Laryngeal Reinnervation by Ansa Cervicalis Nerve Implantation for Unilateral Vocal Cord Paralysis in Humans

Wan-Fu Su, MD, Yaw-Don Hsu, MD, Hsin-Chien Chen, MD, Hwa Sheng, PhD

BACKGROUND: Ansa cervicalis (AC)— recurrent laryngeal nerve anastomosis (RLN) is usually not desirable for correction of paralytic dysphonia when it is difficult to find a viable distal stump of the recurrent laryngeal nerve. Nerve implantation of the thyroarytenoid muscle with the ansa cervicalis is a simple alternative method.

STUDY DESIGN: Ten patients with unilateral vocal cord paralysis were prospectively designed to receive nerve implantation. A minimum period of 12 months after onset of paralysis was allowed to elapse to permit possible spontaneous reinnervation or compensation. Patients were followed long enough (at least 2 years) to determine if the procedure was successful. All patients were subjected to preoperative and postoperative voice recording, acoustic analysis, and videolaryngoscopy. Some of them underwent laryngeal electromyography.

RESULTS: Ten patients underwent nerve implantation of the thyroarytenoid muscles by using the ansa cervicalis, and 8 of 10 (80%) had improved phonatory quality. Laryngeal electromyography showed that the procedure produced satisfactory reinnervation of the thyroarytenoid muscle.

CONCLUSIONS: Nerve implantation of the thyroarytenoid muscle by the ansa cervicalis is a simple and efficient alternative to nerve transfer if dense scarring at the cricothyroid articulation and lack of a viable distal stump of the recurrent laryngeal nerve preclude the procedure of nerve transfer. But careful selection of the appropriate candidate seems to be the earliest prerequisite for a successful procedure. (J Am Coll Surg 2007;204:64–72. © 2007 by the American College of Surgeons)

The literature on laryngeal reinnervation is extensive. The purpose of this procedure is to provide a simple and valid method to rehabilitate the voice of patients with unilateral vocal cord paralysis (UVCP). Various techniques are currently available, including direct neuronal anastomosis and the nerve–muscle pedicle (NMP) procedure. Crumley1 recommended ansa cervicalis (AC, branch to the sternothyroid) anastomosis to the recurrent laryngeal nerve (RLN) for UVCP, with satisfactory results. Evidence of reinnervation was found in his experimental animals. The NMP with the AC used to reinnervate the thyroarytenoid (TA) muscle was reported successfully by Tucker.2 A branch of the AC anastomosis to the adductor branch of the RLN has been carried out with variable results.3

Nerve implantation is a simple alternative to these direct reinnervations. The pioneering work of Stein­dler4 demonstrated that a foreign nerve could reinnervate a denervated, even though dissimilar, muscle fiber. In addition, there is considerable evidence demonstrating that reinnervated muscle takes on the characteristics of the donor nerve.5 Consequently, implantation of AC directly to the TA muscle should have a major impact on the TA muscle’s structure and function. Some studies even showed that all strap muscles fired electrical activity during phonation, and this electrical activity was synchronous with the discharge of the TA muscle and increased with increasing volume of voice.6,7 Using nerve implantation directly, we can even avoid the possibility of disparity between donor nerve and receiving nerve. So, from anatomic and physiologic

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viewpoints, it is possible to reinnervate the adductory muscles by a branch of the AC. Although Zheng and colleagues demonstrated the experimental results in dogs and showed that nerve suture was superior to nerve implantation and NMP techniques, several scenarios serve as the impetus for this procedure. These include failure to identify the distal stump of the RLN, difficulty differentiating between the adductor and abductor branches of the RLN, and the necessity of maintaining the continuity of the RLN. In addition, when earlier operations injure the strap muscles, nullifying the NMP transfer but the AC is still viable, direct nerve implantation offers a desirable alternative to the NMP procedure.

