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ORIGINAL ARTICLE

Selective laryngeal reinnervation: can rerouting of the thyrohyoid nerve simplify the procedure by avoiding the use of a nerve graft?

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Abstract

Purpose The objective of this study was to record the descriptive and metric anatomical characteristics of the thyrohyoid nerve with the aim of rerouting it in a selective laryngeal reinnervation procedure.

Methods An anatomical study was performed on ten formalin-embalmed cadavers. The origin of the thyrohyoid nerve and the superior root of the *ansa cervicalis*, the location of the thyrohyoid nerve ending in the thyrohyoid muscle, and the recurrent laryngeal nerve were established. Then, a rerouting of the thyrohyoid nerve was performed. We measured the length of thyrohyoid nerve, the distance between the thyrohyoid nerve ending and the recurrent laryngeal nerve at the horizontal level of the cricothyroid joint before and after the rerouting, and the distance between the origin of the thyrohyoid nerve and the superior root of the *ansa cervicalis*.

Results The thyrohyoid nerve was identified on both sides in all the cases. The average length of the thyrohyoid nerve was 27 mm. The end of the thyrohyoid nerve was found in 100% of the cases at the upper outer quarter of the thyrohyoid muscle. After the rerouting, an average reduction of 30% of the distance between the end of the thyroid nerve and the recurrent laryngeal nerve at the horizontal level of the cricothyroid joint was measured.

Conclusion The rerouting of the thyrohyoid nerve provided a reduction in the length of the nerve graft in laryngeal reinnervation. Moreover, the constancy of the thyrohyoid nerve and its characteristics make it a valuable anatomical base for laryngeal reinnervation and laryngeal innervated allotransplantation.

Keywords Thyrohyoid nerve · Laryngeal reinnervation · Vocal fold · Infrahyoid muscles · Recurrent laryngeal nerve

Introduction

The thyrohyoid nerve is a collateral ramus of the hypoglossal nerve (XII) for the thyrohyoid muscle. It comes from the cervical part of the hypoglossal nerve, after its reunion with the *ansa cervicalis*, and reaches the posterolateral side of the thyrohyoid muscle obliquely. These structures contribute to the elevation of the larynx during swallowing [2] and are also known to play an expiratory role [8].

The injuries to the recurrent laryngeal nerve or of the vagus nerve [1] may provide severe laryngeal dysfunction. Nevertheless, immediate nerve stitching is rarely immediately performed because of technical difficulties and delayed diagnosis [23, 24]. In cases of bilateral injury, patients can present with severe inspiratory dyspnea [9, 12] related to a fixed paramedian position of the vocal folds. However, phonation is satisfactorily preserved in most cases [17].

Several surgical options are possible in cases of bilateral vocal fold paralysis. Reference techniques aim at enlarging the glottis, with an unpredictable risk of hoarseness, or of insufficient protective glottic closure. In fact, breathing and vocal quality are always in opposition. The laryngeal reinnervation may contribute to solve this equation [17].

Some authors have observed that the reinnervation was an appropriate procedure to recover the voice and to prevent

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the progressive loss of muscular tone and bulk [7, 25]. The most popular laryngeal non-selective reinnervation technique consists in an end-to-end anastomosis of the *ansa cervicalis* to the recurrent laryngeal nerve [26]. However, some authors have reported significant results using a selective reinnervation procedure, i.e., the reinnervation of one or several muscular groups dedicated to the adduction or to the abduction of the vocal folds [6, 13, 19]. In this case, the inspiratory trigger to the vocal fold abductor muscle (the posterior cricoarytenoid muscle) is achieved using the phrenic nerve [21]. The thyrohyoid nerve or the *ansa cervicalis* are used to perform a neurorrhaphy with the recurrent laryngeal nerve supplying the adductor laryngeal muscles [22]. In fact, the thyrohyoid muscle is the only strap muscle that fires during phonation or swallowing: this muscle has a predominant expiratory function. Thatis why the thyrohyoid nerve is selected in selective laryngeal reinnervations for adductors muscles [20].

