SURGICAL ANATOMY OF THE RECURRENT LARYNGEAL NERVE: IMPLICATIONS FOR LARYNGEAL REINNERVATION

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Functional laryngeal reinnervation depends upon the precise reinnervation of the laryngeal abductor and adductor muscle groups. While simple end-to-end anastomosis of the recurrent laryngeal nerve (RLN) main trunk results in synkinesis, functional reinnervation can be achieved by selective anastomosis of the abductor and adductor RLN divisions. Few previous studies have examined the intralaryngeal anatomy of the RLN to ascertain the characteristics that may lend themselves to laryngeal reinnervation. Ten human larynges without known laryngeal disorders were obtained from human cadavers for RLN microdissection. The bilateral intralaryngeal RLN branching patterns were determined, and the diameters and lengths of the abductor and adductor divisions were measured. The mean diameters of the abductor and adductor divisions were 0.8 and 0.7 mm, while their mean lengths were 5.7 and 6.1 mm, respectively. The abductor division usually consisted of one branch to the posterior cricoarytenoid muscle; however, in cases in which multiple branches were seen, at least one dominant branch could usually be identified. We conclude that the abductor and adductor divisions of the human RLN can be readily identified by an extralaryngeal approach. Several key landmarks aid in the identification of the branches to individual muscles. These data also indicate the feasibility of selective laryngeal reinnervation in patients who might be candidates for laryngeal transplantation after total laryngectomy.

KEY WORDS — anatomy, larynx, recurrent laryngeal nerve, reinnervation.

INTRODUCTION

The branching pattern of the superior laryngeal nerve and the recurrent laryngeal nerve (RLN) is complex,[1] but there are several reliable features. The abductor branch, destined for the posterior cricoarytenoid (PCA) muscle, is the first motor branch to emerge as the RLN enters the larynx at the cricothyroid articulation. Beyond this first branch, the remaining fibers of the RLN in turn innervate the adductors: the interarytenoid (IA), lateral cricoarytenoid (LCA), and thyroarytenoid (TA) muscles. The nerve segment constituting a branch or branches to the PCA muscle is referred to as the abductor division. The nerve segment immediately distal to the abductor division and destined for the laryngeal adductors constitutes the adductor division. The branching patterns to the various intrinsic laryngeal muscles are variable and can be divided into different subtypes (Fig 1[2]).

Through advances in microsurgical techniques, the abductor and adductor divisions of the RLN can now be individually approached. This ability has allowed the reinnervation of the larynx for both paralysis and spasmodic dysphonia.[3,4] In the dog, wherein the individual divisions may be smaller than 0.5 mm, selective reinnervation of the abductor and adductor divisions has provided normal vocal fold function in the transplanted larynx.[5] The same approach may one day be particularly relevant for transplantation of the human larynx. Functional transplantation will require either pacing of the larynx[6,7] or separate reinnervation of the abductor and adductor divisions of the recipient RLN.

As interest in and the ability to reinnervate the larynx grows, more precise anatomic data regarding the intralaryngeal anatomy of the RLN will become increasingly relevant. In the realm of human laryngeal transplantation, the question of suitability for transplantation can be considered from the point of view not only of tissue typing, but also of reinnervation. More specifically, the ideal donor larynx would have nerve branches that are easily identified, large enough to permit reanastomosis, relatively predictable in location, and singular.

These experiments were undertaken to elucidate the anatomic features of the abductor and adductor divisions of the RLN, particularly with regard to selective reinnervation or denervation. Although many studies have detailed the variability of the extralaryngeal branching pattern of the RLN, relatively few data

