Nerve-Muscle Pedicle Flap Implantation Combined With Arytenoid Adduction

Eiji Yumoto, MD; Tetsuji Sanuki, MD; Yutaka Toya, MD; Narihiro Kodama; Yoshihiko Kumai, MD

Objectives: To describe a new technique of nerve-muscle pedicle (NMP) flap implantation combined with arytenoid adduction (AA) to treat dysphonia due to unilateral vocal fold paralysis and to examine postoperative vocal function.

Study Design: Retrospective review of clinical records.

Setting: Tertiary academic center.

Patients: Twenty-two consecutive patients underwent NMP flap implantation with AA and were followed up short term over a period of 1 to 6 months (mean, 2.9 months) and long term over a period of 7 to 36 months (mean, 21.4 months).

Interventions: An NMP flap was made using an ansa cervicalis branch and a piece of the sternohyoid muscle. A window was opened in the thyroid ala at the level of the vocal fold. Then, AA was performed and the NMP flap was securely implanted onto the thyroarytenoid muscle through the window under microscopic guidance.

Main Outcome Measures: The maximum phonation time, mean airflow rate, pitch range, and acoustic parameters (jitter, shimmer, and harmonics to noise ratio) were evaluated before surgery and twice after surgery.

Results: All parameters improved significantly after surgery (P < .01). The measurements for maximum phonation time, mean airflow rate, and harmonics to noise ratio were within normal ranges after surgery. Furthermore, the maximum phonation time and jitter were significantly improved after long-term follow-up compared with early postoperative measurements (P < .01 and P < .05, respectively).

Conclusions: Precise harvest of an NMP flap and its placement directly onto the thyroarytenoid muscle combined with AA provided excellent vocal function. The NMP method may have played a certain role in the improvement of postoperative vocal function, although further study with electromyographic examination is required to clarify the innervation status of the thyroarytenoid muscle.


Improvement in breathy dysphonia due to unilateral vocal fold paralysis (UVFP) is usually achieved by implementing various kinds of phonosurgical procedures, including intracordal injection, type I thyroplasty, arytenoid adduction (AA), and combinations thereof. However, some patients do not recover “normal” voices after surgery.1,2 Normal voices can be attained by providing the immobile vocal fold with the median location and the symmetrical bulk and tension of the unaffected vocal fold. Because the phonosurgical procedures offer “static” adjustment of these features, the thyroarytenoid muscle (TA) does not work as the body of the immobile vocal fold, resulting in little contribution to voice production and tuning.

To restore tonus of the immobile vocal fold, Tucker3 described a method of nerve-muscle pedicle (NMP) flap implantation onto the TA muscle through a window in the thyroid ala. May and Beery4 also reported positive effects of NMP implantation onto the lateral cricoarytenoid muscle on breathy dysphonia. However, to our knowledge, no studies, except those noted above, have reported further results regarding the use of the NMP method. Although immediate reconstruction of the severed recurrent laryngeal nerve (RLN) can result in excellent vocal function,5 immediate reconstruction is not feasible in most patients because they usually seek treatment only after the onset of paralysis. We examined the effects of an NMP method in rats and confirmed the effectiveness of the method to reverse or repair atrophic changes in the long-term denervated TA muscle.6,7 We refined the technique of NMP flap implantation onto the TA muscle and have applied this innovative method, together with AA, in the treatment of breathy dysphonia due to UVFP since July 2002. We also refined the original AA method of Isshiki et al.8 The goals of the present study were to describe

Video available online at www.archoto.com

Author Affiliations:
Department of Otolaryngology–Head and Neck Surgery, Graduate School of Medicine, Kumamoto University, Kumamoto, Japan.
Thyroid notch
Cranial side

Figure 1. Location and design of the window in the thyroid ala (58-year-old man, left side). The dotted line indicates the estimated level of the vocal fold.

10-12 mm
5-7 mm
3-5 mm
2 mm

Figure 2. A nerve-muscle pedicle flap, which reached the window without tension in the same patient as in Figure 1. Cartilage is not yet drilled out.

