

Combined Arytenoid Adduction and Laryngeal Reinnervation in the Treatment of Vocal Fold Paralysis

Dinesh K. Chhetri, MD; Bruce R. Gerratt, PhD; Jody Kreiman, PhD; Gerald S. Berke, MD

Objective/Hypothesis: Glottal closure and symmetrical thyroarytenoid stiffness are two important functional characteristics of normal phonatory posture. In the treatment of unilateral vocal cord paralysis, vocal fold medialization improves closure, facilitating entrainment of both vocal folds for improved phonation, and reinnervation is purported to maintain vocal fold bulk and stiffness. A combination of medialization and reinnervation would be expected to further improve vocal quality over medialization alone. **Study Design:** A retrospective review of preoperative and postoperative voice analysis on all patients who underwent arytenoid adduction alone (adduction group) or combined arytenoid adduction and ansa cervicalis to recurrent laryngeal nerve anastomosis (combined group) between 1989 and 1995 for the treatment of unilateral vocal cord paralysis. Patients without postoperative voice analysis were invited back for its completion. A perceptual analysis was designed and completed. **Methods:** Videostroboscopic measures of glottal closure, mucosal wave, and symmetry were rated. Aerodynamic parameters of laryngeal airflow and subglottic pressure were measured. A 2-second segment of sustained vowel was used for perceptual analysis by means of a panel of voice professionals and a rating system. Statistical calculations were performed at a significance level of $P = .05$. **Results:** There were 9 patients in the adduction group and 10 patients in the combined group. Closure and mucosal wave improved significantly in both groups. Airflow decreased in both groups, but the decrease reached statistical significance only in the adduction group. Subglottic pressure remained unchanged in both groups. Both groups had significant perceptual improvement of voice quality. In all tested parameters the extent of improvement was similar in both groups. **Conclusion:** The role of laryngeal reinnervation in the treatment of unilateral vocal cord paralysis remains to be established. **Key**

Words: Vocal cord paralysis, arytenoid adduction, laryngeal reinnervation, ansa cervicalis nerve, perceptual analysis.

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INTRODUCTION

Medialization procedures such as Teflon injection, thyroplasty, and arytenoid adduction are currently popular in the treatment of unilateral vocal cord paralysis.¹⁻³ The optimal medialization procedure continues to be debated. Injection techniques and thyroplasty are suitable for relieving anterior vocal fold insufficiency, whereas arytenoid adduction corrects posterior glottic chinks.^{4,5} Recent reports have proposed laryngeal reinnervation using the ansa cervicalis nerve anastomosis to recurrent laryngeal nerve in the treatment of unilateral vocal cord paralysis.⁶ The ansa cervicalis nerve is an ideal candidate for laryngeal reinnervation because it is located in close proximity to the larynx, and sacrificing this nerve results in no serious functional or cosmetic sequelae.⁷ However, satisfactory physiological motion of paralyzed vocal folds during phonation and respiration has not been achieved with this technique. With this nonspecific method of reinnervation the vocal process remains immobile, glottic closure may remain incomplete,⁶ and functional return of laryngeal movement is hampered by synkinesis, which is the result of random regrowth of axons into the abductor and adductor branches.⁸

In laryngeal paralysis the stiffness of the denervated vocal fold is decreased.⁹ This leads to a deviant vibratory pattern of an inferior quality involving two unequal vocal fold masses. During follow-up studies of thyroplasty type I patients, it was noted that sometimes there was slight decrement of voice over a period of 2 to 3 months after the operation. The main factor responsible for increased dysphonia was reported to be atrophy of the vocal cord.^{10,11} Vocal cord atrophy from denervation injury can be countered by reinnervation. Histological evidence of reinnervation after ansa cervicalis to recurrent laryngeal nerve anastomosis has been demonstrated previously.^{12,13} Posterior commissure closure and symmetric thyroarytenoid stiffness are two important functional characteristics of normal phonatory posture.¹⁴ We hypothesized that a

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combination of medialization and laryngeal reinnervation would lead to better vocal quality over medialization alone in the treatment of unilateral vocal cord paralysis. In a combined procedure, medialization would facilitate closure and reinnervation would preserve vocalis muscle mass and tension.

We describe our initial experience with arytenoid adduction combined with laryngeal reinnervation using ansa cervicalis nerve to recurrent laryngeal nerve anastomosis in the treatment of unilateral vocal cord paralysis. With a combined surgical approach, we expect an immediate postoperative improvement in phonation, which we assume can be attributed to the medialization procedure, followed several months later by further improvement in voice as the functional effects of laryngeal reinnervation are noted. The results of the combination surgery are compared with arytenoid adduction as a single therapeutic modality.