**METHODS**

Ten patients incurring various RLN injuries were referred to us for correction of the voice or prevention of aspiration from 1998 through 2004. The causes of the vocal paralysis included four thyroidectomies, three spinal cord procedures, one heart operation, one case of idiopathic hoarseness, and one parathyroidectomy. A minimum of 12 months was allowed to elapse after known onset of the vocal paralysis to allow possible spontaneous reinnervation or compensation. Patients were followed long enough (at least 2 years) to determine if the procedure was successful. Patients with UVCP for more than 36 months were excluded, and they received thyroplasty type I.

**Technique of operation**

A horizontal skin incision at the cricothyroid level was made on the paralyzed side. The sternohyoid muscle and sternothyroid muscle were dissected out to expose the underlying AC branches. The lower portions of the sternohyoid and sternothyroid muscles are invariably innervated by prominent AC nerve branches derived from the AC loop. If the nerve stimulator demonstrated that the nerve branches were not sufficiently viable because of previous operations, the superior root of the AC in the carotid sheath was used as the donor nerve. The descent of the superior root of the AC can be followed down the neck along its intimate relationship to the great vessels. The nerve ending of the donor nerve was trimmed, without any muscle fragment or redundant perineural sheath left under the microscope. A small window approximately \(1 \text{ cm} \times 0.5 \text{ cm}\) was made 0.3 cm superior to the lower border of the thyroid cartilage lamina to expose the TA muscle. The thyroid perichondrium was opened and hemostasis was secured before nerve implantation. The length of the AC was measured to match the distance between the reflecting point of the nerve stump and the target muscle. The anchoring suture of the nerve stump on the target muscle was performed (Fig. 1) with 2 stitches of 8-0 nylon thread under the microscope (Zeiss microscope \(8 \times\)). The wound was closed with a Penrose drain or suction drain, depending on wound conditions.

**Assessment of surgical effect**

All patients received preoperative and postoperative videolaryngoscopy (VL), speech analysis, and a maximal phonation time test (MPT). Six patients underwent laryngeal electromyography (LEMG) examinations, and four refused this invasive examination. The postoperative assessment was done no less than 3 months after operation in all patients. All patients were followed for a minimum of 2 years; in 1 patient, follow-up was 7 years.

**Abbreviations and Acronyms**

\[
\begin{align*}
\text{AC} & \quad = \text{ansa cervicalis} \\
\text{LEMG} & \quad = \text{laryngeal electromyography} \\
\text{MPT} & \quad = \text{maximal phonation time test} \\
\text{NMP} & \quad = \text{nerve–muscle pedicle} \\
\text{RLN} & \quad = \text{recurrent laryngeal nerve} \\
\text{TA} & \quad = \text{thyroarytenoid muscle} \\
\text{UVPC} & \quad = \text{unilateral vocal cord paralysis} \\
\text{VL} & \quad = \text{videolaryngoscopy}
\end{align*}
\]
Evaluation of subjects

