



Review

A Review of Methods for the Preservation of Laryngeal Nerves During Thyroidectomy

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Abstract

The recurrent laryngeal nerve (RLN) provides motor innervation to the abductor and adductor muscles of the vocal cord, whereas the external branch of the superior laryngeal nerve (EBSLN) provides motor innervation to the cricothyroid muscle, which is the tensor muscle of the vocal cord. Both the RLN and the EBSLN are anatomically close to the thyroid and are therefore at risk of injury during thyroidectomy. These 2 laryngeal nerves must be carefully preserved during surgery to ensure that the function of the vocal cord is not impaired. Currently, complete exposure of the RLN during thyroidectomy is accepted as the gold standard method for the preservation of RLN. Sufficient knowledge of surgical anatomy, clinical experience, and meticulous surgical techniques are key factors in the identification and safe dissection of the RLN. During a thyroidectomy, the RLN can be identified using four different approaches, depending on the type of thyroid growth and choice of the surgeon: There are lateral, inferior, superior, and medial approaches.

The lateral approach is the most commonly used technique in primary thyroid surgery. The RLN is usually found by dissection around the inferior thyroid artery at the level of the middle lobe of the thyroid. RLN is generally found at the site of its entry into the neck region devoid of scar formation when the inferior approach is used especially in cases with secondary surgery. The superior approach is recommended for patients with an huge goiter or large substernal goiter. In this approach, the upper pole of the thyroid is first released and then pulled forward and laterally, and the RLN is exposed on the nerve's entry point (NEP), into the larynx, under the cricopharyngeus muscle. The medial approach is preferred for patients with substernally or retropharyngeally enlarged goiters. In this approach, the isthmus is first dissected and divided, and then the isthmus and the medial part of the lobe are dissected away from the trachea to reveal the anterolateral part of the trachea. The fibers between the lateral aspect of the second or third tracheal rings and the thyroid, and the fibers of the Berry ligament are gradually dissected cranially, to allow RLN to enter into the field of view lateral to the trachea. The preservation of the anatomical integrity of the RLN does not indicate that its functional integrity is also preserved. IONM is a tool for the functional assessment of RLN, and so this method is an addition to visually identifying RLN, which is the gold standard. IONM significantly contributes to visual identification of the RLN, determination of its anatomical variations, intraoperative recognition of RLN injury, prevention of bilateral vocal cord paralysis, and detection and preservation of electrical activity in the nerve in patients with preoperative vocal cord paralysis.

Although there is no standardized method for the preservation of the EBSLN, 3 methods have been defined during the release of the upper pole of the thyroid. These methods involve dividing the branches of the superior thyroidal artery one by one on the capsule without visually identifying the EBSLN, searching and visually identifying the EBSLN before the dissection of the upper pole vessels, or detecting the EBSLN and dissecting the upper pole under the guidance of IONM. IONM also significantly contributes to the detection and confirmation of the EBSLN and dissection and preservation of the upper pole of the thyroid gland.

Keywords: Intraoperative neuromonitorization; recurrent laryngeal nerve; superior laryngeal nerve; thyroid.

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The vocal cords are structures that perform very important tasks, including mainly the formation of sound and keeping the airway open during respiration. The intrinsic laryngeal muscles are responsible for movements of the vocal cords. The recurrent laryngeal nerve (RLN) provides motor innervation to the abductor and adductor muscles of the vocal cord, whereas the external branch of the superior laryngeal nerve (EBSLN) provides motor innervation to the cricothyroid muscle, which is the tensor muscle of the vocal cord.^[1] In this context, both the RLN and EBSLN are at risk of injury during thyroidectomy due to their close vicinity with thyroid gland. Therefore, both of these laryngeal nerves must be carefully preserved during surgery in order to prevent impairment of vocal cord functions.^[2] In this article, the methods of preservation of the RLN and EBSLN during thyroidectomy are discussed.

Anatomy

Recurrent Laryngeal Nerve

Anatomical Course of the Recurrent Laryngeal Nerve

As one of the important branches of the vagus nerve, the RLN innervates the larynx via its motor, sensory, and parasympathetic fibers.^[3] The anatomical course of the RLN is different on the right and left side. The right RLN, which arises from the vagus nerve at the point where the brachiocephalic artery is divided into 2 branches, rotates backward around the right subclavian artery and advances toward the tracheoesophageal groove after passing behind the carotid artery at an angle of 15° to 45° with the trachea. The left RLN arises from the vagus nerve at the level of the ligamentum arteriosum and turns backward from the front aspect of the aortic arch and reaches the tracheoesophageal groove from the medial to the left common carotid artery. Because the angle between the left RLN and the trachea varies between 0° and 30°, it is localized deeper than the right RLN and communicates with the tracheoesophageal groove more inferiorly. Furthermore, the left RLN is approximately 2 times longer than the right RLN due to different levels of origin from the vagus nerve.

One of the important structures associated with the RLN is the inferior thyroid artery (ITA), which may be located in front of or behind this artery or branches or may pass through its branches. The RLN, which usually follows the same anatomical route on both sides after passing the level of the ITA usually comes close to the Zuckerkandl tubercle (ZT) then to the Berry ligament; therefore, the risk of injury to RLN increases in this area.^[4,5]

Non-Recurrent Laryngeal Nerve: The nerve arising from the upper part of the vagus rarely reaches the larynx with-

out turning around the main vessels. This anomaly is defined as non-recurrent laryngeal nerve (non-RLN) and was found on the right side in 0.7% of the cases in the clinical series and 1.4% in cadaver studies according to a recent meta-analysis. On the left side, non-RLN is very rare and is associated with situs inversus.^[6]

Extralaryngeal Branches of the Recurrent Laryngeal Nerve:

Extralaryngeal branching of RLN is not rare. The RLN may mostly divide into branches at the most distal 2 cm. In a recent meta-analysis involving 28.327 RLNs, (extralaryngeal) branching was determined in approximately 39.2% of cases intraoperatively and 73.3% in cadaver studies.^[7] Extralaryngeal branching may be unilateral or bilateral.^[8,9]