MATERIALS AND METHODS

During the years 1989 and 1995, 18 patients underwent arytenoid adduction (adduction group) and 13 patients underwent combined arytenoid adduction and laryngeal reinnervation (combined group) at the University of California Los Angeles (UCLA) Medical Center by the senior author (G.S.B.). Retrospective chart review was performed for all these patients. No set protocol was used to randomly assign patients into the treatment arms. During the initial years of the study period, patients were randomly assigned into the adduction or combined groups. Later in the study period, and as the experience with reinnervation was garnered, patients tended to undergo the combined procedure more frequently. All patients received an objective preoperative and postoperative voice analysis, which included videolaryngostroboscopy, aerodynamic analysis, and voice recording. Patients without postoperative voice analysis were invited back for its completion. Patients were excluded from the study when preoperative voice analysis was of inadequate quality (five patients in adduction group and one patient in combined group) or when the distance of their current residence precluded their return to the medical center (two patients in each group). Other exclusion criteria included second phonosurgery before postoperative voice recording (one patient in adduction group) or lost to follow-up (one patient in adduction group). This resulted in inclusion of 9 patients in the adduction group and 10 patients in the combined group.

Arytenoid adduction was performed essentially as described by Isshiki et al.³ with modifications presented in Bielamowicz et al.¹⁵ In brief, the inferior pharyngeal constrictor muscle was incised off its origin at the oblique line of the thyroid cartilage to expose the posterior margin of the thyroid cartilage. The mucosa of the piriform sinus was then gently teased off the medial surface of the thyroid cartilage using a combination of sharp and blunt dissection. Disarticulation of the cricothyroid joint was not necessary. The dissection proceeded to the point where the muscular process of the arytenoid could be palpated, and a 4-0 nonabsorbable suture was placed through the muscular process. A 14- to 16-gauge angiocatheter was passed through the anteroinferior aspect of the ipsilateral thyroid cartilage, just lateral to midline, then angled posteriorly and laterally hugging the thyroid lamina until it came out into the surgical field just lateral to the arytenoid cartilage. The Prolene sutures were passed through the lumen of the angiocatheter and out again to the anterior surface of the thyroid ala. Gentle traction was placed on the sutures, and they were tied using a two-hole microsurgical plate as a bolster. This rotated the vocal process of the arytenoid medially, thus

adducting the true vocal fold. Proper medialization was verified by flexible nasolaryngoscopy.

The ansa cervicalis to recurrent laryngeal nerve anastomosis was as described by Crumley⁸ and Crumley et al.¹⁶ In a combined operation, localization and preparation of nerves were performed first, followed by arytenoid adduction and, finally, nerve anastomosis. The ansa cervicalis nerve was first exposed overlying the great vessels or within the carotid sheath. A branch of the ansa cervicalis (to the omohyoid or to the sternothyroid) was then identified, followed, and divided at its insertion into its muscle, then transposed over in the region of the tracheoesophageal groove. The recurrent laryngeal nerve was identified by retracting the superior thyroid neurovascular bundle laterally and inferiorly and dissecting posteriorly and inferiorly until the nerve was identified as it came up to enter the larynx at the inferior horn of the thyroid cartilage. The nerve was dissected out distally in the tracheoesophageal groove and divided at a suitable distance that allowed for an unencumbered anastomosis (usually 7-10 mm). Nerve anastomosis was accomplished with microsurgical neurorrhaphy (epineurial repair) using 8-0 to 10-0 suture under magnification.

To perform videolaryngostroboscopy, a 90° telescopic laryngoscope attached to a miniature endoscopic videocamera (Storz Tricam, Karl Storz GmbH & Co., Tuttlingen, Germany) and a stroboscopic unit (Bruel & Kjaer Rhino-Larynx Stroboscope, type 4914, Bruel & Kjaer, Norcross, GA) was inserted into the oropharynx until the vocal folds could be visualized. The patient was instructed to sustain the vowel /i/ at a comfortable pitch and loudness. The video images were recorded on a 3/4-inch video tape recorder (Sony U-matic VO-5800, Sony Electronics, Tokyo, Japan) for later analysis. Glottal closure, mucosal wave on both vocal folds, and symmetry were analyzed. Glottal closure was rated on a five-point scale ranging from complete to absent (Fig. 1). Mucosal wave was rated on a five-point scale ranging from unrestricted to absent (Fig. 2). Symmetry was rated as symmetrical or asymmetrical (Fig. 3).

Laryngeal airflow and subglottic pressure measurements were performed as described by Smitheran and Hixon.¹⁷ Flow was monitored with a pneumotachographic mask, which was placed over the patient's face, connected to a differential pressure transducer (Glottal Enterprises, Syracuse, NY). The acoustic signal was monitored by a cantilever-mounted microphone (AKG, Vienna, Austria) located 5 cm from the patient's mouth. A small-diameter catheter placed through a port in the mask and positioned behind the lips sensed intraoral air pressure. The patient repeated the syllable /pi/ at a rate of approximately 1.5 to 2 syllables per second at normal loudness and pitch. A 10-second sample of phonation was amplified, low-pass filtered at 3 kHz, and digitized at 10 kHz. This sample was then used to determine the average airflow and subglottic pressure during phonation. Glottic resistance was calculated using modification of Ohm's law (subglottic pressure = glottal airflow × resistance).

