Optimal Management of Acute Recurrent Laryngeal Nerve Injury During Thyroidectomy

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Abstract Recurrent laryngeal nerve (RLN) injury is commonly encountered by thyroid surgeons and may carry with it great morbidity. Whether the injury is accidental or due to deliberate resection for oncologic soundness, the surgeon must be prepared to offer the best available treatment to patients, either at the time of injury or early in the recovery process. We review advances in treatment that allow optimal management of an acute RLN injury: ansa cervicalis–RLN reinnervation, in-office unsedated vocal fold injection augmentation, and electromyographic prognostication. The benefits and advantages of each procedure as well as relevant anatomy and techniques are delineated.

Keywords Recurrent laryngeal nerve · Ansa cervicalis · Laryngeal reinnervation · Thyroidectomy · Vocal fold paralysis · Dysphonia

Introduction

Recurrent laryngeal nerve (RLN) injury is a severe consequence of head and neck surgery. It causes dysphonia, dysphagia, and occasionally significant aspiration. In

addition to patient morbidity, injury also results in medicolegal challenges and significant loss of worker productivity at a high cost to both patients and society [1]. Those who operate in the region of the RLN are obligated to strive to protect the nerve and minimize patient morbidity by optimizing management when injury occurs.

This is especially true for thyroid surgeons, where intraoperative preservation of the RLN is a priority. Testament to this is the sheer number of publications produced over many years on the topic [2•]. Consequently, at significant cost, new technology with indeterminate benefit has been developed and used to aid in localization and preservation of the RLN [3, 4]. Despite this, RLN injury is still common. During thyroidectomy, the incidence of permanent postoperative RLN paralysis is 0.3–3 % and is as high as 2–30 % in revision thyroid surgery [2•].

Owing to the increasing rate of surgery for thyroid cancer, it is likely the incidence of iatrogenic RLN injury will be even higher in the coming years. The incidence of thyroid cancer in the USA has been rising since the mid-1990s, and has increased by 5.5 % per year in males and 6.6 % in females since 2004. This growth continues because of both improved detection methods and higher incidence rates in an expanding US population [5]. Approximately 60,220 new cases of thyroid cancer are expected to be diagnosed in the USA in 2013, with 3 in 4 cases occurring in women [6].

One of the areas of highest preoperative concern for thyroidectomy patients is experiencing a postoperative voice change [7]. Poor vocal outcome from an RLN injury is of real concern to physicians and a focal point of medicolegal action. Approximately 46 % of thyroidectomy malpractice cases are related to RLN injury [8]. Over a 24-year period, an estimated \$95 million was paid out in indemnity payments because of thyroidectomy-related

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malpractice claims. The average payment was \$437,852 adjusted for inflation [9].

Considering the above facts, RLN injury will continue to occur with increasing frequency. In contrast to the extensive literature considering the prevention of RLN injury, few studies are devoted to the optimal the management of an acutely injured RLN. To best serve patients and minimize their morbidity, surgeons must be prepared to treat an acutely injured RLN whether it is identified in the operating room or in the early postoperative period. Herein we discuss the optimal management of an acute RLN injury identified either intraoperatively or postoperatively, using ansa cervicalis (ANSA)–RLN reinnervation, in-office vocal fold injection augmentation, and laryngeal electromyography (EMG).

Intraoperative Recognition

Recurrent Laryngeal Nerve Reinnervation

The RLN may be injured inadvertently or purposefully resected to allow oncologic resection of thyroid cancer. When discontinuity of the RLN is recognized intraoperatively, options exist: do nothing and rely on a secondary surgical procedure in the future such as a laryngoplasty, reanastomose the RLN, reconnect the RLN with a nerve graft, or reinnervate the RLN with an alternative nerve source.

Although relying on future surgery for vocal rehabilitation is an option, it is far from optimal, as the patient will suffer the morbidity related to the injury as well as a secondary surgical procedure. In contrast, successful reinnervation of the RLN will obviate the need for a second surgical procedure and demonstrate expertise in cases of inadvertent nerve injury. To decide on the best reparative option, the pathophysiology of RLN reinnervation must be understood as well as the advantages and disadvantages of the different techniques available.