Zuckerkandl Tubercle: The Zuckerkandl Tubercle (ZT) is considered to be the fusion point of the ultimabranial body (lateral thyroid body) and the median thyroid, and may become prominent, usually growing posteriorly.^[10] It is classified as grade 1 if it is observed as a consolidation of the lateral margin of the thyroid lobe, as grade 2 if it is smaller than 1 cm, and grade 3 if it is greater than 1 cm. 63%–77% of thyroidectomies were reported to have an enlarged ZT, and it was found that the RLN mostly (93%) courses medially and rarely, (7%) laterally to the ZT.^[11]

Berry Ligament: The RLN courses between 2 fascial structures after passing immediately cranially to the ITA. The first of these structures is the superficial vascular fascia covering the upper aspect of the RLN, which is observed when the lobe is rotated anteromedially during thyroidectomy. It contains the delicate tertiary artery, branches of veins of the thyroid gland, including the ZT and the upper parathyroid gland. In other words, it covers the RLN from the lateral aspect. When this structure is opened, the RLN becomes visible in the tracheoesophageal groove. At approximately the last 2 cm of the RLN, the real Berry ligament, a deep fibrous facial layer medial to the RLN, appears.^[12] The Berry ligament of the thyroid is a suspensory ligament formed by the consolidation and thickening of the pretracheal fascia, and it allows a limited area of the posteromedial and posterolateral regions of the thyroid to be attached to the cricoid cartilage and the first 2 tracheal rings (Fig. 1, 2).^[3,13] The median length of the true ligament between the thyroid and trachea is 8 to 11 mm, its thickness is 2 to 7 mm, the distance between the middle of the trachea and the ligament is 10 to 20 mm, and the distance between the site of attachment to the cricoid cartilage and the entry of the RLN is 1.9 mm in average (Fig. 3a, 3b).^[13] The vertical length of the ligament was calculated considering the measurements reported by Kim et al.^[14] Taking into account the length of the tracheal ring and the distance between rings, the vertical length was calculated as 11.4 mm for females

and 14.1 mm for males (Fig. 3a). However, the topographical relationship between the RLN and the Berry ligament can be different, depending on the point of view.

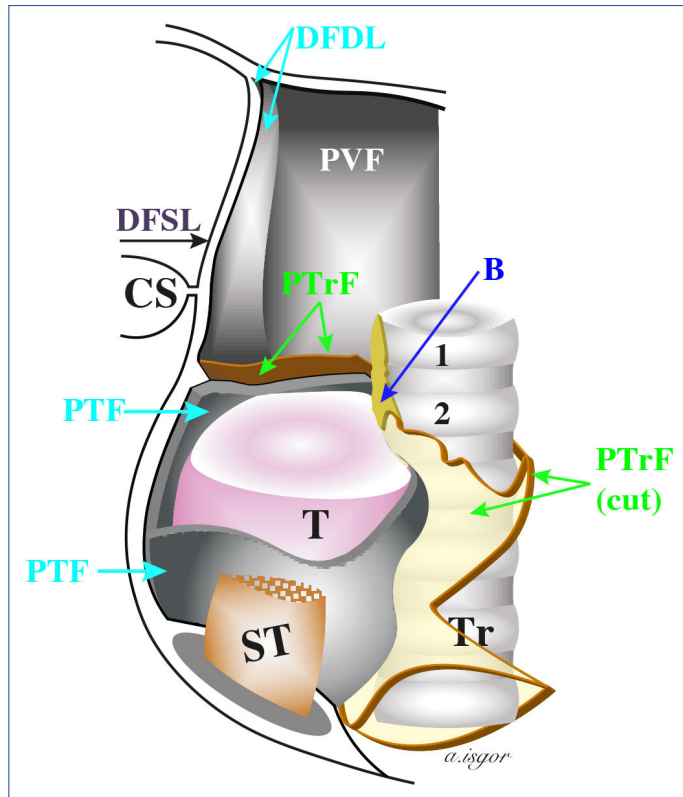


Figure 1. Formation of the Berry ligament by the condensation and thickening of the pretracheal fascia.

(DFDL: Deep layer of deep neck fascia; PVF: Prevertebral fascia; CS: Anteromedial layer of carotid sheath; PTrF: Pretracheal fascia; B: Berry's ligament; T: Thyroid; Tr: Trachea; PTF: Anterior leaf of superficial layers of deep neck fascia; B: Berry ligament; PTrF (cut): Pretracheal fascia cut).

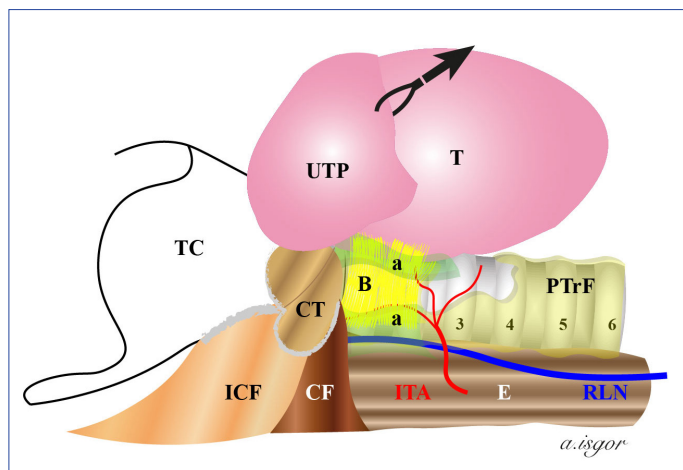


Figure 2. Berry's ligament.

TC: Thyroid cartilage; ICF: Inferior pharyngeal constrictor muscle; TC: Thyroid cartilage; UTP: Upper thyroid pole; T: Thyroid; CT: Cricothyroid muscle; CF: Cricopharyngeal muscle; B: Berry's ligament; a: Vasculary layer; PTrF: Pretracheal fascia; 3-6: Tracheal rings; ITA: Inferior thyroid artery; E: Esophagus; RLN: Recurrent laryngeal nerve.

It can be said that RLN is at the inferior or posterior aspect of the ligament when the lateral approach is applied (Fig. 4) and at the posterolateral aspect of the ligament when the medial approach is applied (Fig. 3a). However, the expression of RLN coursing along the lateral side of the ligament is generally accepted.