To obtain the voice samples for perceptual analysis, the microphone was placed off-axis, 5 cm away from the lips, and the patient was asked to sustain an /a/ for as long as possible. Utterances were low-pass filtered at 8 kHz and sampled at 20 kHz with 12-bit resolution. A 2-second sample was excerpted from the middle of each utterance and stored for later presentation. Stimuli were equalized for peak intensity, and onsets and offsets were multiplied by 40-millisecond ramps to eliminate click artifacts. Steady-state vowel, rather than continuous speech, was studied because the relatively short stimuli enable efficient gathering of ratings for large sets of voices, and the vowel's relatively simple acoustic structure yields consistent, interpretable perceptual ratings.¹⁸ Perceptual studies comparing isolated vowels with connected speech have shown no difference in results.¹⁹

Nine listeners were recruited for perceptual rating of voice

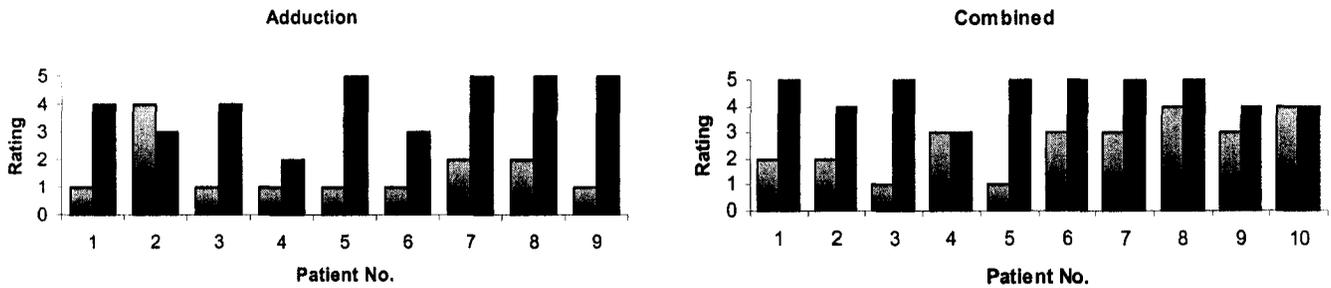


Fig. 1. Preoperative (gray) and postoperative (black) ratings for glottal closure in the arytenoid adduction (adduction) and the combined surgery (combined) groups. Closure was defined as the extent of apposition of the vocal folds along the medial edges during the most closed portion of the glottal cycle and was rated as follows: 1 = absent, 2 = less than $\frac{1}{3}$, 3 = between one and two thirds, 4 = more than two thirds but not complete, 5 = complete. Glottal closure improved significantly in both groups. The extent of improvement was similar in both groups.

samples. Five were otolaryngologists in their fourth year of residency or above, two were speech pathologists, and two were voice scientists. Listeners reported no history of any hearing, speech, voice, or language difficulties. Listeners were tested individually in conditions described by Kreiman and Gerratt.¹⁸ To mimic clinical listening conditions, all testing took place in free field. Listeners were seated 3 feet from a loudspeaker in a sound-treated room. Stimuli were played through a 16-bit digital-to-analogue converter, low-pass filtered at 8 kHz, and presented at a constant comfortable listening level of approximately 85 dB SPL.

A custom-designed computer program randomly selected and presented the voice samples. Two voice samples (one preoperative and one postoperative sample) were represented for each patient. In addition, 20% of the samples (chosen at random) were repeated during each session so that test-retest reliability could be evaluated. The order of stimulus presentation was also ran-

domly chosen across listeners. The computer presented a sound stimulus, then an on-screen menu for keying in of the rating. Listeners judged the severity of vocal pathology for each sample voice on a seven-point scale ranging from normal (rated 1) to severely abnormal (rated 7). Ratings between 2 and 6 represented graded levels of worsening severity as determined by each individual listener. The listener keyed in the rating, the response was automatically recorded and stored, and the next voice sample was presented. Listeners were only aware that they were rating randomized presurgical and postsurgical voice samples and had no way of knowing the particular operation or the preoperative or postoperative status of any voice sample. The quality of recording for the perceptual part of the study had deteriorated in two patients in the adduction group and one patient in the combined group, and the recordings could not be used. Consequently, perceptual analysis was performed on seven and nine subjects in each group, respectively.