The aim of the present anatomical study was to refine the anatomical bases of thyrohyoid nerve rerouting, to establish if this procedure was feasible without the use of a transplant.

Materials and methods

An anatomic study was performed on 10 formalin-embalmed cadavers (5 males and 5 female specimens, mean-age from 75 to 92 year-old at the time of death) at the anatomy laboratory of our Institution. No cervical scar, no sign of previous cervical surgery or trauma was observed. Both sides were systematically approached, so that a total of 20 thyrohyoid nerves were studied.

All the dissections were performed using magnifying glasses (2.5 ×). In a first step, stratigraphic dissection was performed starting with a skin removal and a step-by-step location of the relevant anatomical structures. The sternocleidomastoid region was finally exposed. The deep aspect of the sternocleidomastoid muscle was then released, and the vascular and nervous structures of the area were meticulously dissected, especially the *ansa cervicalis* and the origin of the thyrohyoid nerve. Its ending in the thyrohyoid muscle was observed. Eventually, we found the recurrent laryngeal nerve after a careful thyroidectomy (Fig. 1).

In a second step, the rerouting of the thyrohyoid nerve was performed on both sides. After having cut its end in the thyrohyoid muscle, it was transposed in contact with the ipsilateral recurrent nerve at the level of the cricothyroid joint (Fig. 2). We did not performed a recurrent nerve rerouting because we wanted to mimic the situation in witch

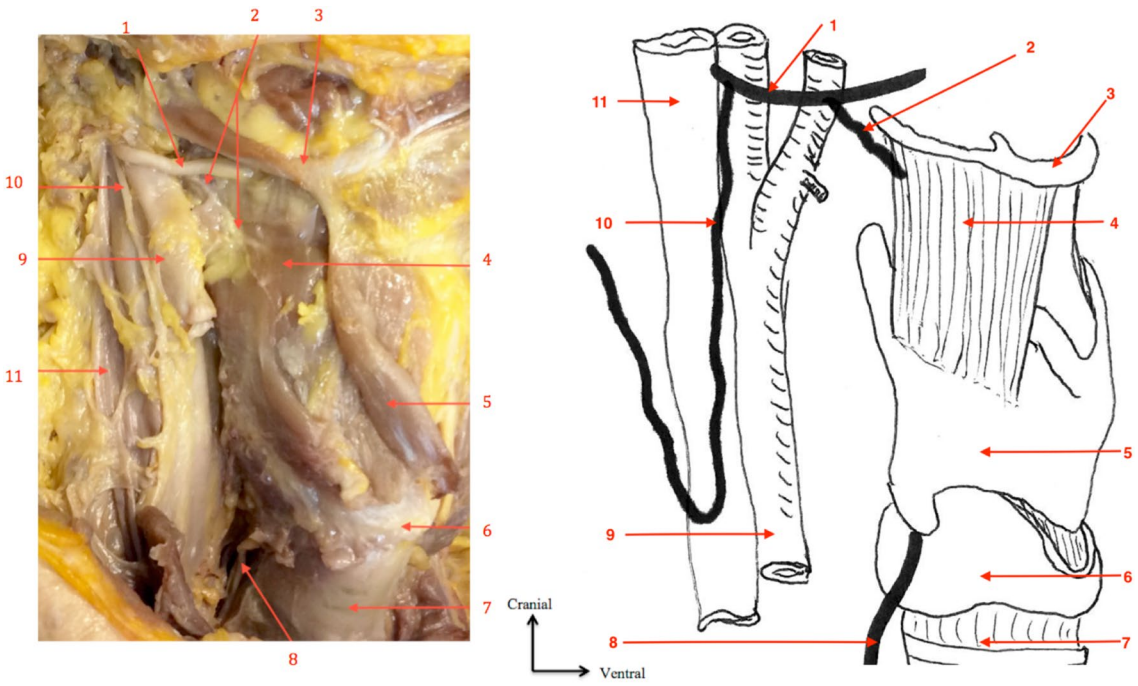

Fig. 1 Exposure of the relevant anatomical structures required in laryngeal reinnervation. 1: hypoglossal nerve, 2: thyroid nerve, 3: hyoid bone, 4: thyrohyoid nerve, 5: thyroid cartilage and omohyoid muscle (photo), 6: cricoid cartilage, 7: trachea, 8: recurrent laryngeal nerve, 9: carotid artery, 10: *ansa cervicalis*, 11: jugular vein