1. Patients were required to sustain the vowel /eee/ on one continuous expiratory breath three times. The greatest value was adopted as the MPT.
2. Frequency perturbation (jitter) and amplitude perturbation (shimmer) were obtained when patients were required to produce a steady and sustained vowel /eee/ for 5 seconds. They were used to reflect the biomechanical characteristics of the vocal cords and variations of neuromuscular control.
3. One speech pathologist and two otolaryngologists performed preoperative and postoperative voice assessment using a perceptual rating scale for voice quality and characteristics. The ratings were accomplished in a blinded fashion, with patient voice samples arranged in a random manner. This perceptual scale is a variant of the GRBAS scale (grade, roughness, breathiness, asthenia, strain), including loudness, breathiness, and hoarseness, and it allows each listener to rate the voice quality on a scale. No improvement of these parameters was classified as “no improvement (−).” Improvement in one or two of these parameters was considered “improved voice (+),” and, if there was improvement in all three, the voice result was considered “greatly improved (++);” if these parameters could not be distinguished from those of normal voice, then we called the improved voice a “return to normal voice (+++)”.
4. Each patient underwent rigid optic VL before and after operation over a 3-month period. The VL was performed with a Karl Storz 70-degree rigid telescope (model 8706CA; Karl Storz) connected to a camera (model 20222130; Karl Storz) and a light source. Video recordings were taken in digital format (Kay Instruments). All patients were observed during “eee” phonation. Findings of vocal fold position (1, lateral; 2, intermediate; 3, paramedian; 4, median), muscle atrophy (present or absent), and glottic gap (0, none; 1, mild; 2, moderate) at the middle and posterior aspects of the vocal fold were rated. The rating methods were developed and described by Maronian and associates. Also, arytenoid position was assessed during static observation of the larynx and during “eee” phonation. The variations in arytenoid position ranged from symmetric with the opposite arytenoid cartilage, to anteriorly displaced, to posteriorly rotated, and medially rotated. If there was a change in arytenoid position with speech from the preoperative state to the postoperative state, this was noted. The arytenoid cartilage normally moves purposefully toward the midline with phonation. Evidence of mildly decreased movement or a lack of movement of the arytenoid cartilage was rated by all observers (0, none; 1, minimal; 2, normal).

5. Six of the 10 preoperative patients and 4 of the 6 postoperative patients had laryngeal electromyography (LEMG) examinations. All LEMG tracings were obtained in our neurologic department. The procedure required the patient to lie supine in the examining room bed with the head supported over a pillow. Sedation was not used, and no local anesthesia was necessary. A disposable concentric needle (0.45 × 40 mm; Spe Medica Srl) was placed percutaneously, with EMG activity monitored continuously during placement. A surface ground disk electrode was placed on the sternum. A Nicolet Viking IVD Electromyographic Instrument (Nicolet Biomedical) was used to obtain the recordings. The TA muscles were localized by techniques previously described by Hirano and Ohala. The accuracy of needle placement was confirmed by insertion activity, anatomic landmarks, and phonatory tasks. When the recording concentric needle was advanced, insertion activity, spontaneous activities, motor unit action potentials firing pattern, and interference pattern were scrutinized and recorded. Patients were asked to phonate “eee” or lift their head when we attempted to catch bilateral motor unit action potentials or interference patterns of the TA muscle preoperatively and postoperatively. The measurements in this study were statistically calculated by paired t-tests. The postoperative course allowed vocalization and oral food intake. Patients stayed in the hospital for 3 or 4 days.

RESULTS

Ten patients with UVCP underwent nerve implantation procedures. Eight of them had not been treated before. One patient with earlier thyroplasty type I underwent nerve implantation at the expense of removing a silicone implant. No major or minor complications were encountered. Six patients achieved consistently good voice quality at 3 months that persisted without any regression (Table 1).

Results of assessment

Phonatory ability test

Table 1 shows the MPT for preoperative and postoperative phonation at least 2 years after the procedure. Normal adult speakers usually sustain longer than 20 seconds. The mean MPT for postoperative phonation was 16 ± 5.52 seconds, which was significantly longer (p < 0.01) than that for preoperative phonation (7 ± 1.22 seconds).

Acoustic analysis

Normal speakers usually have jitters less than 0.5% and shimmers less than 3%. The mean jitter value for post-
operative phonation in this study was 0.54% ± 0.31%, which was significantly lower (p = 0.01) than that for preoperative phonation (2.19 ± 0.71%). The mean shimmer value for postoperative phonation was 2.47 ± 1.27%, which was significantly lower (p < 0.01) than that for preoperative phonation (7.18 ± 0.97%). Voiceless phonation from a widely opened glottal lumen in patient 4 with bilateral vocal cord paralysis was even unable to produce detectable jitter and shimmer. So patient 4 was excluded in calculation of jitter and shimmer.

**Voice quality**
Perceptual voice quality was rated as normal (+++) in three patients, greatly improved (+) in three patients, improved in two patients (+), and not improved (−) in two patients.