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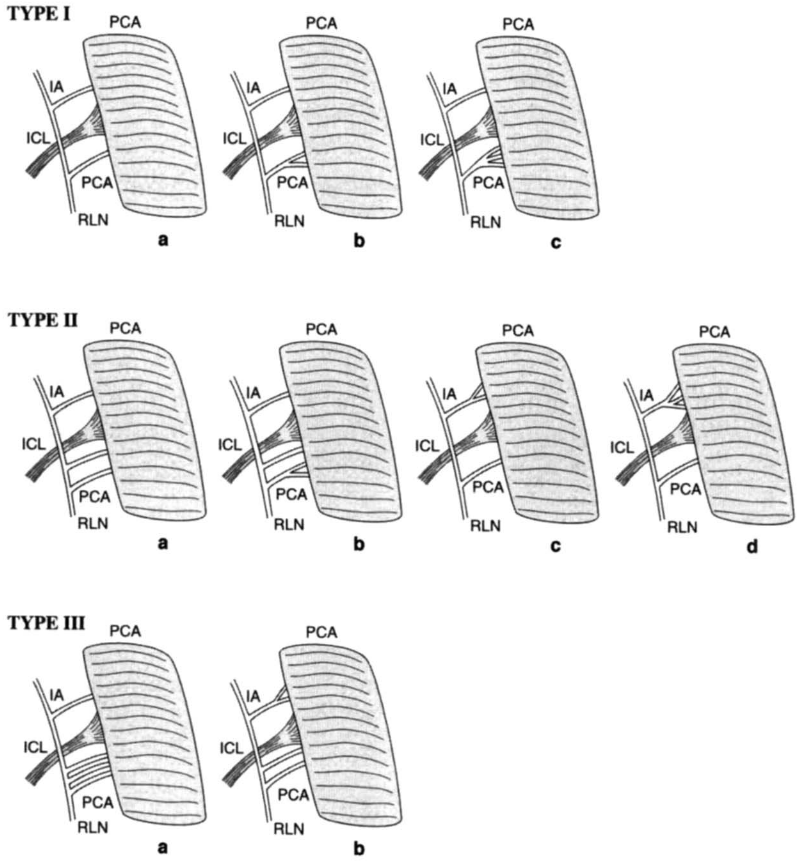

Fig 1. Three major branching patterns of abductor division of recurrent laryngeal nerve (RLN). IA — interarytenoid muscle branch; ICL — inferior cricothyroid ligament; PCA — posterior cricoarytenoid muscle and branch. (Adapted with permission.[2])

exist on the intralaryngeal anatomy of the RLN.[2] These data may become particularly relevant to the laryngeal surgeon as more procedures for selective reinnervation or denervation of the larynx are developed.

MATERIALS AND METHODS

Ten fresh human larynges without known laryngeal disorders were obtained from cadavers. Both sexes were represented, and most subjects were from the geriatric population. Microdissection of the laryngeal nerves was carried out under an operating microscope at 4× power magnification. Both hemilarynges were dissected to give a total of 20 dissections. The main trunk of the RLN and its intralaryngeal branches were identified. The abductor division of the RLN was identified as that nerve segment giving a branch or branches to the PCA muscle. The adductor division of the RLN was identified as that segment of nerve immediately distal to the takeoff of the abductor division and giving branches to the IA, LCA, and TA muscles.

Dissection in the tracheoesophageal groove allowed identification of the RLN. Continued superior dissection allowed identification of the PCA and IA branches. As the RLN coursed superiorly and anteriorly, it could be followed between the thyroid ala and the ipsilateral arytenoid cartilage. Creation of a window in the ipsilateral thyroid ala allowed identification of the LCA and TA branches.

In all cases, the cricoarytenoid articulation was preserved. In no case was it necessary to resect the inferior cornu to follow the course of the RLN, so the cricothyroid articulation was also preserved. After the dissection, the calibers of the abductor and adductor divisions were measured, as was the distance between their lengths. In addition, the branching patterns of the abductor and adductor divisions were noted.

RESULTS

The diameters of the abductor and adductor divisions from the 20 dissections are given in the Table. Also tabulated is the distance between the abductor division and the first branch from the adductor division — that to the IA muscle. The values are given in terms of millimeters. The means are also computed along with the corresponding standard deviations. The various branching patterns of the abductor division are shown in Fig 1. In this series, 4 variations in the abductor division branching pattern were encountered: types Ia, Ic, IIa, and IIb. The relative incidences were 70%, 10%, 10%, and 10% for those types, respectively. Figure 2 demonstrates the type Ia branching pattern, the most common seen in this series. The anterior division can be seen coursing