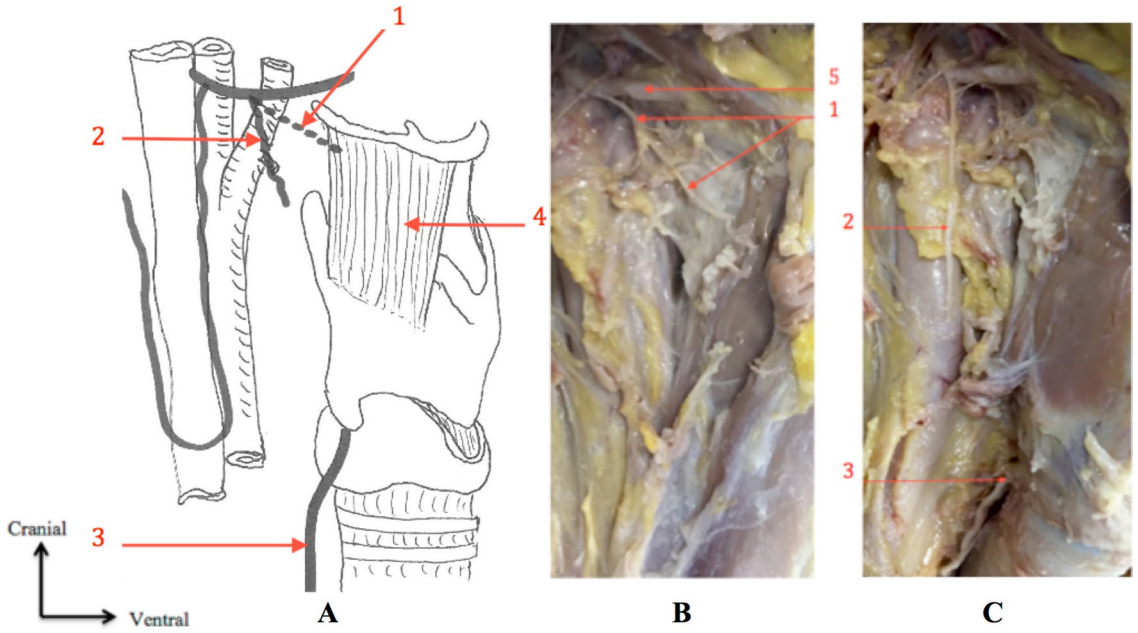

Fig. 2 Surgical technique of TH nerve rerouting [schema **a** and photography **b** (before rerouting), and **c** (after rerouting)]. 1: thyrohyoid nerve in anatomical position, 2: thyrohyoid nerve after rerouting, 3: recurrent laryngeal nerve, 4: thyrohyoid muscle, 5: hypoglossal nerve

recurrent nerve injury occurred (post thyroidectomy in most of the cases) so the recurent nerve was not reroutable.

The following measurements were performed by the main author of this study (FC) using a graduated ruler (Fig. 3): length of the thyrohyoid nerve (*a*-distance), distance between the thyrohyoid nerve ending in the thyrohyoid muscle and the recurrent laryngeal nerve at the horizontal level of the cricothyroid joint before (*b*-distance), and after the rerouting (*c*-distance), and distance between the origin of the thyrohyoid nerve and the superior root of the *ansa cervicalis* (*d*-distance).