**Videolaryngoscopy (VL)**
Videolaryngoscopy was performed on all patients before and after operation. No visible movement of cord or arytenoid could be detected in the reinnervated vocal cords of all patients. Vocal fold position was variably improved. In 6 of the 10 patients, there was a change from a paramedian position to a median position and showed good apposition with the normal cords during phonation after operation. In 2 of the 10 patients, the reinnervated cords remained in a paramedian position. Vocal cord atrophy was ameliorated, and resultant mid-glottal gaps were obliterated or improved in 8 of the 10 patients. Ipsilateral arytenoid cartilage didn’t move before or after operation in all 10 patients. In 9 of the 10 patients, the position of the arytenoid cartilage as compared with that on the contralateral side during quiet respiration, was judged to be anteriorly and medially located before operation. But during phonation, the position of the arytenoid cartilage appeared symmetrical in five of nine patients, was anteriorly located in two of nine, and was posteriorly located in two of nine, preoperatively. After reinnervation, seven of the nine patients showed symmetrical arytenoid positions during attempted phonation. Two patients carried a change in arytenoid position with speech from the preoperative state to the postoperative state (Fig. 2); they changed from posterior location to symmetrical position.

**Laryngeal electromyography (LEMG)**
Only 6 of 10 patients underwent preoperative awake LEMG evaluations and 4 of them consented to postoperative LEMG. The preoperative LEMG findings were consistent with the dense denervation seen in all six tested patients. Denervation patterns of LEMG response were defined as fibrillations or positive waves in multiple sites of the muscle tested (Fig. 3). A comparison of preoperative and postoperative LEMG findings is shown in Figure 4. No obvious recruitment was noted before operation in any patients tested. Those motor unit action potentials were not activated during speech attempts and head lift (Fig. 4, upper 2 tracings). Activation with head lift was present in all patients tested after reinnervation (Fig. 4, tracing d). This activation was even greater than the recruitment during attempts at phonation (Fig. 4, tracing c) in all four tested patients. This increased amplitude of recruitment reflected reinnervated animation of the TA muscle from the AC.

### Table 1. Patient Characteristics and Results

<table>
<thead>
<tr>
<th>Patient No./ gender/ age, y</th>
<th>Cause</th>
<th>Duration of symptoms, mo</th>
<th>Jitter, % Preop</th>
<th>Jitter, % Postop</th>
<th>Shimmer, % Preop</th>
<th>Shimmer, % Postop</th>
<th>MPT, sec Preop</th>
<th>MPT, sec Postop</th>
<th>Result*</th>
<th>Follow-up, mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/M/27†</td>
<td>Thyroidectomy</td>
<td>21</td>
<td>2.50</td>
<td>0.61</td>
<td>6.91</td>
<td>2.90</td>
<td>6</td>
<td>13</td>
<td>(+++)</td>
<td>12</td>
</tr>
<tr>
<td>2/M/46</td>
<td>Thyroidectomy</td>
<td>17</td>
<td>2.32</td>
<td>0.36</td>
<td>5.74</td>
<td>2.09</td>
<td>8</td>
<td>12</td>
<td>(+)</td>
<td>15</td>
</tr>
<tr>
<td>3/M/57</td>
<td>Chest surgery</td>
<td>17</td>
<td>2.01</td>
<td>0.52</td>
<td>7.84</td>
<td>1.71</td>
<td>5</td>
<td>22</td>
<td>(+++)</td>
<td>13</td>
</tr>
<tr>
<td>4/F/16†</td>
<td>Idiopathic</td>
<td>23</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>(-)</td>
<td>14</td>
</tr>
<tr>
<td>5/M/47</td>
<td>Spinal cord procedure</td>
<td>24</td>
<td>1.30</td>
<td>1.31</td>
<td>5.52</td>
<td>5.41</td>
<td>7</td>
<td>7</td>
<td>(-)</td>
<td>13</td>
</tr>
<tr>
<td>6/M/54‡</td>
<td>Spinal cord procedure</td>
<td>24</td>
<td>1.20</td>
<td>0.42</td>
<td>7.41</td>
<td>3.03</td>
<td>9</td>
<td>14</td>
<td>(+)</td>
<td>14</td>
</tr>
<tr>
<td>7/M/66</td>
<td>Spinal cord procedure</td>
<td>14</td>
<td>3.63</td>
<td>0.21</td>
<td>8.21</td>
<td>1.21</td>
<td>7</td>
<td>19</td>
<td>(+++)</td>
<td>60</td>
</tr>
<tr>
<td>8/F/44</td>
<td>Thyroidectomy</td>
<td>12</td>
<td>2.62</td>
<td>0.46</td>
<td>7.61</td>
<td>1.91</td>
<td>7</td>
<td>24</td>
<td>(+++)</td>
<td>14</td>
</tr>
<tr>
<td>9/F/57</td>
<td>Thyroidectomy</td>
<td>14</td>
<td>2.10</td>
<td>0.50</td>
<td>7.40</td>
<td>1.41</td>
<td>8</td>
<td>20</td>
<td>(+++)</td>
<td>12</td>
</tr>
<tr>
<td>10/F/52</td>
<td>Parathyroidectomy</td>
<td>12</td>
<td>2.11</td>
<td>0.51</td>
<td>8.13</td>
<td>2.62</td>
<td>6</td>
<td>13</td>
<td>(+++)</td>
<td>16</td>
</tr>
</tbody>
</table>