An operative view after completion of arytenoid adduction in the same patient as in Figure 1. The dotted line indicates the estimated level of the vocal fold. The asterisks indicate the silicone shim; arrowheads, the exposed thyroarytenoid muscle.

our refined technique in detail and to report patient data from vocal function tests. The study was approved by the institutional review board of the Graduate School of Medicine, Kumamoto University.

METHODS

PATIENTS

Twenty-four consecutive patients with breathy dysphonia due to UVFP underwent NMP flap implantation together with AA between July 2002 and September 2007 at Kumamoto University Hospital, Kumamoto, Japan. Two patients, however, were excluded. One patient with left vocal fold paralysis underwent total thyroidectomy simultaneously; the next day, she underwent a tracheostomy because of paralysis of the preoperatively mobile right vocal fold. Another patient was not followed up for the requisite time. Therefore, our study included 22 patients who were followed up for more than 6 months.

SURGICAL PROCEDURE

General anesthesia with endotracheal intubation is administered. The patient lies in the supine position with a pillow under the shoulder. Generally, an endotracheal tube with an inner diameter of 6 or 7 mm is used for female or male patients, respectively. The use of a relatively thin tube allows the vocal fold to adduct passively through the anteroinferior pull of the muscular process of the arytenoid cartilage.

An incision is made horizontally from the midline to the anterior margin of the sternocleidomastoid muscle at the level of the inferior one-fourth of the thyroid cartilage. The space anterior to the sternocleidomastoid muscle is opened, exposing the internal jugular vein where the ansa cervicalis (AC) nerve (superior root) and its branch to the omohyoid muscle are identified. The omohyoid muscle is transected, and the AC nerve is followed until it enters the sternohyoid (SH) muscle. Electrical stimulation is applied to confirm the presence of nerve fibers innervating the SH muscle. A relatively thick AC branch to the SH muscle is harvested together with a 3 × 3-mm piece of the muscle at the point of nerve entrance to the muscle to form a NMP flap. The NMP flap is elevated with meticulous care, and the course is reversed cranially so that the NMP flap reaches the midportion of the thyroid ala with no tension. The inferior root of the AC nerve is usually preserved.

Arytenoid adduction is performed according to the method of Ishihiki et al.8 The cricoarytenoid joint is not opened in our technique. Care is taken to preserve the external branch of the superior laryngeal nerve and to avoid injury to the pyriform sinus mucosa. The muscular process is grasped with a pair of Adson forceps to confirm the passive mobility of the arytenoid. This step is necessary to estimate the degree of traction of the muscular process. Two 3-0 nylon threads are then placed through the muscular process and tied for later use.

The location and design of a window in the thyroid ala is shown in Figure 1. The window base is set 2 to 3 mm cranial to the lower edge of the thyroid ala. Diamond-tip drills are used under microscopic control to make a window with the inner perichondrium intact. Figure 2 shows the NMP flap, which reaches the window without tension. After the cartilage in the window is drilled out, the perichondrium is excised with electrocautery, and the TA muscle is carefully exposed as wide as possible to secure contact of the NMP flap with the TA muscle.

The nylon thread tied to the muscular process is introduced to the anterior surface of the thyroid ala medially from the inferior tubercle, with one end through the lower edge of the window and the other end through the cricothyroid membrane. Another thread is also introduced in the same way, slightly more medially. These threads pull the muscular process in a direction similar to the lateral cricoarytenoid muscle and are secured using a silicone shim. Figure 3 shows a picture after completion of AA. The TA muscle bundle is widely exposed (Figure 3, arrowheads).

The muscle piece of the NMP flap is positioned in the window to make as wide contact as possible with the TA muscle.
and is secured with the surrounding tissues using 8-0 nylon threads. This step is crucial and is performed under microscopic guidance. Subsequently, the window is covered with the outer perichondrium (Figure 4). Meticulous hemostasis is undertaken throughout the operation. Two Penrose drains are placed in the wound, one at the site of the NMP flap harvest and the other toward the paraglottic space.