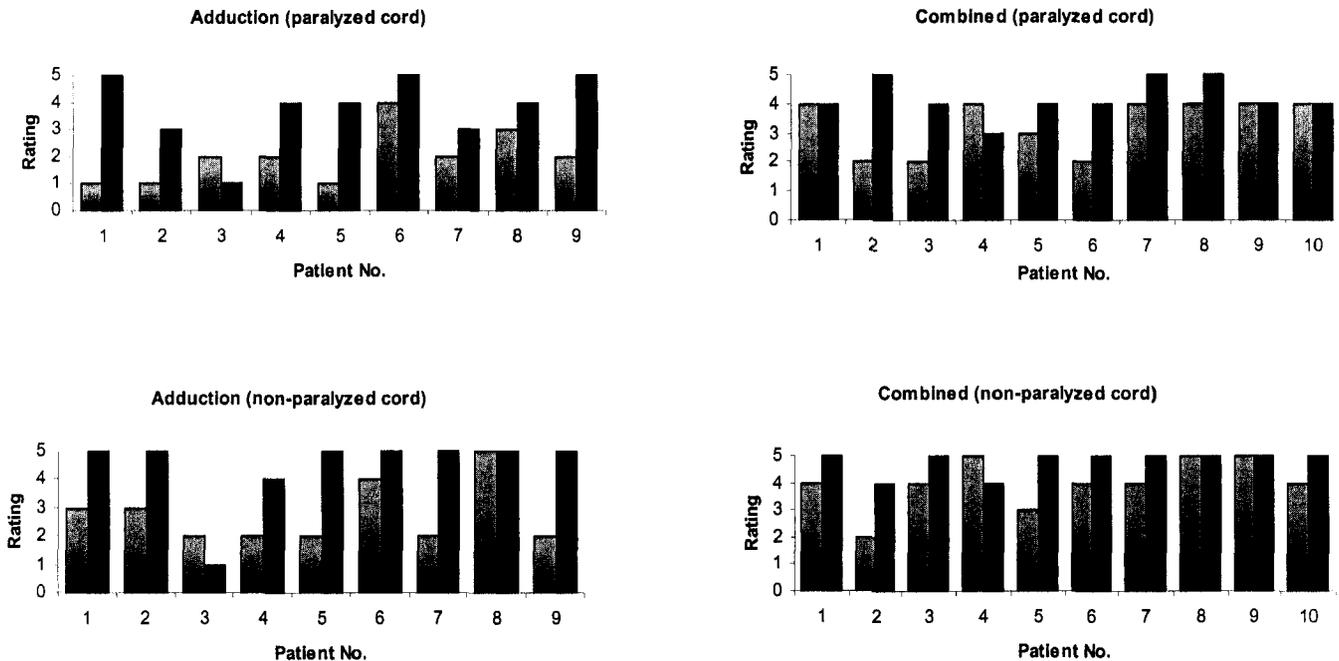


Fig. 2. Preoperative (gray) and postoperative (black) ratings for mucosal wave in the arytenoid adduction (adduction) and the combined surgery (combined) groups. Mucosal wave was defined as the traveling wave visualized on the superior surface of the vocal folds during phonation and was rated as follows: 1 = absent, 2 = limited to most medial edge, 3 = present laterally up to $\frac{1}{4}$ of the width of the vocal folds, 4 = present up to but less than $\frac{1}{2}$ the width of the vocal folds, 5 = present at or more than $\frac{1}{2}$ the width of vocal folds. Both paralyzed and nonparalyzed vocal folds were evaluated. Mucosal wave motion was significantly improved bilaterally in both groups. The extent of improvement was similar in both groups.

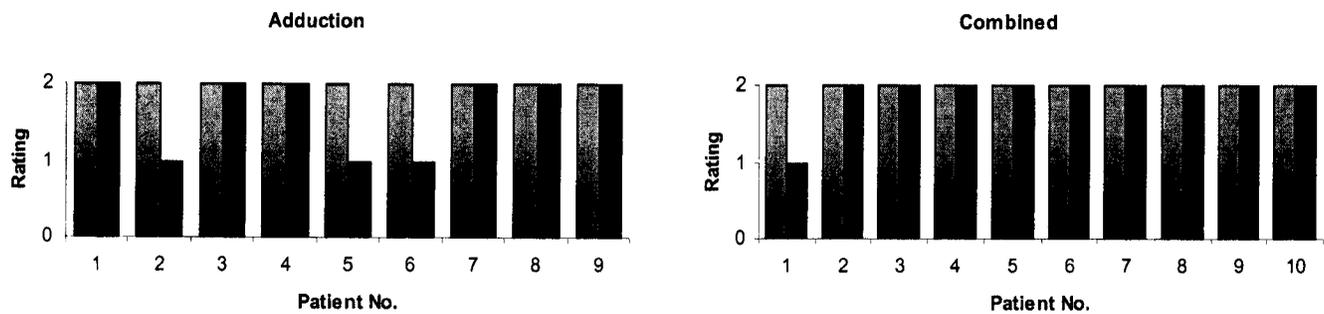


Fig. 3. Preoperative (gray) and postoperative (black) ratings for glottal *symmetry* in the arytenoid adduction (adduction) and the combined surgery (combined) groups. Glottal *symmetry* was defined as the degree to which the two vocal folds performed the same movements as one another during phonation and was rated 1 (symmetrical) or 2 (asymmetrical). *Symmetry* was not significantly changed in either group.