* (++), return to normal; (+), greatly improved; (+), improved; (-), not improved.
† Patient received thyroplasty type I as prior voice surgery.
‡ Voiceless phonation couldn’t be detected by machine.
MPT, maximal phonation time; postop, postoperative; preop, preoperative.
DISCUSSION

The pioneering work of Steindler, and Elsberg demonstrated that a foreign nerve may reinnervate a denervated muscle fiber, even if they are dissimilar. Reinnervation must occur during a poorly delineated period before the muscle fiber undergoes atrophy from denervation. The length of time for this atrophy to occur is not clear, because it varies among species, among individuals in a certain species, and among different muscles of the same subject. There is evidence that human muscle does not undergo substantial denervation until at least 3 years after nerve interruption. Although denervated motor endplates maintain certain components of normal architecture, the rest of the muscle fiber’s membrane becomes hypersensitive to acetylcholine, resulting in “denervation hypersensitivity.” The process of reinnervation is fascinatingly complex and poorly understood. After Steindler showed that a foreign nerve would reinnervate a denervated muscle, Elsberg demonstrated that a normal muscle would not accept any additional innervation (“hyperneurotization”). But if the muscle’s original nerve is injured when the foreign nerve is implanted, the muscle will become reinnervated by both normal and foreign nerves, a phenomenon known as “dual innervation.”

The mechanism for regenerating axon sprouting has been investigated in depth by Hines and coworkers. It appears that local motor nerves sprout axons freely near denervated motor endplates in response to the production of “neurocletin” described by Hoffman and nerve growth factor–like substances reported by Lundborg and Hansson, or the absence of “axon-sprouting inhibitor factor,” a substance normally found near intact distal axons motor endplates. Van Harreveld demonstrated that a denervated muscle adjacent to a normally innervated muscle can stimulate the nerve fibers within the innervated muscle to produce axon sprouts.

Virtually all investigators agree that implantation of a new nerve into an innervated muscle will not result in the formation of any new motor endplates. Besides, a subclinical innervation would preclude reinnervation through nerve transplant, because an innervated muscle fiber cannot accept additional innervation. This might be seen after partial RLN transection, crushing injuries, or when the nerve is partially ligated. These are most important and especially true in posterior cricoarytenoid muscle reinnervation surgery.
The neuromuscular pedicle concept arose during laryngeal transplantation research. The entire pedicle unit was transposed to a denervated TA muscle. In 1989, Tucker described that 64 of 73 operations were judged successful on the basis of marked voice improvement. This procedure definitely provides its own motor endplates. Crumley, in 1991, described that the AC’s reinervation of the laryngeal muscles produces resting tone in the TA, posterior cricoarytenoid, lateral cricoarytenoid, and interarytenoid muscles. The necessary transection of the RLN in the procedure removes the inappropriate innervation, and the weak tonic reinervation from AC yields a denervation hypersensitivity.