Results

The thyrohyoid nerve was identified on both sides in all the dissections, and a total of 20 nerves were studied ($N=20$). In all the cases, the origin of the thyrohyoid nerve was distal to the reunion of the *ansa cervicalis* and the hypoglossal nerve (XII). All the measurements are summarized in Table 1. The mean *d*-distance separating the origin of the thyrohyoid nerve and the *ansa cervicalis* was 17 millimeters (5–23 mm). No significant difference was found between the right and left sides (18 mm on the right side, and 17 mm on the left side). In two cases, the thyrohyoid muscle had a double (1 case) or a triple innervation (1 case). In these cases, a main branch with a larger diameter was observed and considered the main thyrohyoid nerve.

The thyrohyoid nerve then continued downwards, inwards and forwards, above the plane of the thyroid membrane and the extremity of the greater horn of the hyoid bone. The average length of the thyrohyoid nerve (*a*-distance) was 27 mm (15–49 mm). No significant difference was observed between both sides (an average of 26 mm on the right side and 29 mm on the left side). In case of multiple nerves (two cases), all the supernumerary ramus followed the same route, parallel to the main trunk.

The distal extremity of the thyrohyoid nerve was found in 100% of cases at the upper outer quarter of the thyrohyoid muscle. The nerve was used to end into two or three terminal ramus in contact with the muscle.

The average distance between the thyrohyoid nerve distal extremity and the recurrent laryngeal nerve at the level of the cricothyroid joint (*b*-distance) was 55 mm (47–80 mm). No significant difference was found between both sides (average distance of 53 mm on the right side and 56 mm on the left side).

The average distance between the thyrohyoid nerve distal extremity and the recurrent laryngeal nerve at the level of the cricothyroid joint after the rerouting procedure (*c*-distance) was 38 mm (26–60 mm), with an average of 37 mm on the right side and of 40 mm on the left side. No significant differences were found between both sides.

Moreover, an average shortening of the distance between the distal extremities of the thyrohyoid and the recurrent laryngeal nerves of 30% (16–45%) was observed after the rerouting procedure.