When the Berry ligament comes close to the thyroid, i.e., when it adheres to the posteromedial and posterolateral surfaces of that part of the thyroid, it appears as 2 layers, and this becomes more apparent when the thyroid grows between these layers and approaches the RLN.

Generally, RLN is located lateral to the Berry ligament in the tracheoesophageal groove, and the thyroid tissue may oc-

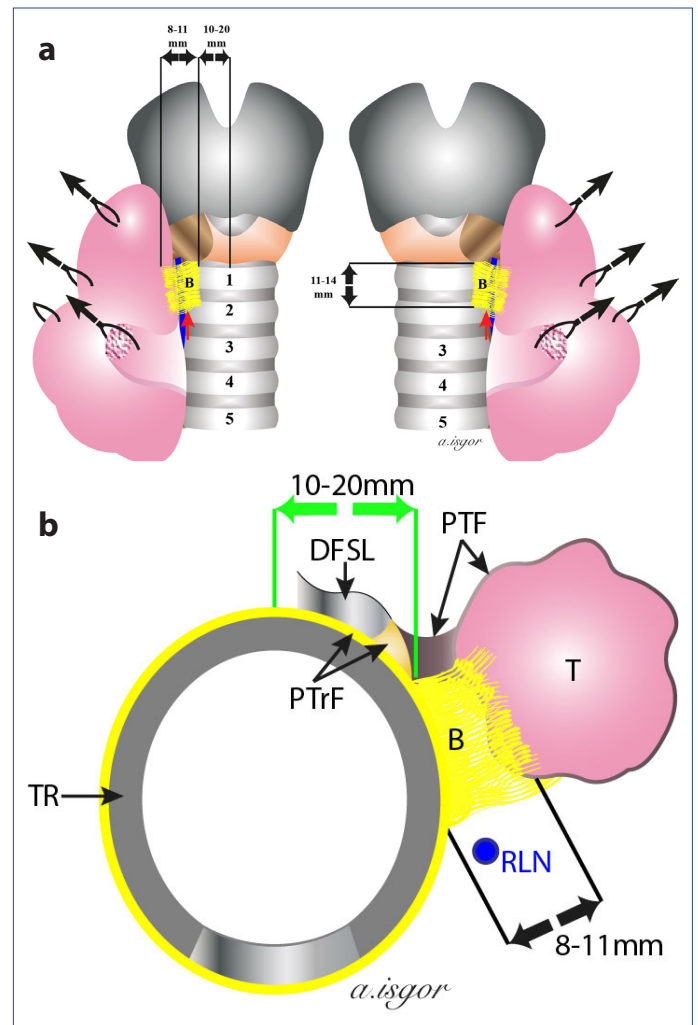


Figure 3 (a, b). The medial approach to the recurrent laryngeal nerve and Berry's ligament. B: Berry's ligament; T: Thyroid; Red arrow: Cutting site of Berry's ligament. (a) Transverse section through the level of the second tracheal ring and Berry's ligament. TR: Trachea; PTrF: Pretracheal fascia; DFSL: Superficial layer of deep neck fascia; B: Berry's ligament; PTF: Anterior leaf of superficial layer of deep neck fascia; RLN: Recurrent laryngeal nerve. (b)

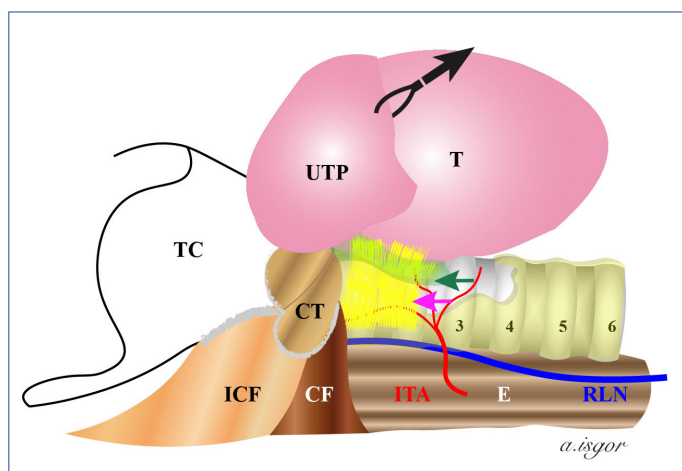


Figure 4. The lateral approach to the recurrent laryngeal nerve.

TC: Thyroid cartilage; ICF: Inferior pharyngeal constrictor muscle; UTP: Upper thyroid pole; T: Thyroid; CT: Cricothyroid muscle; CF: Cricopharyngeal muscle; B: Berry's ligament; 3-6: Tracheal rings; ITA: Inferior thyroid artery; E: Esophagus; RLN: Recurrent laryngeal nerve; Green arrow: Cutting level of the vascular layer; Pink arrow: Cutting level of Berry's ligament.

asionally extend posteriorly toward the RLN.^[15] It should not be forgotten that the RLN is most commonly injured due to this anatomical structure. In this case, the anterior layer of the ligament is first cut, and then the posterior layer is cut after applying traction to the thyroid to the medial aspect in the lateral approach and to the lateral aspect in the medial approach, ensuring that the thyroid is not under excessive tension. If the thyroid extends posteriorly toward the RLN and does not contain cancerous tissue, no further dissection should be performed, and it should be left at the site under the RLN.^[15]

External Branch of the Superior Laryngeal Nerve

The superior laryngeal nerve (SLN), which is the branch of the vagus nerve, divides into two branches as internal (IBSLN) and external (EBSLN) nerves at the level of the greater horn of the hyoid bone in the posterior of the internal carotid artery. The IBSLN is a sensory branch that does not appear in the field of view during a thyroidectomy. It is thicker than the EBSLN, and after leaving the SLN, IBSLN courses in an inferomedial direction and enters the larynx by piercing the thyroid membrane together with the superior laryngeal vessels. The EBSLN passes along the dorsal aspect of the carotid sheath after it is branched out of SLN. While it runs parallel to the superior thyroid artery, it crosses the artery behind from the medial–inferior direction and descends into the cricothyroid muscle. During this descent, it may course beneath the superficial pretracheal fascia covering the lateral aspect of the inferior pharyngeal constrictor muscle either above the muscle, or under or between the muscle fibers.^[16] The insertion site of the sternothyroid muscle is a good indicator for the identification