Our encouraging results in these patients supported the fact that synaptic contacts can be established, provided that the TA muscle is previously denervated, even when subclinical innervation may exist. We deduce that a partially denervated muscle may contain denervated and innervated (including regenerated ones) motor endplates. The more denervated motor endplates exist, the more nerve growth factors cause the implanted nerves to sprout axons toward them. So if the human muscle does not undergo substantial denervation (less than 3 years after nerve interruption), a denervated muscle with a complete transected nerve is more sensitive to acetylcholine than is a stretched or partially injured muscle. In addition, the sooner a functional connection is made between the regenerating axon and muscle fiber, the more likely the resulting anatomy and function of the muscle cell will be normal. A delay in reinervation allows more fibrosis in the muscle and more collagen accumulation in the motor endplates, which prevent the sprouting axons from reaching them. In addition, a delay in reinervation allows more potential for subclinical innervation to hinder surgical reinervation. Patients who obtained less improvement from operation in this study seemed to have symptoms longer than those who had better improvement (+ + +, Table 1). This can be explained by the greater potential for subclinical innervation, or debilitated AC branches.

Most authors recommend waiting 6 to 12 months before operation. Although this concept is widely accepted, information on the course and prognosis of vocal cord paralysis is not conclusive. Spontaneous regeneration after RLN injury usually occurs in the first 3 months and is never replicated after a silent plateau. Actually, Crumley noted that if normal function does not return within 3 months, it is highly likely that some motion impairment will be permanent. So a compromised 12-month observation period seemed justified for desirable spontaneous regeneration and sufficient denervated motor endplates to be surgically reinervated. The outcomes obtained from our surgical procedure were considered to be from surgical reinervation, which can be demonstrated by the increased recruitment during head lift in LEMG (Fig. 4).

Although nerve transfer and NMP transfer are well-established laryngeal reinervation methods for voice restitution, nerve implantation appears to be a more attractive option because of its simplicity and efficacy. Sparing the time-consuming task of identifying the distal stump of the RLN in dense scar, as in nerve transfer, the surgeon simply opens a window in the lower thyroid alae and defines the target muscle in just 10 minutes in the nerve implantation procedure. Compared with NMP transfer, nerve implantation uses the AC branch without its innervated muscle patch as donor nerve. So the superior loop of the AC in the carotid sheath becomes eligible if the strap muscle is not so viable. This will extend the indications for nerve implantation.

There appear to be several explanations for the excellent phonatory quality achieved by nerve implantation into the TA muscle, just like the other reinervative
procedures. Severance of the sternothyroid muscle branch of the AC produces denervation of the sternothyroid muscle and subsequent medialization of the ipsilateral thyroid alae, which, in turn, medializes the vocal fold. This is a very small effect. The TA muscle is the chief target we aim at and is critical for phonation. With static tonic tone from the AC, vocal fold tension and mass are restored to the TA muscle. And this tone never fades away if the AC survives well. The reinnervated TA muscle can offer supplementary muscular bulk, occupy the glottal lumen, and consequently decrease the volume of air loss during phonation. But compared with the nerve transfer procedure, the sole effect from the TA muscle seemed to be weaker than the combined effect from the TA muscle, lateral cricoarytenoid muscle, and interarytenoid muscle. This can be seen in Zheng and colleagues’ study and in our unpublished data. Besides, there was a consistent interval of 2 to 3 months to the vocal result. It seemed to be comparable to Tucker’s result.