The RLN is a mixed nerve with random positioning of both adductor and abductor axons [10]. When the axons of the nerve are transected, they regenerate in random fashion with some adductor axons innervating abductor muscles and vice versa [11]. This results in synkinetic reinnervation. In 2000, Crumley [12] detailed the clinical characteristics of synkinesis, describing four types of synkinesis to explain various laryngeal phenomena after recovery: type I—an immobile or poorly mobile vocal fold with unaffected voice; type II—spasmodic or twitching vocal folds; type III—hyperadducted vocal folds; type IV—hyperabducted vocal folds with possible aspiration. Only type I was deemed “favorable.” Owing to unfavorable synkinetic reinnervation, RLN–RLN reanastomosis or free

nerve grafts can result in dysfunctional vocal folds, resulting in morbidity requiring intervention to correct the detrimental effects of synkinetic reinnervation [13, 14]. Overall, however, RLN–RLN or free graft anastomosis appears to result in favorable synkinetic reinnervation approximately 70–75 % of the time, although the study series are small [14–17].

Considering this success rate, if both nerve endings are identified and a tension-free anastomosis can be performed, although suboptimal, RLN–RLN reanastomosis is a viable option. In the situation of an inadvertently transected RLN, this reanastomosis should be performed at minimum, as without it the patient will inevitably need further surgery for vocal rehabilitation [14]. If it appears the anastomosis will be under tension, a greater auricular nerve graft can be used. The results are the same as with RLN–RLN, but the graft is in a separate surgical field and results in anesthesia of the ear lobule and surrounding skin. Other options for reinnervation include the neuromuscular pedicle, nerve implantation, and ANSA, hypoglossal, or vagus nerve to RLN anastomosis. Neuromuscular pedicle and nerve implantation do not appear to be as successful as ANSA–RLN reinnervation, and harvesting all or part of the vagus or hypoglossal nerve may result in significant patient morbidity [18•, 19].

The ANSA is an ideal nerve for RLN reinnervation. There is no morbidity related to its sacrifice. During a thyroidectomy, it is close to the surgical field and is rarely injured unless an aggressive neck dissection is being performed. The ANSA is approximately 1 cm from the RLN, so the nerve length needed for this short transposition is minimal (Fig. 1). Because of this, a tension-free anastomosis is nearly always possible. The ANSA has a diameter similar to that of the RLN and can be used for both ipsilateral and contralateral anastomosis [12, 20, 21]. The

Fig. 1 Left recurrent laryngeal nerve (*solid arrow*) and superior root of the ansa cervicalis (*arrowhead*) with loop (*hollow arrow*) and common branch (*dashed arrow*). Note the proximity of the nerves after mobilization prior to transection

ANSA also naturally fires during phonation, and there is increased recruitment with increasing vocal volume [22, 23]. Success of ANSA–RLN reinnervation is attributed to restoration of bulk and tone in glottic musculature resulting in medialization of the vocal fold and correction of arytenoid malposition and muscular atrophy. Owing to the innervation of the adductor and abductor muscles with one type of axon, synkinesis does not occur as with RLN–RLN anastomosis. Additionally, the anatomic structure of the larynx is preserved. This allows subsequent injection augmentation or type 1 laryngoplasty to be performed in the 1–2 % of cases in which failure occurs. One limitation to ANSA–RLN reinnervation is that in elderly patients, reinnervation is not as robust, and they may have increased risk of failure [24•, 25].

Although first described in 1924 by Frazier [26], ANSA–RLN reinnervation had been dormant until Crumley [27] published his original series in 1986. In 1991, he published an update of 20 cases, of which seven and five patients had “excellent” and “normal” voice outcomes, respectively [28]. The study included three patients with preoperative synkinesis, corrected following ANSA–RLN reinnervation. One patient required postoperative injection medialization to improve voice quality, and one patient with a history of multiple prior laryngeal surgical procedures and subglottic stenosis did not show any voice improvement. Vocal fold position, muscle mass, and tension were restored and no synkinesis was seen. A 95 % success rate was reported for ANSA–RLN reinnervation.