Hypothesis testing was performed at a significance level of $P = .05$. Mean preoperative and postoperative ratings were compared within a treatment group using the Student t test. The *extent* of change in mean ratings between groups was compared using two way ANOVA of surgery type (factor A) by presurgical and postsurgical measurement, with repeated measures on presurgical and postsurgical condition (factor B). The F -ratio statistic of interest is the *interaction effect* between surgery technique and improvement, with a significant P value indicating that one technique led to a significantly better outcome in that parameter.

RESULTS

Patient characteristics are tabulated in Table I. Patient numbers in Table I correlate to all subsequent figures and discussions. Mean patient age was 48.2 years in

the adduction group and 40.1 years in the combined group. Mean patient ages were similar (two-sample Student t test, $t(17) = 1.06, P > .05$). Summary of videostroboscopic measures, aerodynamic measurements, and perceptual analysis is presented in Table II. Further details on closure (bowing vs. posterior chink) and complications are presented in Table III.

Mean glottal closure rating increased significantly in both groups (Fig. 1; Table II). The extent of improvement in closure was similar in both groups. Incomplete closure was either due to the presence of bowing or the result of residual posterior glottic chink (Table III). Forty-four percent of patients achieved complete closure in the adduction group ($n = 9$). Incomplete closure was attributed to

TABLE I.
Patient Demographics.

No.*	Age (y)/Sex	Etiology of Paralysis	Duration of Paralysis	Previous Treatment	Follow-up Voice Recording
Group 1: Arytenoid adduction					
1	61/F	Idiopathic	9 y		36 m
2	37/M	Vagal schwannoma excision	3 m		2 m
3	78/M	Trauma	4 y	Thyroplasty	16 m
4	61/M	Idiopathic	5 y		3 w
5	22/F	Thyroidectomy	8 m		3 m
6	56/F	Carotid endarterectomy	10 m		60 m
7	65/M	Thoracoabdominal aneurysm repair	3 m	Thyroplasty	2 w
8	23/M	Idiopathic	1 y		1 m
9	31/F	Vagal schwannoma excision	6 m		1 m
Group 2: Combined arytenoid adduction and reinnervation					
1	44/M	Mediastinal biopsy	3 m		18 m
2	53/M	Vagal schwannoma excision	3 m		36 m
3	40/M	Thyroidectomy	10 m		3 m
4	42/M	Idiopathic	2 y		8 m
5	43/F	Vagal schwannoma excision	7 m		36 m
6	38/M	Vagal schwannoma excision	2 y	Thyroplasty	15 m
7	53/F	Idiopathic	4 y		24 m
8	41/M	Anterior cervical discectomy	1 y		8 m
9	30/M	Idiopathic	4 y	Thyroplasty	18 m
10	23/F	Coronary artery bypass surgery	1.5 y		7 m

*Patient number in this table correlates to all figures and discussions.

TABLE II.
Summary of Results: Mean Ratings and Measurements.

Parameter	Group 1: Arytenoid Adduction			Group 2: Combined Adduction and Reinnervation			Interaction Effect
	Pre	Post	P Value	Pre	Post	P Value	
Closure	1.6	4.0	<0.05	2.6	4.5	<0.05	F(1,17) = 0.61, P = 0.45
Mucosal wave							
P	2.0	3.8	<0.05	3.3	4.2	<0.05	F(1,17) = 2.1, P = 0.17
NP	2.8	4.4	<0.05	4.0	4.8	<0.05	F(1,17) = 2.6, P = 0.13
Symmetry		χ^2	>0.05		χ^2	>0.05	
Pressure	8.0	7.7	>0.05	8.6	8.2	>0.05	
Airflow	586	326	<0.05	445	298	>0.05	F(1,17) = 0.70, P = 0.42
Resistance	14.8	35.3	<0.05	22.3	31.5	>0.05	F(1,17) = 0.70, P = 0.42
Perceptual	5.2	3.8	<0.05	4.3	2.9	<0.05	F(1,14) = 0.01, P = 0.93