Table 1. Cernea classification

- Type 1** The EBSLN crosses the superior thyroid vessels from ≥ 1 cm above the boundary of the upper pole
- Type 2a** The EBSLN crosses the superior thyroid vessels from < 1 cm above the boundary of the upper pole
- Type 2b** The EBSLN crosses the superior thyroid pedicle at the level of the upper pole or more caudally

Table 2. Friedman classification

- Type 1** The EBSLN courses entirely on the surface of the inferior pharyngeal constrictor muscle
- Type 2** While coursing on the surface of the inferior pharyngeal constrictor muscle, the EBSLN enters into the inferior pharyngeal constrictor muscle about 1 cm proximal of the cricothyroid muscle
- Type 3** The EBSLN courses under the inferior pharyngeal constrictor muscle up to the cricothyroid muscle

of the EBSLN because this nerve runs 1–2 mm immediately posterior to the oblique insertion site of the laryngeal tip of the sternothyroid muscle to the thyroid cartilage.^[17] In a study of 200 human cadavers, Mossman and Dewase^[18] found the EBSLN in an area they defined as the sternothyroid–laryngeal triangle (Jolles area). The boundaries of this area, which should be considered a 3-dimensional triangle, is formed anteriorly by the sternothyroid muscle, inferolaterally by the upper pole of the thyroid, and posteromedially by the inferior pharyngeal constrictor and the cricothyroid muscle.^[18] However, the above-described course of the EBSLN has many anatomical variations, and several relevant classifications have been made. The most widely used is the Cernea classification, which defines the relationship between the EBSLN and the superior thyroid vessels according to the distance to the top of the upper pole of the thyroid. In this context, the Cernea classification considers the risk of EBSLN injury by evaluating the relationship between the superior thyroid artery and the EBSLN (Table 1).^[19]

It has been reported that 17% to 60% of type 1, 17% to 59% of type 2a, and 10% to 56% of type 2b EBSLNs have been detected.^[20-27] The factors responsible for this wide range of incidence rates include the weight of the patient, the size of the thyroid, the presence of a toxic or nontoxic goiter, the determination of the nerve by visual or neuromonitoring, and the scope of the study. According to this classification, type 2b is more frequently observed in cases with large goiters and the risk of injury in type 2b is higher in the dissection of the upper pole.^[20]

The Friedman classification is a classification of the EBSLN in relation to the inferior pharyngeal constrictor muscle before its entry into the cricothyroid muscle.^[28] It should not be considered as an alternative to the Cernea classification

but as a complementary classification (Table 2).^[2]

However, detailed incidence rates for EBSLN types were not given in the study in which Friedman classification was published, and about 20 years before this study, Lennquist et al.^[29] reported that the EBSLN was observed in the inferior pharyngeal constrictor muscle in 20% of cases and that the nerve was not observed in these cases. Subsequent studies have provided detailed information on these incidence rates. Patniak et al.^[30] detected 57%, 27%, and 16% of type 1, type 2, and type 3 EBSLN, respectively, according to the Friedman classification in 29 cadaveric dissections. Uludag et al.^[26, 27] reported that these rates were 59% to 60%, 11% to 12%, and 29% to 30%, respectively, in 2 different clinical series.

Human communicating nerve: There are several internal anastomoses between the RLN and the IBSLN. An anastomosis has also been determined between the RLN and the EBSLN, which is called the human communicating nerve. A branch that separates from the EBSLN enters the larynx by passing through the cricothyroid muscle and anastomoses with the RLN to innervate one-third of the anterior part of the thyroarytenoid muscle, which is the adductor of the ipsilateral vocal cord. In anatomy studies, the human communicating nerve was detected in 41% to 85% of the cases.^[31-33] IONM studies of the EBSLN also tend to support this finding, and it has been shown that in 68% to 80% of cases, positive electromyographic waveforms can be obtained from the vocal cord with the stimulation of the EBSLN.^[26, 27, 34, 35]

Preservation Methods of the Recurrent Laryngeal Nerve

RLN injuries are one of the most serious complications of thyroidectomy. Bilateral RLN injuries can lead to life-threatening respiratory problems,^[1] whereas unilateral RLN injuries can cause problems such as hoarseness and aspiration at different degrees of severity that can significantly impair quality of life.^[1] In a recent meta-analysis on RLN injuries, 25,000 cases were evaluated; the rates of transient and permanent vocal cord paralysis (VCP) were found to be 9.8% (1.4%–38.4%) and 2.3% (0%–18.6%), respectively.^[36] In another meta-analysis, the incidence rate of bilateral VCP was 2.43 and 5.18 per thousand for whom IONM was used or not used, respectively.^[37]

The risk factors that increase RLN injury during thyroidectomy are primary or recurrent malignant diseases, recurrent benign diseases, thyrotoxicosis (Graves' disease), the extent of the surgery, routine non-observance of RLN (no RLN dissection), low-volume hospital or surgeon, substernal goiter, nerve branching, aberrant course of the nerve, and presence of non-RLN.^[38-44] Even after Lahey^[45] indicated

that the risk of RLN injury could be reduced from 1.6% to 0.3% within 3 years with routine visual identification and dissection, it has still been a topic of discussion for a long time. Jatzko et al.^[46] evaluated the literature compared with their own series of RLN procedures and detected that the rate of transient and permanent VCP significantly decreased with routine visual identification of the RLN. Similarly, in a study conducted between 1979 and 1999 in which a single-center primary surgery was performed for benign thyroid diseases and 27,000 RLNs were examined, Hermann et al.^[47] found that the number of injuries significantly decreased with visual identification of the RLN. They found that complete dissection is highly superior to a only localized, or partial exposure of the nerve. Currently, the complete appearance of the RLN during thyroidectomy is accepted as the gold standard method for the preservation of the RLN.^[48] The meaning of the above-mentioned term "RLN dissection" is important. We believe that this should imply visual identification of the nerve in an area, and its course must be fully revealed throughout the surgical field with one of the approaches (defined below) used to identify the RLN. For this purpose, particularly in patients who did not undergo central neck dissection, as much as possible, the nerve should not be separated from its bed and the thyroid should be dissected from the nerve by dissecting medially to the nerve.