Sprouting of the regenerative axons of the AC to the motor endplates in the TA muscle was successful according to EMG findings and the eventual glottal configuration. The successful reinnervation was confirmed by the increased activity during phonation, and that this was gained specifically from the AC could be confirmed by the increased recruitment during head lift in the postoperative EMG. Some studies showed that all strap muscles fire electrical activity during phonation, and this electrical activity was synchronous with the discharge of the TA muscle and increased with increasing volume of voice. When denervated, the absence of cricoarytenoid muscle tone allows the unopposed cricothyroid muscle to pull the arytenoid anteriorly and inferiorly, which is a common finding seen in UVCP. But during speech, the arytenoid cartilages still touched in the midline with attempted glottic closure in 5 of the 10 patients. Two arytenoids in our series even appeared posteriorly located during phonation. In VL, they seemed to be passively squeezed posteriorly by the opposite normal arytenoid. After reinnervation, the TA muscle stabilized the arytenoid from squeezing posteriorly by the opposite arytenoid during phonation and appose well with the normal one (Fig. 2C).

Although the scar or fibrosis in the TA muscle from an earlier silicone block may or may not impact the reinnervation between the TA muscle and the muscle patch, as in NMP transfer, nerve implantation provided improved function in 2 revised operations (patients 1 and 6). One of these two patients, undergoing unsatisfactory earlier thyroplasty type I, achieved improvement with nerve implantation at the expense of removing the silicone implant.

Crumley, in 1991, pointed out that “you want to remember in the first year of their loss not to perform a reinnervation procedure disruptive of the continuity of the RLN, especially for some patients with idiopathic paralysis or surgical paresis.” Some series showed that most cases of UVCP not from direct trauma to the RLN will spontaneously recover or will
compensate within 6 months to a sufficient extent so that no other intervention is required. A good regeneration achieving synkinesis type III (tonic adduction relative to the paramedian position) might be unwillingly deteriorated by the nerve transfer procedure, at least during the first 3 months. This scenario seems to justify nerve implantation. In addition, difficulty defining the distal stump of the RLN may be another reason to consider nerve implantation as an alternative, although silicone implantation can be assumed to be an option. To keep the continuity of RLN, we did nerve implantation in patient 4.

Two of the 10 patients included in this article had improved voice quality (+), but were not fully satisfied with their vocal results. We surmised that the variability of results was from insufficient reinnervation to the TA muscle. Subclinical innervation may also prevent excellent surgical reinnervation. No improvement was obtained in another two patients. Lack of viability in the AC may have played a contributing role in patient 5. Separation of the nerve implantation may occur after wound closure and represents another cause of failure. In patient 4, cricoarytenoid joint fixation was confirmed in a subsequent arytenoid adduction procedure.

Nerve transfer still assumes priority in our clinic practice if the operative scenario provides an iatrogenic severance of the RLN, and immediate nerve repair is unfeasible in the primary operation. Otherwise, we performed the nerve implantation in the secondary corrective operation if the patient has fulfilled appropriate criteria, including a laterally paralyzed vocal cord with a mobile cricoarytenoid joint, RLN injury of less than 3 years, and available AC branches.

In conclusion, nerve implantation is a simple and efficient alternative to nerve transfer and NMP transfer. Patient satisfaction with this procedure is high, and reliable results of reconstitution of the vocal fold bulk may be anticipated. But patient criteria for this reinnervation procedure have yet to be established. Given this small patient sample, we cannot provide uniform inclusion or outcomes guidelines. Although the reinnervated vocal cord didn’t offer a vigorous antagonist, it could present itself at the midline for precise apposition with the non-paralyzed cord. So we believe that this technique may present the laryngologist with another tool in the arena of vocal rehabilitation after UVCP.

**Author Contributions**

Study conception and design: Su  
Acquisition of data: Su  
Analysis and interpretation of data: Su, Hsu, Sheng  
Drafting of manuscript: Chen  
Critical revision: Su, Hsu, Sheng

**REFERENCES**