Statistical test of significance within a group was performed using matched sample *t* test unless noted otherwise. Interaction effects were calculated using two-way analysis of variance. See Figure 1–7 legends and text for rating information and discussion. Stroboscopic parameters and perceptual quality were rated and aerodynamic parameters measured. Units of measurements were cmH₂O (pressure), mL/s (airflow), and cmH₂O/cm/s (resistance). P = paralyzed cord; NP = nonparalyzed cord; pre = preoperative mean; post = postoperative mean.

vocal fold bowing (two patients), tiny residual posterior chink (two patients), and new-onset contralateral vocal cord paresis (one patient). Sixty percent of patients achieved complete closure in the combined group (n = 10). Incomplete closure was attributed to vocal fold bowing (two patients) and tiny residual posterior chink (two patients). All cases of “tiny” residual posterior glottic chinks

were at or posterior to the vocal process and were clinically insignificant.

Mucosal wave during phonation was rated in both the paralyzed and nonparalyzed folds and improved significantly in both groups on both folds (Fig. 2; Table II). The extent of improvement of the mucosal waves was similar in both groups on both folds. Only one patient

TABLE III.
Bowling (B), Posterior Chink (PC), Complications.

No.	B (Pre)	B (Post)	PC (Pre)	PC (Post)	Complications
Group 1: Arytenoid adduction					
1	No	No	Complete	Tiny	Laryngospasm
2	No	Yes	No	No	Laryngospasm
3	No	No	Complete	Tiny	None
4	No	No	Complete	Large	None
5	No	No	Complete	No	Stridor
6	Yes	Yes	No	No	None
7	No	No	Very large	No	None
8	No	No	Large	No	None
9	No	No	Very large	No	None
Group 2: Combined adduction and reinnervation					
1	No	No	Tiny	No	None
2	No	Yes	Very large	No	None
3	No	No	Complete	No	None
4	Yes	Yes	No	No	None
5	No	No	Complete	No	None
6	No	No	Large	No	None
7	Yes	No	No	No	None
8	No	No	Tiny	No	None
9	No	No	Large	Tiny	None
10	No	No	Tiny	Tiny	None

Pre = preoperative; Post = postoperative; Complete = no closure; Tiny = small gap posterior to vocal processes; Large = about 1/3 gap; Very large = 1/3 to 2/3 gap.

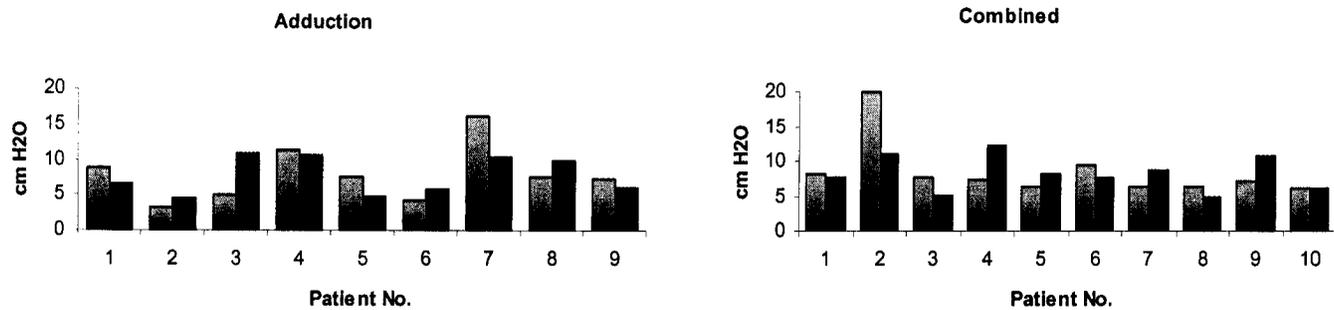


Fig. 4. Preoperative (gray) and postoperative (black) *subglottic pressure* measurement in the arytenoid adduction (adduction) and the combined surgery (combined) groups. Mean subglottic pressure was not significantly changed in either group.

from each group had postoperative worsening of vocal fold mucosal waves. From the adduction group, patient 3 was the eldest and presented with a history of progressive vocal fold paralysis over a 4-year period after a motorcycle accident. Thyroplasty had been performed previously, but closure was essentially absent. After arytenoid adduction the vocal fold was well medialized, but the midglottis formed a convexity as a result of the thyroplasty implant that was left in situ. Although closure improved tremendously (rating change from 1 to 4) mucosal waves were almost nonexistent (rating change from 2 to 1). From the combined group, patient 4 had noted a slight decrement in voice at the time of voice analysis, and videolaryngostroboscopy revealed reduced mucosal waves (rating change from 4 to 3), as well as evidence of mild reflux changes and residual bowing. No significant improvement in vocal cord symmetry was observed in either group (Fig. 3; Table II).