In 2008, Lorenz et al. [25] studied a series of 46 patients who underwent delayed ANSA–RLN anastomosis with a median time to repair of 12 months. Thirty-seven of 38 patients who were followed up for a minimum of 3 months showed evidence of reinnervation and did not need a secondary procedure, a 97 % success rate. All patients who underwent preoperative and postoperative Consensus Auditory–Perceptual Evaluation of Voice (CAPE-V) and laryngovideostroboscopy showed improvement in voice severity, roughness, breathiness, and strain as well as glottic closure, straightened vocal fold edge, and decreased supraglottic effort.

Wang et al. [18••] performed a case–control study looking at the long-term efficacy of delayed ANSA–RLN reinnervation following thyroid cancer surgery. In a large series, 237 Chinese patients underwent ANSA–RLN reinnervation 6–42 months after surgery. The patients were followed for a mean of 5 years and matched with 237 controls. On laryngovideostroboscopy, 92.4 % of the patients had straight vocal fold edges, median or near-median vocal fold position, and symmetric and regular vocal fold vibration, with complete glottic closure during phonation. Significant improvement was demonstrated using the GRBAS scale. Maximum phonation time, jitter, shimmer, and noise to harmonic ratio

were equivalent to those of controls. Reinnervation was confirmed on laryngeal EMG by the presence of significantly increased recruitment of motor unit action potentials in the thyroarytenoid muscle with phonation. Only four of 237 patients failed to restore adequate phonation. Two failures were due to technical reasons; one anastomosis was performed under significant tension and the other was avulsed during evacuation of a hematoma. Only two failures were due to inadequate reinnervation. Essentially, 98–99 % of the ANSA–RLN reinnervations were successful.

Aynechi et al. [21] systematically reviewed the outcomes from 14 case series of laryngeal reinnervation procedures for unilateral vocal fold paralysis between 1966 and 2009. Owing to the heterogeneity of the available literature and difficulty in analyzing techniques and outcomes, it is difficult to extrapolate direct data comparing different techniques. However, an improvement in acoustic, perceptive, EMG, and glottic gap analysis was seen with all reinnervation techniques. ANSA–RLN anastomosis was the commonest reinnervation technique, performed in 43.5 % of procedures following thyroidectomy. It resulted in statistically significant better glottal closure than the other techniques, with a mean postsurgical time to reinnervation of 4.5 months.

It is clear that ANSA–RLN reinnervation works well when performed in a delayed fashion, with results similar to those of a type 1 laryngoplasty [24•]. Either can be performed for treatment of a chronic injury, but only ANSA–RLN reinnervation is available during surgery at the time of an acute injury. It is in the acute injury scenario when ANSA–RLN reinnervation is most powerful, especially in the face of a preoperative vocal fold paralysis or after RLN resection for cancer. The success of acute reinnervation is as good as that of delayed anastomosis, and the presence of malignancy does not affect the outcome of reinnervation.

Sanuki et al. [29] reported a series of 12 patients with thyroid cancer who experienced either nerve sacrifice or injury intraoperatively. Six patients had preoperative vocal fold paralysis and six underwent intraoperative sacrifice. Reconstruction was performed immediately using direct anastomosis ($n = 1$), free nerve graft ($n = 9$), or ANSA–RLN reinnervation ($n = 2$). Postoperative vocal perceptual analysis scores, aerodynamic function, and laryngovideostroboscopy findings were improved in all groups compared with values obtained before surgery from patients with preoperative vocal fold paralysis.