Methods for Detecting the Recurrent Laryngeal Nerve

During a thyroidectomy, the RLN can be identified using 4 different approaches, depending on the type of thyroid growth and the choice of the surgeon: there are lateral, inferior, superior, and medial approaches.^[3] Visual identification of the RLN requires adequate knowledge of surgical anatomy and clinical experience. In addition, some basic rules contribute to safe dissection of the nerve. The surgical field must be appropriately exposed during surgery, and if the retraction of the strap muscles and the thyroid are not sufficient to provide an adequate visual field, the strap muscles should be cut and adequate light should be provided.^[49]

It is extremely important to work in a bloodless surgical field during identification and visualization of the RLN. Despite careful dissection, particularly in the Berry ligament area, bleeding may occur due to dissection or rupture of thin veins due to excessive tension on the thyroid. If the nerve is observed in this case and is within a safe distance, then these bleeding vessels can be clamped or controlled with bipolar cautery. Otherwise, bipolar cautery or clamping should not be used blindly, and minor bleedings should

be checked using gently applied compression with a gauze tampon.^[49] In this context, it is very important not to cut any tubular structure without detecting the RLN. After the RLN is observed, a minimal dissection from the medial aspect of the RLN should be performed, if possible. Care must be taken to protect the nerve's vaso-nervosums, and energy devices should not be used near the nerve. Forceful aspiration and compression with gauze tampons should not be applied. The use of magnifying glasses with sufficient light also significantly contributes to dissection.^[50]

Lateral Approach (Fig. 4)

This technique, which is often applied in primary thyroid surgery, should not be confused with lateral intervention, also called the "backdoor approach," performed between the sternocleidomastoid and strep muscles as secondary surgery or parathyroid surgery.^[51] In this method, the thyroid and strep muscles are first dissected away and the lateral thyroid veins are ligated with cauterization. If there is no suspicion regarding the presence of non-RLN on the right side, then releasing the upper pole initially may provide an additional advantage. Before performing dissection for the RLN during the surgery, the stimulation of the vagus nerve with IONM provides important clues in terms of non-RLN. Non-RLN can also be detected with preoperative radiological methods.

Usually, the strep muscles and carotid artery are retracted laterally and the thyroid anteromedially to expose the paratracheal region where the RLN is anatomically located.^[49] While looking for the RLN, the parathyroid, ZT, ITA, and the lower border of the inferior horn of the thyroid cartilage can be used as a guide. The RLN is usually found by dissection around the inferior thyroid artery at the level of the middle pole of the thyroid. To preserve the inferior parathyroid artery, a branch of ITA, the RLN may be found when the inferior parathyroid is dissected from lower pole of the thyroid, just before the lobe is retracted medially.^[52]

At this level where RLN is visualized, because the nerve stands at a more lateral position than the trachea and thyroid at the right side, it may not need to be exposed proximally, but it is useful to visualize it to the last point where the lower pole is released on the left side (Fig. 5). It should be kept in mind that extralaryngeal branches may separate particularly in the last 2 cm of the nerve when cranial dissection is advanced from the area where the RLN is first observed.^[51] This approach can be difficult in cases of large goiters or a large ZT. In secondary surgeries, searching for the nerve within this area may have risks, due to the formation of dense scar tissue. Also, in the presence of non-RLN, the lateral approach may be risky because the nerve courses perpendicularly to its normal course in secondary cases.^[49, 51]

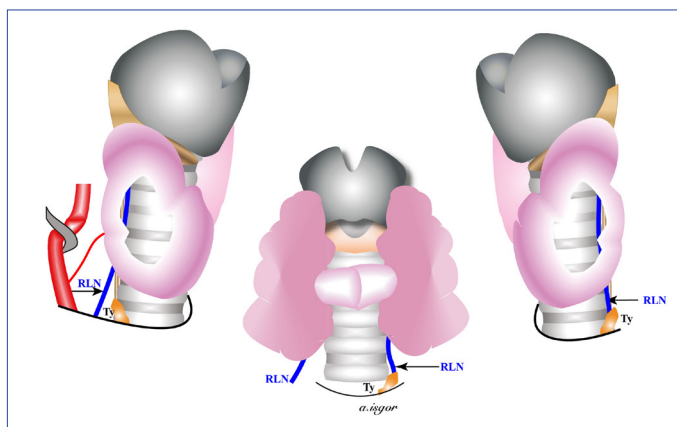


Figure 5. The inferior approach to the recurrent laryngeal nerve.

RLN: Recurrent laryngeal nerve; Ty: Thymus.

Inferior Approach (Fig. 5)

This approach generally describes the detection of the RLN from its entry in the neck region devoid of scar tissue during secondary surgical procedures.^[3] This area is also known as the RLN triangle with the boundaries defined in 2 different ways. According to the definition of Lore et al.,^[53] the thoracic entry forms the top of the triangle, the common carotid artery forms the lateral margin, the trachea and esophagus form the medial margin, and the lower border of the inferior lobe of the thyroid forms the base. In recent publications, it has been stated that the lateral edge of the triangle which is delineated by the placement of retractors in the thyroid, is formed by the strep muscles and the medial edge is lined with trachea. In fact, both of these definitions are correct, according to the method of approach in the region. According to this, the second definition is valid in the conventional midline approach, whereas the first definition is valid for the lateral intervention (backdoor approach), in which the strep muscles are retracted medially and the common carotid artery laterally. As indicated in the anatomy section, because the entrance of the RLN to the thyroid area differ, the RLN is sought at an area more lateral to its thoracic inlet on the right side, whereas it is sought closer to the paratracheal area on the left side. Extralaryngeal branching is rare in this region, and the RLN is present as a single trunk, and thus, its laryngeal course may be easily visualized. However, it is stated that the dissection in the long segment may increase the risk of nerve injury.^[3, 49] In addition, because the inferior parathyroid vessel runs in a lateral to medial direction,^[51] the risk of parathyroid devascularization may increase. In order to avoid this, after identifying the RLN, the fatty tissue area through which the parathyroid vessel passes is bypassed and the dissection is continued toward the cranial region.^[17] The inferior approach is not appropriate for patients with large substernal goiters and in the presence of non-RLN.^[3, 49]