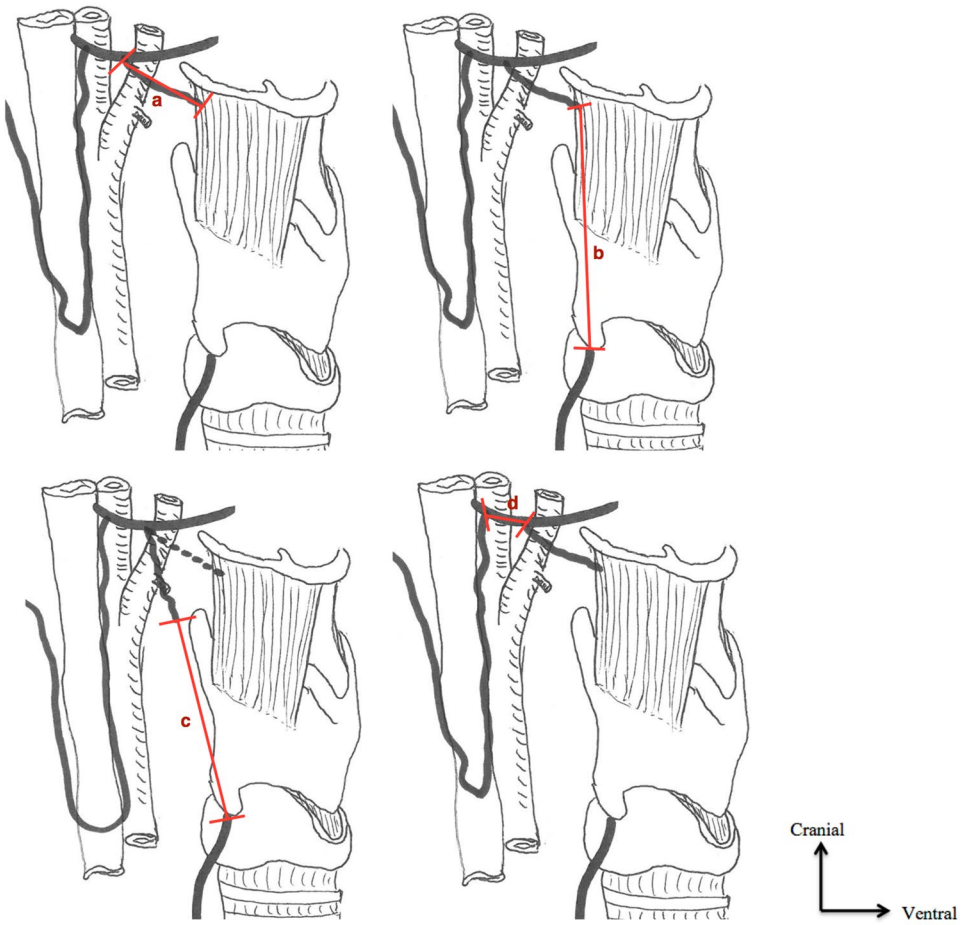

Fig. 3 Measurements performed in the present study: length of the thyrohyoid nerve (*a*-distance), distance between the thyrohyoid nerve ending in the thyrohyoid muscle and the recurrent laryngeal nerve at the horizontal level of the cricothyroid joint before (*b*-distance), and after the rerouting (*c*-distance), and distance between the origin of the thyrohyoid nerve and the superior root of the ansa cervicalis (*d*-distance)

Discussion

In all the cases, the rerouting of the thyrohyoid nerve allowed a significant reduction in the length of the nerve graft required in a selective laryngeal reinnervation, but we were not able to succeed without a free lengthening nerve graft.

Breathing, swallowing, and phonation are the main functions of the larynx. They result from a fine and complex musculo-articular mechanism, under the control of the right and left recurrent laryngeal nerves. A bilateral laryngeal paralysis is in the majority of cases related to an iatrogenic cause (especially total thyroidectomy [1]), or to a tumor infiltration. Dyspnea is often the most symptomatic consequence of vocal fold paralysis in adduction, sometimes requiring a tracheotomy. The aim of the treatment of bilateral laryngeal paralysis is to release the dyspnea using vocal fold lateralization techniques, or by a posterior enlargement of the glottis [12].

Laryngeal reinnervation techniques have been developed since the first non-selective reinnervation described by Frazier in 1924 [11]. Bilateral selective reinnervation techniques with a different supply for adductor and abductor laryngeal muscles are the latest update of the procedure. In fact, selective laryngeal reinnervation is widely used for the rehabilitation of laryngeal paralysis [17]. It combines a different reinnervation of the laryngeal dilator muscles (posterior cricoarytenoid muscles) using a branch of the phrenic nerve, and of the laryngeal adductor muscles via a surgical anastomosis of the thyrohyoid and recurrent laryngeal nerves with a nerve graft [19, 21, 22].

Although the morbidity rate of the unilateral reinnervation procedures using the *ansa cervicalis* is low [10], bilateral selective reinnervation, using both thyrohyoid nerves and thus preserving the *ansa cervicalis*, does not disturb the function of the other infrahyoid muscles, sometimes solicited in very dyspneic patients (in cases of bilateral laryngeal paralysis in adduction most of the time). Moreover, the thyrohyoid muscle is stretched during the expiration phase [5, 8], phonation and deglutition [20]. Unlike sternothyroid and omohyoid muscles that are activated in forced inspiration [8, 10], it appears that the thyrohyoid muscle is activated during the closure of the larynx and swallowing reflex [9]. That is the reason why the thyrohyoid nerve, conveying an electric activity during phonation and expiration, is used in bilateral selective reinnervation of the thyroarytenoid muscles (i.e.,

Table 1 Demographics data and distances in mm

Cadaver body #	Age	Gender	Side	Distance *a*	Distance *b*	Distance *c*	Distance *d*	*b*/*c* (%)[a]
1	88	M	R	25	60	45	20	25
			L	15	80	60	20	25
2	86	F	R	23	54	38	23	30
			L	25	60	37	21	38
3	92	F	R	18	47	26	14	45
			L	21	48	31	16	35
4	75	F	R	31	54	35	16	35
			L	32	55	40	17	27
5	89	F	R	29	51	35	6	31
			L	28	49	38	5	22
6	90	M	R	25	51	37	20	27
			L	35	50	33	15	34
7	91	M	R	31	55	38	21	31
			L	49	54	41	20	24
8	89	M	R	31	52	31	20	40
			L	26	54	40	17	26
9	83	M	R	21	56	47	22	16
			L	28	55	41	18	25
10	87	F	R	26	52	37	19	29
			L	28	55	40	16	27
Average	87	5 M, 5 F	R	26	53	37	18	31
			L	29	56	40	17	28
			All	21	55	38	17	30
Standard Dev	5		All	7	7	7	5	7