More detailed and extensive work on acute RLN reinnervation has been performed in Japan by Miyauchi et al. [20]. They retrospectively reviewed a series of patients who had undergone immediate reconstruction of the RLN after thyroid cancer resection. Thirty-four patients underwent reinnervation procedures, of which 19 were ANSA–RLN reinnervation [direct anastomosis ($n = 5$), free nerve

graft ($n = 8$), vagus–RLN anastomosis ($n = 2$), and ANSA–RLN reinnervation ($n = 19$)]. Recovery of voice began between 2 and 5 months postoperatively, with maximum improvement at 12 months. On laryngoscopy, patients had a minimal glottal gap, with good bulk and tension of the vocal folds. Maximum phonation time was not significantly different from that in the 34 normal controls. A most important insight from Miyauchi et al. was that once they began using ANSA–RLN reinnervation, it became their preferred method of reconstruction. This was due to consistent access to the nerve, the available length of the ANSA for a tension-free anastomosis, no morbidity related to the graft harvest, and the ease of the procedure performed primarily with surgical loupes. Once they had adopting ANSA–RLN reinnervation, they had a statistically significant increase in their anastomosis rate from 18 to 82 %, further proving the utility of this method.

In 2009, Miyauchi et al. [30] reviewed 88 cases of RLN reconstruction after nerve sacrifice during thyroid surgery. Sixty-five patients had reconstruction with ANSA–RLN anastomosis. Patients' voices began to improve within 3–5 months. Laryngoscopy revealed midline vocal folds with good tension and tone as well as a minimal glottal gap. Recovery of phonatory function was assessed quantitatively with the phonation efficiency index (PEI), a ratio of maximum phonation time to vital capacity. Eighty-seven percent of patients had a PEI similar to that of normal subjects at 1 year. The validity of the PEI, which Miyauchi et al. constructed, is unclear. Of note, 47 % of anastomoses were performed intralaryngeally to the distal end of the RLN. This is critical because RLN injury or cancer invasion often occurs close to the cricothyroid joint. This leaves only a small section of exposed distal nerve, making performing an anastomosis technically difficult. In these cases, incision of the inferior constrictor with removal of the inferior horn of the thyroid cartilage exposes extra length of usually undisturbed RLN. This extra length of intralaryngeal nerve allows a tension-free anastomosis to be performed despite a distal nerve injury.

Operative Technique and Anatomy

Anatomy

To successfully perform an ANSA–RLN reinnervation, a surgeon must be mentally prepared, know the relevant anatomy, and understand the surgical technique. The ANSA is formed from two nerve roots that join inferiorly to form a loop. The superior root, or the descendens hypoglossi, receives branches of communication from C1 and C2 and comes off cranial nerve XII, whereas the inferior root arises from the junction of the cervical rami, usually C2–C4 [31]. The superior root leaves cranial nerve XII just

inferior to the origin of the occipital artery and descends obliquely along the carotid artery. The inferior root passes posterolaterally to the internal jugular vein 57–81 % of the time, otherwise passing medially. The two branches join as a loop deep to the superior belly of the omohyoid, at the point where the muscle crosses the great vessels. The loop is in this location 64 % of the time, although it may rest anywhere between the occipital artery and 4 cm above the sternum. Following formation of the loop, the nerve branches innervate the sternohyoid and sternothyroid. The common ANSA branch is approximately 4.3 cm long and 0.9 mm wide, making it a good anatomic fit in length and diameter for anastomosis to the RLN [32]. In the past, the nerve branch to the sternothyroid or common branch was used with good surgical outcome [12]. However, the ascending fibers or descending fibers of the superior root are slightly easier to mobilize and are commonly used for ANSA–RLN reinnervation as well. An elegant study of the ANSA using Sudan black to stain the axons noted a greater number of motor axons traveling cranially versus caudally in the superior root of the ANSA [31]. Considering this, the best nerve to use for reinnervation may be the ascending aspect of the superior root.