Superior Approach (Fig. 6)

This approach is also called the medial superior approach and may be recommended for patients with huge goiters or large substernal goiters because releasing the lobe using the inferior or lateral approach may make it difficult to find RLN. The superior approach is also a good option for non-RLN suspected cases or remote-approach endoscopic thyroidectomies such as transoral thyroidectomy, or when RLN is not found with the other approaches.^[49]

The most important anatomical hallmark in this approach is the lower border of the cricopharyngeal muscle, and under this muscle, RLN enters to the larynx. In all these cases, the position of the RLN is fixed and does not change. After the upper pole of the thyroid is released, the pole is pulled forward and laterally. With a careful dissection, the cricothyroid and cricopharyngeal muscles are found, and the lower part of the cricopharyngeal muscle is reached to reveal the laryngeal entry of the RLN. Subsequently, the Berry ligament is cut step by step medially from the RLN, and the lobe is gently retracted toward the lateral aspect and is separated from the proximal section of the RLN and the trachea.

The cervical thyroidal segment, which was previously dissected from the strap muscles or dissected just at this stage of the surgery, can be moved circularly to the left and to

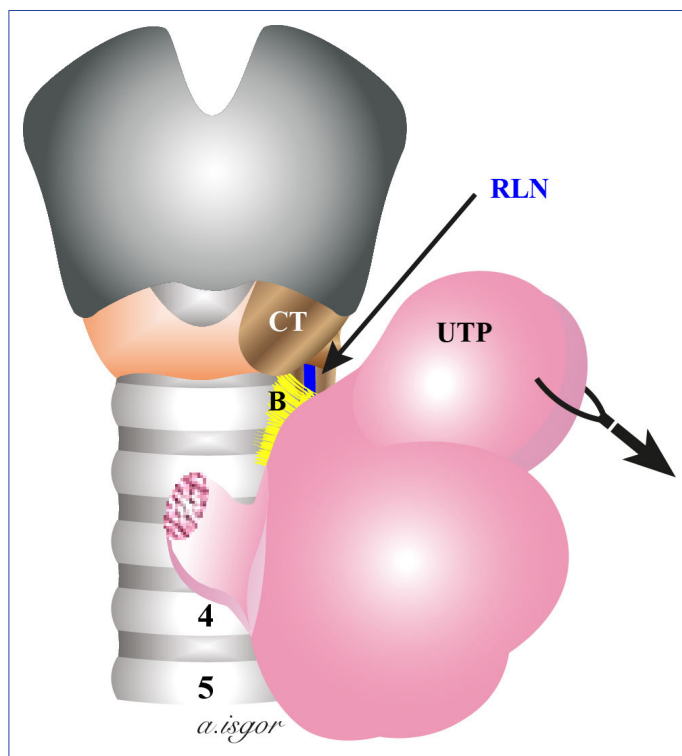


Figure 6. The superior approach to the recurrent laryngeal nerve
RLN: Recurrent laryngeal nerve; UTP: Upper pole of the thyroid; B: Berry's ligament; CT: Cricothyroid muscle.

the right, and by that, the enlarged lower pole and the substernal fragment, if present, can be delivered without overstretching the nerve.^[3] However, this approach also has disadvantages. Minor bleeding that may occur during dissection in the Berry ligament region can mask the field of view. The RLN can also enter the larynx in several branches, and distinguishing thin branches can be difficult.^[17] However, it should not be forgotten that there is a high risk of tension-related neuropraxic trauma because the RLN is fairly fixed in this area.^[49]

Medial Approach (Fig. 3a)

This approach is preferred for patients with substernal or enlarged retropharyngeal goiters.^[15, 49] In this method, the isthmus is first divided, and then the isthmus and medial part of the lobe are dissected away from the trachea to reveal the anterolateral part of the trachea. At this stage, visual identification of the cricothyroid muscle fascia and dissection between the medial part of the superior thyroid pole and cricothyroid muscle fascia may provide ease at the later stages. The fibers between the trachea and the thyroid, and the Berry ligament fibers are gradually divided to the cranial direction by starting from the inferior portion of the second tracheal ring which is already laterally revealed or from 3 mm medial to the lateral aspect of the third tracheal ring,^[54] allowing the RLN to enter the field of view from the medial aspect of the thyroid and the lateral aspect of the trachea.^[15, 49] The later stages are similar to those of the superior approach.

If the RLN is displaced posterior to the trachea, it may not be detected with this approach. In this case, the upper pole is dissected, and the upper pole and thyroid are pulled in the lateral direction; the RLN can be found under the cricopharyngeal muscle where it enters into the trachea as observed in the superior approach. The remaining connections of the Berry ligament are cut after the nerve is located at this point.^[15]

Intraoperative Neuromonitoring in Thyroidectomy

The preservation of the anatomical integrity of the RLN does not indicate that its function is also preserved. IONM is a tool for the functional assessment and identification of RLN, and so this method is an addition to visually identifying RLN, which is the gold standard.^[48] The use of IONM in thyroidectomies has increased in recent years. Currently, IONM with the application of an endotracheal tube containing a surface electrode has become the standardized non-invasive method. This method is based on the electromyographic (EMG) determination of the contraction of the thyroarytenoid muscle, the main adductor of the vo-

cal cord, via the stimulation of the RLN.^[48] The standards of IONM were defined by the Intraoperative Neural Monitoring Study Group (IONMSG).^[48, 55] The best outcome from IONM is achieved by applying it according to the defined standards (Table 3). The most sensitive test that predicts postoperative vocal cord function is the glottis response achieved by the vagus nerve stimulation at the end of the operation (V2).^[48]

The Contribution of IONM to the Protection of RLN (Table 4)

Visual Identification of the RLN

Identifying the RLN may not always be easy, and the nerve may not be visible.^[56] Many studies have shown that IONM has made a significant contribution to the detection of the RLN. Wojtczak et al.^[57] reported that 46% of RLNs could be identified, and total thyroidectomy was performed in 48% of the cases in 2011 before using IONM. With the introduction of IONM in 2012, the detection rate of RLN significantly increased to 87% in 2012, 91% in 2013 and 2014 ($p < 0.0001$) even during surgeries performed without using IONM. The prevalence of RLN injuries significantly decreased to 6.8%, 3.61%, 2.65%, and 1.45% in the 4 years since 2011 ($p < 0.05$). The total thyroidectomy rate reached to 100% in 2014 ($p < 0.0001$).^[57]

After using IONM in the same center, the detection rate of RLN using IONM reached 92% in 2012, 95% in 2013, and 99% in 2014.^[58] In a center where RLN was routinely searched since 1995, the visual detection rate of RLN has been 93.2%, and after using standard IONM, the rate has reached to 100%.^[59] IONM may facilitate safer dissection^[57, 59] by making the projection of the nerve visible, and by mapping RLN in cases where it cannot be observed previously.