MEAN DIAMETERS AND LENGTHS OF ABDUCTOR AND ADDUCTOR DIVISIONS OF RECURRENT LARYNGEAL NERVE

		Abductor Division (mm)		*Adductor Division (mm)*	
No.		*Diameter*	*Length*	*Diameter*	*Length*
1	Right	0.6	4	0.9	5
	Left	0.6	3	0.9	6
2	Right	0.5	8	1.0	5
	Left	0.5	8	1.0	5
3	Right	0.5	10	0.5	7
	Left	0.5	7	0.7	8
4	Right	0.5	10	0.5	6
	Left	0.5	6	0.8	10
5	Right	0.5	5	0.5	6
	Left	0.5	5	0.5	8
6	Right	0.3	3	0.5	7
	Left	0.5	3	0.8	7
7	Right	0.5	5	0.6	8
	Left	0.6	7	1.0	8
8	Right	1.0	6	0.8	5
	Left	1.0	5	0.5	4
9	Right	1.0	5	0.8	6
	Left	1.0	5	1.0	3
10	Right	1.0	4	1.0	3
	Left	1.0	5	0.8	4
Mean		0.7	5.7	0.8	6.1
SD		0.2	2.0	0.2	1.8

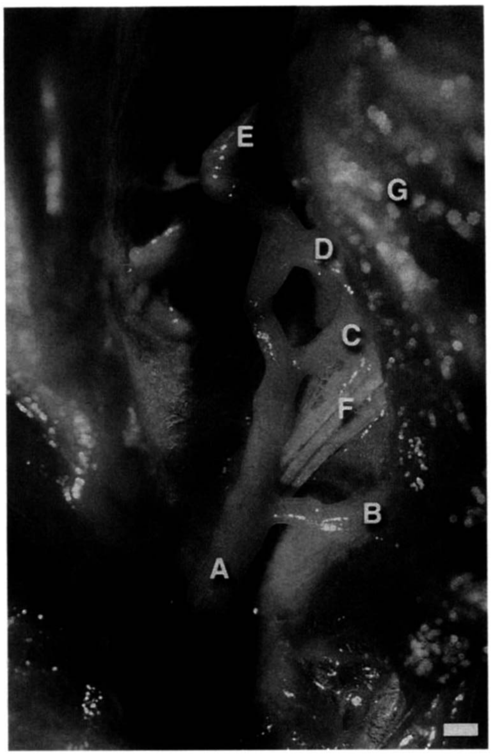

Fig 2. Abductor and adductor divisions of left RLN (A) in typical dissection specimen. Type Ia branching pattern of abductor division is depicted. B — branch to posterior cricoarytenoid muscle; C — branch to interarytenoid muscle; D — branch to lateral cricoarytenoid muscle; E — branch to thyroarytenoid muscle; F — inferior cricothyroid ligament; G — posterior cricoarytenoid muscle and arytenoid cartilage; scale bar — 1 mm.

anteriorly and superiorly between the thyroid ala and the ipsilateral arytenoid cartilage with its overlying PCA muscle. Figure 3 demonstrates the type IIb branching pattern. In Fig 4, the TA and LCA branches of the adductor division can be seen through a window in the thyroid cartilage. This exposure provides adequate visualization of the TA and LCA branches if selective denervation and reinnervation of the TA muscle alone is desired.

In the 3 specimens in which the type Ic, IIa, and IIb branching patterns were seen, both IIa and IIb had a branch that was at least 0.5 mm in diameter. In the type Ic specimen, wherein 3 branches to the PCA muscle were seen, all 3 branches were less than 0.5 mm in diameter. Therefore, 95% of these specimens possessed an abductor branch that would be suitable for neurorrhaphy.

The mean distance from the abductor division to the takeoff of the IA branch was 5.7 mm. The branch to the IA muscle arises at the superior margin of the inferior cricothyroid ligament, while the branches to the PCA muscle arise inferior to this ligament (Figs 2 and 3). The inferior cricothyroid ligament may therefore be a useful landmark in identifying the transition between the abductor and adductor divisions.

DISCUSSION

In 1989, Nguyen et al[2] characterized the branching patterns of the abductor and adductor divisions of the RLN. Three innervation patterns have been described for the PCA muscle. In type I, a single nerve pedicle innervates the PCA muscle, but may subdivide into 2 or 3 smaller branches. In types II and III, 2 and 3 pedicles innervate the PCA muscle, respectively. These may also subdivide into smaller branches. The different branching patterns are displayed in Fig 1. Nguyen et al reported incidences of 66%, 27%, and 7% for types I, II, and III, respectively. In this series, only the type I and II patterns were encountered, specifically, types Ia, Ic, IIa, and IIb.