ANSA–RLN Reinnervation Procedure

Variations of the procedure have been described; however, the most important factor is exposure of the relevant nerve endings and achieving a tension-free anastomosis. To identify the ANSA, the superior belly of the omohyoid can be found crossing beneath the sternocleidomastoid muscle. The omohyoid is then dissected from surrounding fascia and retracted superiorly where it overlies the internal jugular vein. The loop of the ANSA is generally just beneath the muscle. The common branch to the strap muscles is then identified and dissected distally. A branch similar in thickness to the ANSA should be chosen, transected, and mobilized toward the RLN. Alternatively, the superior root of the ANSA can be dissected cranially. The root is then transected far enough cranially so the ascending aspect of the ANSA can be mobilized and sutured to the RLN without tension. On occasion, the RLN is injured or sacrificed at the cricothyroid joint; as such, a distal stump is not readily available for anastomosis. In this case, the inferior constrictor muscle can be divided and the inferior horn of the thyroid cartilage removed to identify an additional 0.5–1 cm of intralaryngeal RLN [18•, 30]. When the ipsilateral ANSA has been resected or its viability is in question, a contralateral ANSA anastomosis can be performed by routing the nerves anterior to the thyroid cartilage [33•]. Nerve edges are trimmed sharply and epineurium is exposed and gently peeled back to allow separation and identification of fascicles. Three to four 9.0

nylon sutures are used to approximate the nerve ends. Care should be taken to suture only the epineurium and protect the fascicles from injury. The sutures should approximate the nerve endings so they are not strangulated or do not overlap. Performing the anastomosis with either surgical loupes or an operating microscope does not appear to affect vocal outcome [20].

Temporary Injection Augmentation

As it takes 3–5 months for the reinnervation to significantly improve the voice, a temporary bridging injection augmentation of the paralyzed vocal fold should be performed [20]. This can be conducted in the operating room if the contralateral RLN was not placed at risk during the surgery and is known to be functioning normally. If the status of the contralateral nerve is unknown, the patient should be awoken and adequate motion of the corresponding vocal fold confirmed. The injection is then performed while the patient is unsedated, under topical anesthesia at any time when the patient is mentally and physically ready. Typically, the injection is performed 1–2 weeks following surgery, but can be performed as early as the first postoperative day (see later for injection details).

The combination of ANSA–RLN reinnervation and an early vocal fold injection results in a patient having only 1–2 weeks of morbidity from their vocal fold paralysis, as long as the reinnervation is successful, as is expected 97–99 % of the time. This algorithm for treatment relegates one of the most feared complications of thyroid surgery to a minimally morbid treatable circumstance.

Postoperative Recognition

Injection Augmentation

If a patient has symptomatic vocal fold paralysis recognized in the early postoperative period, the “watching and waiting” approach is no longer the preferred method of treatment. Injection augmentation of the vocal fold can be performed in the office soon after thyroid surgery, under topical anesthesia with minimal patient morbidity or discomfort and with a low complication rate [34, 35•]. As evidence of its utility, the rate of in-office injections has eclipsed that of those performed in the operating room [35•]. Additional benefit is realized by the decreased cost of an injection performed in the office compared with the operating room [36].

There are many options for temporary injectable materials [37•]. The choice is usually based on duration of the material’s persistence, as well as the surgeon’s familiarity

and success with it. The authors prefer micronized AlloDerm as it causes minimal inflammation and is very forgiving. Its drawback is that it must be reconstituted prior to use. There are also multiple approaches to performing the injection: peroral, transcutaneous, or transnasal [38•]. The authors prefer the thyrohyoid approach as described by Achkar et al. [39•] and Amin [40] with a needle bending modification. The benefit of most injections lasts 3–4 months and allows the patient good phonatory function while reinnervation occurs. As the injected material resorbs, vocal fold bulk, position, and phonatory function will be maintained by the newly innervating axons, whether arising from a reinnervated RLN or an injured but intact RLN.

The benefits of early vocal fold injection go beyond that of just “positioning” the vocal fold while reinnervation occurs. It appears that early vocal fold injection decreases patients’ need for a secondary laryngoplasty. Friedman et al. [41•] retrospectively reviewed 35 patients with postsurgical or idiopathic vocal fold paralysis into whom hyaluronic acid gel has been injected within 1 year of injury. Twenty of thirty-two patients (62.5 %) with injection medialization performed less than 6 months following injury maintained adequate voice outcomes, whereas all three patients with injection later than 6 months after injury needed further reconstruction. Yung et al. [42•] retrospectively reviewed 54 patients with vocal fold paralysis and also found that patients who underwent temporary injection medialization were less likely to undergo permanent medialization laryngoplasty (26 %) as compared with patients who were conservatively managed (65 %).

