch in zone 3.

Although not necessary, stapling and transecting the Ligamentum Arteriosum improves exposure of zone 3 and facilitates nodal harvesting of station 4L (as well as making it possible to sample precarinal 4R nodes). Blind fishing for nodes under the Arch, even after identifying the recurring motor branch might damage the motor branch on its way to the tracheo-oesophageal groove. It is safe to dissect tissues and guy ropes to the left of the motor branch, but unsafe to do the same on the right side of the motor branch (Figure 9). There is a constant sensory twig to the left of the reflection point that arises from the motor RLN and supplies either the pulmonary artery, main stem trachea or one of the 4L nodes. It is a major cause of confusion and reluctance in decision taking. It could be cut with impunity. Within the fisherman's net, each fish must be grabbed neatly and separately from the sensory nerves (the net). An eye must be kept on the motor branch at all times and should the need arise the node should be peeled off the motor branch without using any form of energy whatsoever. It could not be overemphasised that no nerve should be disconnected until the surgeon has decided beyond reasonable doubt that 'it is not the motor branch'. There is no place for guessing here.

Zone 4 of the left RLN is very well known to the oesophageal surgeons. The course of the RLN in this groove is rather constant [20]. Three-field nodal dissection during VATS oesophagectomy in the prone position gives exceptional views from the back of the trachea and oesophagus [21]. Safe nodal dissection dictates exposing the RLN to avoid iatrogenic injury in zone 4. The main motor nerve is seen to be sizable, and it gives small hairline twigs right and left to the trachea and oeosphagus. This is helpful information to the general thoracic surgeon not exposed to such views. The RLN remains in the tracheo-oesophageal groove heading up and out of the thoracic inlet. In the neck, the RLN cannot help but annoy thyroid surgeons before reaching its final destination [1]. The thoracic surgeon encounters the ascending left RLN when performing Mediastinoscopy. Biopsy of the left high paratracheal 2L nodes and low paratracheal and tracheo-bronchial station 4L nodes can cause RLN palsy [22,23]. The incidence is roughly 0.6% of cases. The recommendation is to expose the nerve before dissecting for these nodes.

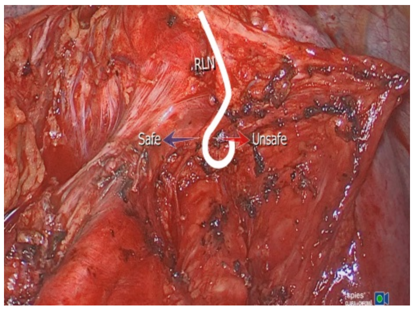

Figure 9: Safe area of dissection around the left RLN at origin of Ligamentum Arteriosum.

Zone 5 is the domain of the ENT surgeons. As the nerve reaches its final destination, it pierces the cricothyroid membrane and start doing what it was designed to do; giving motor branches to the vocal chords as well as sensory branches to the larynx. By that time it had collected all the sensory information from the surrounding structures to coordinate vocal cord movement with the contralateral cord.

Results

We have used monopolar diathermy for the majority of cases in this series. By the end of 2015, we moved on to using a flexible bipolar energy device to harvest mediastinal nodes (Enseal, Johnson & Johnson, Ethicon, Cincinnati, USA). In 600 cases of SND, there was no RLN palsy on the right side and 3 on the left side. The first was simply due to thermal injury close to the point of reflection (using monopolar diathermy). In the second case bleeding of the artery accompanying the vagus occurred a short distance down from the reflection point (usually a low risk zone). Metal clips were used to stop the bleeder fortified by diathermy touching the clip. Thermal energy must have been transmitted proximally to the RLN. The third left palsy was due to truncal vagotomy (transection) of the descending vagus in zone 1 (using bipolar diathermy). Laccourreye O. et al reported the largest series of 122 patients with unilateral laryngeal paralysis after pulmonary resection with mediastinal nodal dissection for cancer referred to the Department of Otorhinolaryngology in France [24]. This series collected data during 14 years 1993-2007, and highlight the extent of the problem. 89.8% of these were left sided, during pneumonectomy. In 50.7% (35 of 69) the operative report mentioned transection of either the inferior laryngeal [RLN] or X^{th} [vagus] nerve during surgery. Filaire et al. (2001) reported a 31% incidence of RLN palsy in a series of 99 patients undergoing lung and nodal dissection for lung cancer [25]. There is a general consensus that the incidence of RLN paralysis is under reported.

Conclusion

There is a need for new understanding of the course of the RLN in the chest. It's imperative to understand the anatomy of the course of the nerves in extreme details before having the confidence to preserve the motor branch. In the chest the course of the right RLN is short and the thoracic surgeon is unlikely to cut it inadvertently. The left RLN is more complex and requires in-depth understanding. Absolute mastery of the RLN anatomy is the best way to preserve it, and we strongly believe that 'the best way to avoid injuring the RLN is to expose it and note the course of its motor branch'. By improving exposure of the RLN and armed with the knowledge of detailed anatomy it was possible to point out a safe way to harvest nodes in stations 3p, 2-4R, 5-6L, 4L and 2L. RLN palsy should be an historical event for the thoracic surgeon.

Acknowledgement

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