Mean subglottic pressure decreased minimally in both surgical groups (Fig. 4). The reduction of subglottic pressure was not significant in either group (Table II). Glottic mean airflow decreased after surgery in both groups (Fig. 5). However, mean airflow decrease was significant only for the adduction group (Table II). The extent of airflow decrease was similar in both groups. In one patient a dramatic increase in airflow was seen. This patient (patient 4 in the adduction group) had a well-medialized vocal fold but developed a new-onset contralateral vocal fold paresis, resulting in a wide posterior chink. Mean calculated postoperative glottic resistance increased in both surgical groups, but the increase in glottic resis-

tance was significant only for the adduction group (Fig. 6, Table II).

Perceived severity of vocal pathology decreased significantly in both groups (Fig. 7, Table II). The extent of perceptual improvement in voice was not significantly different in the two groups. Both groups improved similarly once the preoperative conditions were accounted for. Two patients worsened perceptually in their postoperative voice rating. The first was patient 4 from the adduction group, who, as described earlier, had a new-onset contralateral cord paresis resulting in incomplete closure and increased airflow. The second was patient 4 from the combined group, who, also as mentioned earlier, had a slight decrement of mucosal waves, an increase in airflow, and no change in closure (attributable to persistent bowing). His worsened mucosal waves were attributed to persistent bowing of the contralateral vocal cord, as well as to reflux changes. This patient also had an extensive psychiatric history and was referred for complex voice evaluation and assessment for collagen augmentation

DISCUSSION

The optimal medialization procedure of choice continues to be an active topic of discussion. Slavitt and Maragos⁴ used arytenoid adduction as the primary procedure and added concurrent thyroplasty for persistent anterior bowing or gap. Other authors have performed thyroplasty as the primary procedure and added arytenoid adduction for any residual posterior glottic chink.^{5,20,21} Bielamowicz et al.¹⁵ reported a comparison of type I thyroplasty and ary-

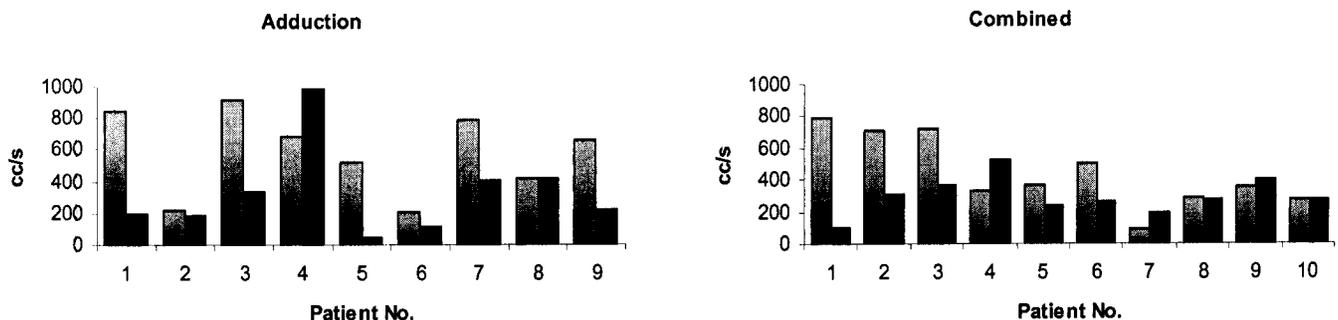


Fig. 5. Preoperative (gray) and postoperative (black) glottal *airflow* measurement in the arytenoid adduction (adduction) and the combined surgery (combined) groups. Mean airflow was decreased in both groups (statistical significance only in the arytenoid adduction group).

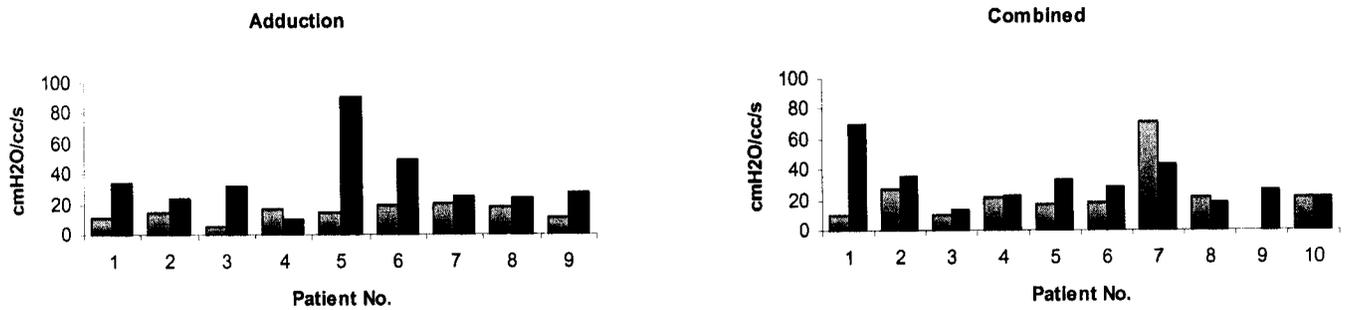


Fig. 6. Preoperative (gray) and postoperative (black) glottal resistance calculated in the arytenoid adduction (adduction) and the combined surgery (combined) groups. Mean resistance was increased in both groups (statistical significance only in the arytenoid adduction group).