Only 1 of the 20 dissections demonstrated a type Ic branching pattern, and the largest branch was 0.3 mm. This branching type appears to be rare. In a majority of cases, then, it appears that a single dominant branch or 2 co-dominant branches supply motor innervation to the PCA muscle. End-to-end neurorrhaphy could be accomplished with either of these types and allow reinnervation of the PCA muscle.

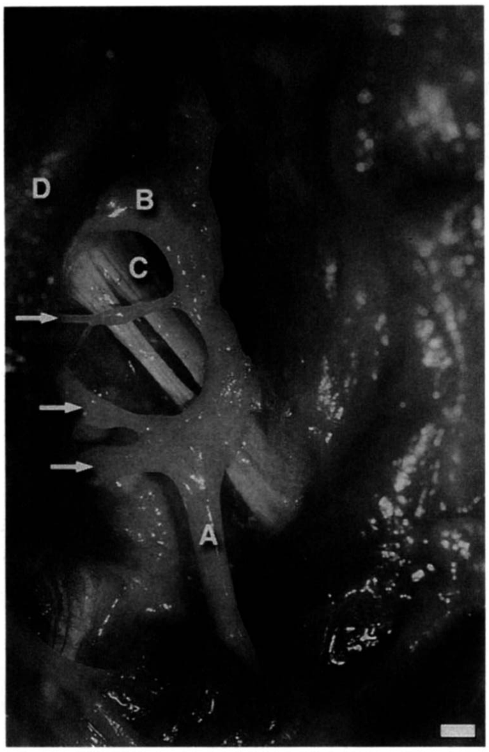

Fig 3. Type IIb branching pattern of abductor division of right RLN (A). Arrows — branches to posterior cricoarytenoid muscle; B — branch to interarytenoid muscle; C — inferior cricothyroid ligament; D — posterior cricoarytenoid muscle and arytenoid cartilage; scale — 1 mm.

The branching pattern to the PCA muscle may also have relevance for patients with abductory spasmodic dysphonia. Those patients with a type II or III branching pattern could be amenable to selective lysis of 1 or 2 branches. This could potentially weaken the PCA muscle, but should not completely denervate it. The human PCA muscle appears to comprise 2 muscle bellies.[8] Although the various branching patterns demonstrate the potential complexity of the motor innervation of the PCA muscle, intraoperative selective stimulation could aid in the identification of which branch corresponds to a given muscle belly.

Identification of the PCA branch or branches can be aided by finding the inferior cricothyroid ligament (Figs 2 and 3). The inferior cricothyroid ligament courses from the medial thyroid ala superiorly to the lateral cricoid ring inferiorly. Those branches destined for the IA muscle can be found above the plane of the ligament, while the PCA branches can be found at or below the plane of this ligament.

Another key landmark in localizing the various branches to the laryngeal muscles is the cricothyroid articulation. In the series of Nguyen et al,[2] the inferior cornu of the thyroid ala was resected and the cricothyroid articulation was disrupted. In this series, dissection of the RLN could be accomplished

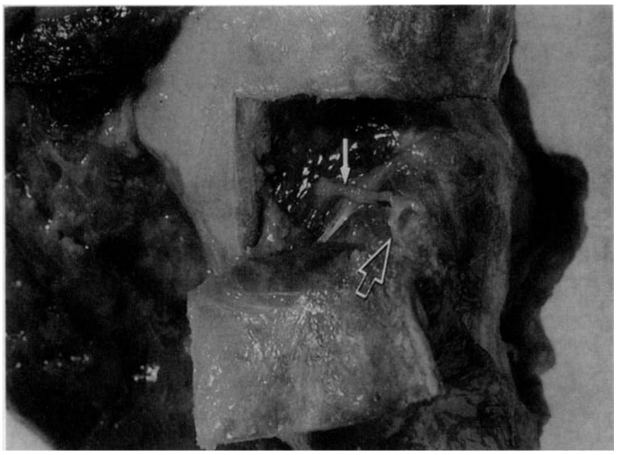

Fig 4. Window in thyroid cartilage demonstrates thyroarytenoid (solid arrow) and lateral cricoarytenoid (open arrow) branches from adductor division of RLN.