Table 3. Standard stages of RLN monitorization during intraoperative nerve monitorization

Stage	Symbol	Procedure
I	L1	Preoperative examination of the vocal cord
II	V1	Stimulation of the ipsilateral vagus before exploration of the RLN
III	R1	Stimulation of the RLN at its first detection
IV	R2	Stimulation of the RLN after completion of dissection at the most proximal point of its exposure
V	V2	Stimulation of the vagus after achievement of hemostatic control
VI	L2	Postoperative vocal cord examination

RLN: Recurrent laryngeal nerve.

The Contribution of IONM to the Determination of Anatomical Variations of the RLN

Extralaryngeal Branching of the RLN: This common and potentially asymmetric feature is an important anatomical variation that increases the risk of RLN paralysis.^[7-9, 43, 60] IONM significantly increases the detection rate of extralaryngeal branches. Anuwong et al.^[59] reported the incidence of branching as 21.6%, with visual identification of the RLN at 43.7% with standard intermittent IONM and 46% with continuous vagus IONM. IONM also facilitates the determination of functions of the branches. IONM studies have shown that the anterior branch of the RLN always has motor function, whereas the posterior branch also has motor function in 1.14% to 28.2% of cases.^[61-64] The highest rate (28.2%) was reported by Cho et al.,^[63] but with a lower branching rate (14.5%). For this reason, motor function rate may be overestimated. Although the reported rates for RLN branching and functions are different, it is important to evaluate all branches of the RLN with functional IONM and to protect all branches with motor function.

Non-Recurrent Laryngeal Nerve: The presence of a non-RLN is an anomaly that increases the risk of VCP. An incidence rate below 0.51% has been reported in cases where IONM was not used.^[65-67] The incidence of non-RLN was higher (0.6%–2.7%) in the IONM applied series. The stimulation of the vagus nerve with IONM, particularly before RLN is sought, contributes to the early detection and protection of non-RLN if present.^[68-71]

Variation in the course of the RLN: A substernal goiter or recurrent goiter may cause the course of RLN change. This has been reported in 80% of cases with recurrent goiter, whereas in 57% of the cases, the RLN runs inside the scar tissue.^[72] Even in experienced centers, the incidence of visualizing RLN in secondary interventions was reported to be 44.4% in the non-IONM group and 91.6% in the IONM

Table 4. The contribution of intraoperative nerve monitorization to the preservation of the RLN and EBSLN

Visual identification of the RLN
Determination of anatomical variations of the RLN
Extralaryngeal branching of the RLN
Non-recurrent laryngeal nerve
Variation in the course of the RLN
Intraoperative detection of RLN injury
Prevention of bilateral vocal cord paralysis
Preservation of the nerve in patients with preoperative vocal cord paralysis
Detection, confirmation, and preservation of the EBSLN, and dissection of the upper pole

EBSLN: External branch of the superior laryngeal nerve; RLN: Recurrent laryngeal nerve.

applied group.^[73] It has also been reported that in 20% of cases with recurrent goiter, the RLN was initially identified with IONM and was later made visible.^[73] Salari et al.^[74] have suggested that IONM is an important contributor to the detection and preservation of the RLN localized in its inferior position in cases with recurrent thyroid cancers and that the rate of VCP can be minimized in most cases. These aforementioned findings demonstrate that IONM provides significant contributions to distinguishing whether or not a tubular structure in scar tissue is RLN, thus facilitating the visual identification of the RLN.

Intraoperative Recognition of RLN Injuries

In approximately 90% of RLN injuries, the nerve is anatomically intact and a visible injury is detected in 7% to 15% of cases.^[75] However, RLN injuries can be determined in 100% of the cases with standard IONM.^[59] In a large series related to the detection of 6093 RLNs using IONM, RLN injuries were shown to be caused by traction injury in 71%, thermal injury in 17%, compression injury in 4.2%, clamping injury in 4.2%, ligation injury in 1.6%, and aspiration injury in 1.4% and nerve section in 1.4% of the cases. Injuries due to traction (5%), thermal injury (22%), clamping (1.4%), ligation (80%), aspiration (50%), and nerve section (100%) can be visible, whereas injuries due to compression are not visible. In visible injuries, the incidence rate of permanent nerve paralysis was found to be 56%, whereas IONM-revealed permanent nerve paralysis in anatomically intact nerves was found to be in 1.2% of the cases.^[76] One of the most important benefits of IONM is its ability to determine the location of RLN injuries. If RLN injuries are due to a suture, clipping, or squeezing with a band, they can be opened to prevent permanent nerve paralysis. In addition, IONM facilitates detection of the distal part of the transected nerve; if there is more than one branch cut off at the distal end, it also allows determination of the motor branch and an appropriate anastomosis.

Prevention of Bilateral Vocal Cord Paralysis

Bilateral VCP is one of the most serious complications of a thyroidectomy, and only 16% of bilateral RLN injuries can be visualized intraoperatively.^[39] Bilateral VCP can be prevented when IONM detects signal loss on the first side and the surgical strategy is changed or surgery is terminated. If the surgical procedure is continued, then bilateral VCP may develop in 17% of these cases.^[77, 78] Therefore, it can be said that IONM is an important adjunct to prevent bilateral VCP.