**ASSessment of Vocal Function**

The vocal function of each patient was assessed before surgery and within and after 6 months after surgery. To measure the maximum phonation time (MPT) and mean airflow rate (MFR), each patient was asked to sustain the vowel /a/ at a comfortable pitch and loudness for as long as possible. Of the 2 consecutive measurements, the longer performance was analyzed. Pitch range was also measured and expressed in semitone scale. These parameters were measured using a phonation analyzer (SK-99; Nagashima, Tokyo, Japan). The preoperative and postoperative voices were recorded on a cassette tape recorder (TD75M; Sony, Tokyo, Japan) or a digital recorder (PMD670; Marantz, Kanagawa, Japan) in a soundproof room using a dynamic microphone (FP280; Sony) at a mouth-to-microphone distance of 30 cm. For the acoustic analysis, each patient was asked to sustain the vowel /a/ at a comfortable pitch and loudness. Jitter, shimmer, and harmonics to noise ratio (HNR) were measured from a relatively stable part of the recording using the Multi-Dimensional Voice Program (MDVP; KayPentax, Lincoln Park, New Jersey). The HNR was calculated in the following way: $HNR = 10 \times \log_{10}(1/NHR)$, where NHR is the noise to harmonics ratio.

**statistical analysis**

All measurements are shown as mean (SD). The paired $t$ test was used to compare the measurements of 3 different occasions: before surgery, at short-term follow-up, and at long-term follow-up (StatView; SAS Institute, Cary, North Carolina). The significance level was set at $P < .05$.

**Results**

The study included 10 men and 12 women (age range, 28–82 years; mean [SD], 56.6 [16.4] years). The left side was affected in 16 patients; the right, in 6. The period from onset to surgery ranged from 1 to 48 months (mean [SD], 15.6 [10.8] months); the short-term follow-up ranged from 1 to 6 months (mean [SD], 2.9 [1.2 months]); and the long-term follow-up ranged from 7 to 36 months (mean [SD], 21.4 [7.1] months). The cause of UVFP in the study patients is shown below.

<table>
<thead>
<tr>
<th>Cause</th>
<th>No. of Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laryngocutaneous (postoperative)</td>
<td></td>
</tr>
<tr>
<td>Thyroid cancer</td>
<td>5</td>
</tr>
<tr>
<td>Graves disease</td>
<td>1</td>
</tr>
<tr>
<td>Aortic aneurysm</td>
<td>3</td>
</tr>
<tr>
<td>Thymus tumor</td>
<td>2</td>
</tr>
<tr>
<td>Cerebral aneurysm</td>
<td>2</td>
</tr>
<tr>
<td>Meningioma</td>
<td>1</td>
</tr>
<tr>
<td>Vagal schwannoma</td>
<td>1</td>
</tr>
<tr>
<td>Lung cancer</td>
<td>1</td>
</tr>
<tr>
<td>Thyroid cancer</td>
<td>1</td>
</tr>
<tr>
<td>Subarachnoid hemorrhage</td>
<td>1</td>
</tr>
<tr>
<td>Aortic aneurysm</td>
<td>1</td>
</tr>
<tr>
<td>Idiopathic</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>22</strong></td>
</tr>
</tbody>
</table>

The preoperative voice recording was missing in one patient, and the vocal function test was not carried out before surgery in another patient because she underwent a tracheostomy. Acoustic analysis was not possible in 4 preoperative voice samples because of poor voice quality and short duration. Three patients did not undergo vocal function testing within 6 months after surgery.

**Figure 5** summarizes the results of preoperative and postoperative vocal function tests. All parameters improved significantly after surgery. For reference, the Table shows the mean (SD) ranges obtained from healthy Japanese men and women in their 50s for MPT, MFR, and pitch range.$^8$ The normal ranges for jitter ($<1.04%$), shimmer ($<3.81%$), and HNR ($<7.21$ dB) were calculated according to the MDVP software assessment by Kay-Pentax. The measurements for MPT, MFR, and HNR were within normal ranges after surgery. Furthermore, the MPT and jitter were significantly improved after long-term follow-up compared with early postoperative measurements ($P < .01$ and $P < .05$, respectively). The video (available at http://www.archoto.com) shows preoperative and postoperative stroboscopic images of a representative case.