[a]Difference between the distance *b* and the distance *c* expressed as a relative percentage to the length *b*

laryngeal adductor muscles). The thyrohyoid nerve is anastomosed with the ipsilateral recurrent nerve (with the use of a nerve graft) since the experimental works of Crumley [6] and Marie et al. [20].

The thyrohyoid nerve is a well-known structure described in all anatomy reference books. It macroscopically emerges from the hypoglossal nerve (XII), but vehicles motor fibers from cervical C1 and C2 spinal nerves. In fact, this nerve is a terminal ramus of the deep cervical plexus [30] for the motor innervation of the thyrohyoid muscle [28].

In our study, we identified the thyrohyoid nerve in 100% of cases, in a constant and reproducible location, whereas the topographic and morphologic variations of the *ansa cervicalis* are numerous [4, 14, 29]. In a few cases reported in the literature, the thyrohyoid nerve directly arises from the anterior root of *ansa cervicalis* [27]; we did not observe this variation in our study on 20 specimens, thus preserving other possible selective laryngeal reinnervation techniques [17] in case of failure.

Based on this anatomical study, the rerouting of the thyrohyoid nerve was feasible in all cases, making it a continued nerve of interest, and quite easily used. These observations confirmed our clinical experience for years. In fact, the rerouting of the thyrohyoid nerve was easy, requiring a simple splitting of the thyrohyoid nerve from the thyrohyoid membrane. No relevant neurovascular structure at this level was observed, potentially providing a risk of morbidity or surgical difficulty. No other anatomical study, to our knowledge, has yet been reported in the literature concerning the rerouting of the thyrohyoid nerve.

In all of our dissections, there was a significant reduction in the distance between the ending of the thyrohyoid nerve and the recurrent laryngeal nerve after the rerouting. This permitted an average gain of 30%. As a consequence, the size of the nervous interposition graft required to connect these two nerves could be reduced, with a theoretical higher rate of success of the nervous growth. In theory, a direct end-to-end anastomosis between the thyrohyoid and the recurrent nerves would be the best solution to recover optimal nervous function, but this was anatomically impossible. In general, an end-to-end nervous anastomosis provides better results than a nerve graft interposition [3].

To date, in the ENT department, more than 50 patients were enrolled in a bilateral selective laryngeal reinnervation procedure with this technique [22, 27] with satisfactory results and motivating a permanent improvement in the surgical technique such as reducing the length of the interposed nerve graft. Other further major indications of

thyrohyoid nerve rerouting are the forthcoming laryngeal innervated allotransplants, a technique associating laryngeal allotransplantation with bilateral selective reinnervation of the transplant from recipient subject rerouted nerves (branch of the phrenic nerve and thyrohyoid nerves) in addition to vascular anastomosis [15, 16, 18].

In conclusion, the present anatomical study investigated the possibility of rerouting the thyrohyoid nerve in bilateral laryngeal selective reinnervation. In this technique, the rerouting of the thyrohyoid nerve allowed a reduction in the length of the nerve graft. Moreover, the constancy of the thyrohyoid nerve and its features made it a valuable anatomical base for the reinnervation of a larynx allotransplant. Nevertheless, the rerouting did not make it possible to manage without the use of a transplant.

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Author contributions Protocol/project development: FC, JPM; data collection or management: FC; data analysis: FC; manuscript writing/editing: FC, FD, JPM, OT.

Compliance with ethical standards

Conflict of interest The authors declare no competing financial interest.

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