IONM in Patients with Preoperative Vocal Cord Paralysis

Preoperative electrophysiological activity was detected in 14% to 50% of patients with VCP.^[79, 80] This finding suggests

that some activity was preserved in the laryngeal muscles, preservation of the RLN sustained the neural tone, and vocal cord atrophy was prevented, maintaining sound quality.^[81] Therefore, RLN should be preserved if a positive EMG signal is detected in patients with benign disease and with preoperative VCP. Despite the detection of invasion in the RLN during the surgery of malignant diseases, if a positive EMG signal with IONM is detected, the preservation of RLN should be attempted with providing macroscopic disease-free surgical site.^[80]

Methods for the Preservation of the External Branch of the Superior Laryngeal Nerve

The EBSLN is another laryngeal nerve that is at risk of injury during a thyroidectomy due to its close association with the upper pole vessels. The actual EBSLN injury rate has been reported to be up to 58%, although its incidence is not known exactly due to difficulties inherent to the intraoperative or postoperative period. The most important reasons for the inability to detect the EBSLN injury are that the symptoms are varied and unclear, and the laryngoscopic examination often fails to identify the EBSLN injury.^[20, 82] Although a standardized method for the preservation of the EBSLN does not exist, 3 methods have been defined during release of the upper pole of the thyroid.

1. Protection of the EBSLN without visual identification:

This method is primarily based on the principle of separately dividing the superior thyroid vessel branches on the capsule. Bellantone et al.^[83] reported that this method was safe in terms of preservation of the EBSLN. Currently, many surgeons use this technique and refrain from visual identification of the EBSLN.

2. Investigation and observation of the EBSLN: This method is based on the principle of attempting to identify the EBSLN within the previously defined sternothyroid–laryngeal triangle. For the first time, Lenquist et al.^[29] suggested that during upper pole dissection, the EBSLN has a visible course in 80% of the cases and should therefore be observed in order to preserve the nerve. However, they emphasized that dissection of the involved muscle may increase the risk of nerve injury due to the presence of the EBSLN between the inferior pharyngeal muscle fibers in approximately 20% of the cases; thus, no dissection should be performed in the muscle.^[29] This proposal is also currently valid in cases where IONM is not used.^[83] However, it is not easy to visually identify and distinguish EBSLN from fibrillar structures resembling nerves even for experienced surgeons.^[84]

3. The detection, verification, and preservation of the EBSLN and upper pole dissection with IONM (Table 4):

This method is based on the observation and functional

evaluation of the EBSLN in the sternothyroid–laryngeal triangle with IONM.^[26, 27, 35]

With the stimulation of the EBSLN with IONM, the function of the nerve is evaluated by observing cricothyroid muscle contractions or twitches, or by getting an electromyographic glottic response through endotracheal tube surface electrodes which is detectable in 70% to 80% of patients.^[2]

The strep muscles are dissected away from the upper pole of the thyroid under the guidance IONM and then retracted laterally. In patients with large goiters or a short neck, one-third of the upper part of the strep muscles can be cut to increase the field of view. In some cases, cutting the sternothyroid muscle may suffice. The upper pole of the thyroid is retracted inferolaterally, and then avascular tissue between the upper pole and the cricothyroid muscle is dissected to expose the sternothyroid–laryngeal triangle.

If a pyramidal lobe obstructs visual identification of the cricothyroid muscle, it should be released without damaging the muscle fibers of the cricothyroid muscle. The structure in the triangle thought to be the EBSLN is stimulated with an electrode, and the glottic response of the vocal cord and/or cricothyroid muscle contraction is observed (if any). In particular, visible contraction of the cricothyroid muscle indicates the presence of the EBSLN. If contraction of the cricothyroid muscle is not visible despite the current delivered from the stimulating electrode, and if the muscle relaxant effect has been eliminated, it can be stated that this structure is not the EBSLN.

When the EBSLN is not visible in the surgical field using a stimulating electrode, the EBSLN is investigated 1 to 2 mm below the entry of the sternothyroid muscle to the thyroid cartilage or on the inferior constrictor muscle coursing parallel to this insertion site. The EBSLN can be visually identified around the point of response trying not to interpose between muscle fibers. If EBSLN cannot be seen, then the EBSLN is mapped using a stimulating electrode in an attempt to reveal its relationship to upper pole vessels. Once the EBSLN is visually identified and/or identified using IONM, the upper pole vessels are separately released from the thyroid capsule and dissected. At this stage, it is recommended to check the released vessels with a stimulating electrode before they are cut. After completion of upper pole dissection, nerve integrity is checked by stimulating the EBSLN from the point proximal to the excision of the superior pole vessels.^[26, 85, 86]

As previously mentioned, the relationship between the upper pole vessels and the EBSLN changes according to the size of the thyroid. In terms of EBSLN injuries during upper pole dissection, in addition to Cernea type 2b which

is in the high-risk group, type 2a is potentially a group at risk. In 2 studies, Uludağ et al. detected Cernea type 1, type 2a, and type 2b in 24% to 31%, 60% to 68%, and 8.5% to 9% of cases, respectively. According to these results, approximately 10% of the EBSLNs are at high-risk, and two-thirds have some risk of nerve injury. Although the EBSLN was seen in 28% to 35% of cases, this rate is reported to increase to 83% to 95% with the use of IONM.^[26, 35, 85] These studies reveal that after the localization of the EBSLN with IONM, the visibility of the nerve increases by 33% to 41%.

However, in nearly 25% of cases, though the EBSLN is functionally detected with IONM, it cannot be seen because it is beneath the muscle. IONM provides significant contributions to both the visual and functional determination of the EBSLN.^[26, 85] Two randomized comparative studies have shown that IONM can reduce the risk of EBSLN injury. These studies, in which the function of the EBSLN was assessed by intraoperative or postoperative EMG of the cricothyroid muscle, demonstrated that the rate of EBSLN injury was significantly reduced from 12% to 25% in thyroidectomized patients without using IONM, to 0%–1.5% when using IONM.^[20, 27]

As mentioned earlier, the most common cause of RLN paralysis is traction injury, and the vast majority of these injuries are transient. However, 60% of EBSLN injuries are due to sectioning of the nerve which can cause permanent RLN paralysis.^[26] These data demonstrate the importance of the contribution of IONM in the preservation of the EBSLN.

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