One patient complained of sudden inspiratory dyspnea on postoperative day 1 and immediately underwent a tracheostomy. However, laryngofiberscopy revealed that her glottis was wide on postoperative day 2, and the cause was considered to be paradoxical adduction of the healthy vocal fold as a result of vocal fold dysfunction.$^{10}$ Her stoma was subsequently closed; her condition has not changed since then. In another patient, inspiratory dyspnea occurred suddenly on postoperative day 3 as a result of laryngeal edema. A tracheostomy was performed on an emergency basis. Her stoma was closed a few days later, and her condition has not changed since then. No other postoperative complication occurred.

**Comment**

Laryngeal reinnervation can provide the affected vocal fold with bulk and tension. Procedures aiming at the reinnervation include direct anastomosis of the severed stumps of the RLN, anastomosis between the RLN stumps by interposition of a foreign nerve section, anastomosis...
between the peripheral RLN stump and the AC nerve,\(^{11-14}\) and NMP flap implantation.\(^{3,4}\) The former 3 methods cannot usually be applied in patients with UVFP as it is related to neck operations because the peripheral stump of the RLN is buried in the cicatricial tissue. In contrast, the NMP method provides a practical way of reinnervating laryngeal muscles because the peripheral stump of the RLN is not required.

Tucker\(^1\) first described an NMP method to reinnervate the unilaterally paralyzed larynx and later combined the NMP method with a type I thyroplasty.\(^{15}\) May and Beery\(^4\) also implanted a NMP flap onto the lateral cricoarytenoid muscle. To our knowledge, there are no other clinical reports on this subject. This paucity of data may be ascribed to a lack of consistent effects of the NMP method reported in animal experiments. Some studies have used the NMP method successfully,\(^{16,17}\) whereas others have reported difficulty in achieving reliable results with the procedure.\(^{18,19}\) Using a rat UVFP model, we found that the NMP method was effective in repairing the atrophic changes of the TA muscle, even in long-term denervated animals.\(^6,7\) Miyamaru et al\(^7\) also reported that stimulation of the AC nerve elicited action potentials of the TA muscle. The occurrence of the evoked potentials of the TA muscle was attributable to successful reinnervation via the transferred AC nerve through reconstruction of the neuromuscular junction. Formation and implantation of an NMP flap were carefully performed under microscopic control, and direct contact of the muscle flap with the TA muscle fibers was later histologically ascertained. Based on these experimental results, we have refined the technique of the NMP method and combined it with AA in the treatment of UVFP.

There are major differences between our surgical techniques using the NMP method and combined surgery and those of Tucker\(^1\) and May and Beery.\(^4\) First, we harvested an NMP flap from the SH muscle and its major AC branch, although Tucker\(^1\) and May and Beery\(^4\) used an NMP flap from the superior belly of the omohyoid muscle and its AC branch. The lower portion of the SH muscle is invariably innervated by a prominent branch from the loop of the AC nerve. It branches farther, and 1 major branch is wider and contains more nerve fibers than the omohyoid branch.\(^20\) Therefore, a larger number of regenerating axons are expected to reach the target muscle. Electrical stimulation was always applied to confirm the presence of nerve fibers innervating the SH muscle. Second, the TA muscle was the target muscle in the present series and in Tucker’s\(^1\) technique. In contrast, May and Beery\(^4\) sought to reinnervate the lateral cricoarytenoid muscle to mediate the affected vocal fold. Seven of 29 patients in their series experienced no improvement in their voices. Third, window opening, incising the inner perichondrium, exposure of the TA muscle, and fixation of the NMP flap were crucial steps and were performed with great care under microscopic control in the present series. Fourth, AA was performed together with NMP flap implantation to locate the affected vocal fold at the median position, while Tucker\(^1\) performed a type I thyroplasty and May and Beery\(^4\) did not combine another method. All patients in the present series had relatively wide glottal gaps and required AA. Type I thyroplasty may not be indicated for combination with the NMP method because successful reinnervation of the TA muscle provides the affected vocal fold with increased bulk and tension.