The decreased need for intervention after early vocal fold injection is likely secondary to more rapid and robust reinnervation. Experiments involving reinnervation of the facial nerve demonstrate that periodic stimulation of an animal’s whiskers will increase the rate and function of facial nerve regeneration [43•, 44]. This concept can be applied to RLN reinnervation. If the vocal folds are brought into apposition with an injection augmentation, the paralyzed vocal fold will receive vibrotactile and afferent nerve stimulation during phonation that it otherwise would not have had if it were lateralized and injection augmentation had not been performed. This stimulation may parallel that of whisker stimulation, hence increasing the rate and robustness of RLN reinnervation. In this vein, voice therapy may be beneficial as an adjunctive treatment, providing patients exercise and mandated vocal fold stimulation be performed throughout the day.

Electromyographic Prognostication

Electromyographic prognostication is an important adjunct in the care of patients in whom RLN paralysis is

recognized postoperatively. Two to 6 months after injury, EMG helps predict which patients may regain vocal fold function and which are unlikely to recover. Temporary augmentation should be offered to those awaiting recovery, whereas early laryngoplasty for permanent medialization would benefit those with minimal chance of return of vocal fold function. Thus, EMG can be used to guide treatment, limit unnecessary temporary procedures, and speed the time to full rehabilitation.

Munin et al. [45] have investigated the role of EMG in evaluating synkinesis and prognosticating recovery. In their original study performed in 2003, they retrospectively evaluated 31 patients with vocal fold paralysis for whom EMG was performed less than 6 months after injury. An excellent prognosis was predicted by EMG findings of normal motor unit recruitment and configuration with a full or slightly decreased interference pattern and no fibrillation potentials. A poor prognosis was determined by diminished motor unit recruitment, repetitive motor unit firing, and a decreased interference pattern with spontaneous activity. A fair prognosis showed moderately decreased motor unit recruitment, diminished interference pattern, and normal or polyphasic motor unit potentials. The positive predictive value for recovery of vocal fold motion was 66.7 %, as four of six patients prognosticated as excellent showed recovery. Only in five of 25 patients with a poor prognosis was there resolution, giving a negative predictive value of 80 %.

In 2010 the same group proposed an EMG protocol for determination of adductor synkinesis to combine with their previous criteria. Forty-six patients with vocal fold paralysis and available EMG data were retrospectively reviewed. Synkinesis was determined by the ratio between motor unit potentials in the thyroarytenoid muscle during adductor and abductor tasks. Synkinesis was defined as a ratio of 0.65 or greater. For patients with good motor unit recruitment who prognostically had potential for excellent recovery using their original EMG criteria, the presence of synkinesis downgraded them to a poor prognosis. This addition of synkinesis to the protocol improved the negative predictive value of EMG from 53 to 100 %, whereas the positive predictive value was 76 % [46•].

Smith et al. [47] further improved the positive predictive value of EMG by adding quantitative analysis of wave amplitude and turns. Adding this information to the previous criteria improved the positive predictive value to 100 %, whereas the negative predictive value dropped slightly to 89.5 %, with seven of eight correct predictions.

Conclusions

RLN injury after thyroid surgery can cause significant patient morbidity. Surgeons treating this injury should be

aware of the optimal treatment following injury. If it is recognized intraoperatively, using the most current techniques of ANSA–RLN reinnervation and in-office vocal fold injection augmentation will restore the voice within 1–2 weeks of surgery. If RLN injury is recognized postoperatively, early vocal fold injection will decrease the length of disability and the need for a secondary operation, whereas EMG will shorten the waiting time to permanent rehabilitation and minimize the unnecessary use of further temporary procedures. Together, these management techniques decrease patient morbidity, demonstrate surgical and medical expertise, and decrease costs to society associated with lost worker productivity, extra surgical procedures, and medicolegal costs.

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