without disrupting the cricothyroid articulation. By creating a window in the thyroid ala that is based anterior to the cricothyroid articulation, it is possible to gain access to the TA and LCA divisions without compromising the integrity of the articulation.[3] The articulation can serve as a landmark for the identification of the nerve. The RLN courses anteriorly and superiorly deep to the thyroid ala before giving off the LCA and TA branches. Dissection in the groove between the thyroid ala and the ipsilateral arytenoid cartilage approximately 1 cm above the cricothyroid articulation reveals the nerve at a point immediately proximal to the takeoff of the remaining 2 branches.

In this series, the distance between the PCA branch and the IA branch was measured. This segment of nerve corresponds to a transition between the abductor and adductor divisions of the RLN. Distal to the takeoff of the PCA branches (the abductor division), the RLN comprises adductory fibers destined for the IA, LCA, and TA muscles. An anastomosis here would allow reinnervation of the ipsilateral laryngeal adductor muscles, which would be particularly relevant for human laryngeal transplantation.

Laryngeal transplant surgery can be performed with and without neural reinnervation. Although the only recent human transplant was performed without motor reinnervation,[9] functional reinnervation could provide laryngeal transplant recipients with an oral instead of a tracheal airway. Although pacing of the transplanted larynx may provide an electronic method of laryngeal airway patency,[6,7] functional reinnervation of the transplanted organ could provide comprehensive laryngeal rehabilitation without the attendant complications that implantable artificial devices and materials may entail.

Functional laryngeal reinnervation will rely on precise identification of the abductor and adductor divisions of the RLN and subsequent reanastomosis of these branches to their counterparts in the donor larynx. In the ideal donor larynx, these branches would be easily identified, large enough to permit reanastomosis, predictable in location, and singular. In this study, the abductor and adductor divisions were easily identified through an extralaryngeal approach. In addition, those dissections that revealed multiple branches to the PCA muscle also showed that at least 1 of the branches was usually 0.5 mm or larger, sufficient to permit neurorrhaphy. These findings are consistent with previously reported data.[2] Therefore, most human larynges exhibit neurologic anatomy that would allow physiologic reinnervation following transplantation.

Functional reinnervation has been demonstrated to occur in canine and feline laryngeal models with the hypoglossal, phrenic, and native recurrent laryngeal nerves.[5,10,11] Green et al[12] reported physiologic motion in 3 canine laryngeal transplant recipients. To date, however, there has been more emphasis on sensory reinnervation of the transplanted larynx than on functional motor reinnervation. The importance of laryngeal sensation has been emphasized from the standpoint of both swallowing and airway protection,[9,13] and the feasibility of sensory reinnervation in the transplanted human larynx has already been demonstrated.[9] The predictable branching pattern of the RLN, however, with all adductors arising from a single nerve branch, makes selective reinnervation possible. There is little disadvantage to reinnervating the larynx in transplantation. The risk of synkinesis is eliminated by reinnervating the abductor and adductor divisions individually.

The average lengths of the abductor and adductor divisions, 5.4 and 5.6 mm, respectively, should allow a nerve pedicle in the transplant recipient sufficient to permit end-to-end anastomosis with the donor larynx. This may prove important to those patients who undergo total laryngectomy for cancer. Modifications to the method of laryngectomy, except in cases in which tumor encases the abductor and adductor divisions, could be made that preserve RLN branches for later reinnervation following laryngeal transplantation.

Because of the risk of tumor recurrence from immunosuppression, patients undergoing total laryngectomy for cancer would undergo delayed transplantation after a recurrence surveillance period of several years. Previous research has sought to define methods of nerve banking that preserve the abductor and adductor RLN divisions for future reinnervation. Preservation of the RLN through implantation in a muscle pocket or neurorrhaphy to the ansa cervicalis has allowed functional reinnervation in the canine model.[14] In the case of non-neoplastic indications for laryngeal transplantation, simultaneous laryngectomy and transplantation would allow for immediate reinnervation of nerve branches, obviating the need for nerve banking and allowing immediate reconstruction in the laryngectomy patient.

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