Kimura et al\(^7\) performed intracordal collagen injection in 40 patients who had undergone AA and whose vocal fold geometry as observed with videostroboscopy was inadequate. They reported that the mean MPT and MFR were 15 seconds and 223 mL/s, respectively, after injection. However, the perceptual quality of postinjection voice remained G1 according to the Grade of the Severity of Dysphonia, Roughness, Breathiness, Ashenstic, and Strain scale.\(^21\) Mortensen et al\(^7\) compared vocal function after AA combined with type I thyroplasty with that after intracordal injection or type I thyroplasty alone and found that there was a statistically significant difference between the 2 groups. The patients who underwent AA with type I thyroplasty had worse preoperative function and better postoperative function. The postoperative mean MPT and MFR in patients who underwent AA with type I thyroplasty were 14.8 seconds and 219 mL/s, respectively. Mortensen and colleagues’ results demonstrated that postoperative vocal function improved, but not to “normal,” according to their description.\(^2\) In contrast, in the present series, not only the mean values of all parameters measured improved significantly after surgery, but also the MPT, MFR, and HNR were within normal ranges (Figure 5 and Table). Furthermore, the MPT

**Table.** Ranges for MPT, MFR, and Pitch Range Obtained From Healthy Japanese Men and Women in Their 50s\(^4\)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPT, s</td>
<td>12.5-30.4</td>
<td>14.2-19.8</td>
</tr>
<tr>
<td>MFR, mL/s</td>
<td>113-262</td>
<td>99-173</td>
</tr>
<tr>
<td>Pitch range, semitone</td>
<td>18.2-28.6</td>
<td>18.7-30.4</td>
</tr>
</tbody>
</table>

Abbreviations: HNR, harmonics to noise ratio; MFR, mean airflow rate; MPT, maximum phonation time.
and jitter improved significantly beyond 6 months after surgery. These results suggested that an addition of the NMP method may have played a certain role in the improvement of postoperative vocal function.

Further study focusing on electromyographic examination is required to clarify the innervation status of the TA muscle. Also, long-term follow-up of vocal function, including aerodynamics, acoustic analysis, stroboscopic assessment, and patients' self-evaluation, is in progress, and the results will be reported separately.

Although 7 of the 22 patients in the present series had undergone thyroid operations, NMP flap implantation was feasible. During the same period as the present series, the NMP flap could not be made in 2 patients with thyroid cancer. One patient had the thyroid cancer removed, and an RLN-AC nerve anastomosis was performed at another hospital. However, his voice did not improve for 1½ years after surgery. The other patient had recurrent thyroid cancer, which invaded the trachea, so the RLN, AC nerve, and strap muscles were removed along with the tumor. These 2 patients underwent AA with intracordal injection and AA alone, respectively. Therefore, there are a certain number of patients in whom the NMP method is not feasible. In conclusion, although the patients in the present series had severe breathy dysphonia as a result of UVFP, their voices improved greatly after surgery, and their MPT, MFR, and HNR were within normal ranges. Precise formation and implantation of an NMP flap onto the TA muscle combined with AA provided excellent vocal function. The NMP method may have played a certain role in the improvement of postoperative vocal function, although further study focusing on electromyographic examination is required to clarify innervation status of the TA muscle.

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Correspondence: Eiji Yumoto, MD, Department of Otolaryngology—Head and Neck Surgery, Kumamoto University, 1-1-1 Honjo, Kumamoto, Japan 860-8556 (yu167@gpo.kumamoto-u.ac.jp).

Author Contributions: Dr Yumoto had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Study concept and design: Yumoto. Acquisition of data: Yumoto, Kodama, and Kumai. Analysis and interpretation of data: Yumoto, Sanuki, Toya, and Kodama. Drafting of the manuscript: Yumoto and Kodama. Critical revision of the manuscript for important intellectual content: Yumoto, Sanuki, Toya, and Kodama. Administrative, technical, and material support: Yumoto and Toya. Study supervision: Yumoto.

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