tenoid adduction. They found no differences between the two operations in the acoustic measures of jitter, shimmer, and harmonics-to-noise ratio or in the aerodynamic measures of airflow, subglottic pressure, and glottic resistance. Compared with thyroplasty, arytenoid adduction is a technically challenging procedure with a significant learning curve. We encountered two occurrences of laryngospasm requiring intervention and one episode of transient stridor in this series of patients (Table III). All three were cases from the first year of the study period.

It is generally accepted that large posterior glottic chink of the paralyzed larynx is best corrected by arytenoid adduction. Some evidence also suggests that the paralyzed glottis undergoes other complex alterations that may also be better corrected with arytenoid adduction. Woodson²² reported that on the side of the paralyzed glottis the arytenoid cartilage was tipped anteriorly and the cord shortened, requiring compensatory hyperadduction and shortening of the mobile fold during phonation. In a follow-up study, arytenoid adduction increased the vocal fold length and closed the posterior gap in all patients.²³ However, a subset of patients who had long-term vocal paralysis (>20 y) were not benefited, because of vocal fold atrophy and presumed soft tissue contracture. Slavit and Maragos⁴ also noted in several patients a vertical displacement of the paralyzed glottis that was corrected with arytenoid adduction. Thyroplasty alone is unlikely to correct these anatomical changes. Furthermore, in one in vivo canine study of laryngeal paralysis the mean postoperative vocal efficiencies (ratio of the acoustic power of the

voice to the subglottic power) were 2%, 56%, and 67% of normal after thyroplasty, arytenoid adduction, and combined thyroplasty and arytenoid adduction, respectively.²⁴ These reports suggest that arytenoid adduction by itself corrects many of the anatomical derangements of the paralyzed glottis. Any bowing observed after surgery is usually minor and can easily be corrected effectively by collagen injection in the clinic if necessary. Additional medialization thyroplasty is rarely needed.

Preoperative vocal fold bowing was present in one patient (11%) in the adduction group and two patients (20%) in the combined group. The low incidence of bowing can be explained by the fact that such a conformation is not attainable in the presence of a significant posterior glottic chink or absent closure. These conditions were present in 78% of the adduction group and 50% of the combined group (Table III). Of the three cases of preoperative bowing, arytenoid adduction was able to correct only one (patient 7, combined group). Of the other two cases of residual bowing, one was improved (patient 6, adduction group) and the other was unchanged (patient 4, combined group). Of the two new occurrences of bowing observed after surgery, one was mild (patient 2, adduction group) and the other was minimal (patient 2, combined group). In all cases of bowing the *contralateral* mobile fold contributed significantly to the bowing (Fig. 8). This phenomenon has been reported previously where the process of compensatory hyperfunction of the mobile larynx results in anteroposterior compression of the glottis and bowing of the normal vocal fold.²² It is important to note that post-

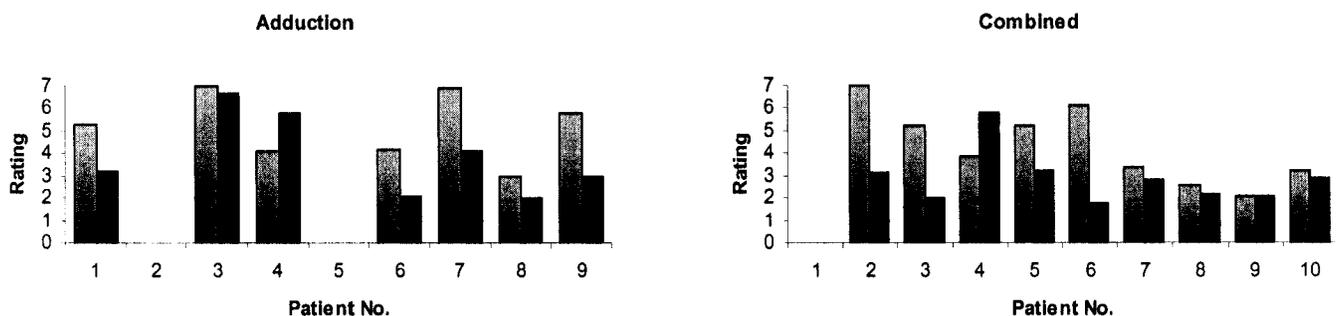


Fig. 7. Preoperative (gray) and postoperative (black) ratings for perceptual analysis in the arytenoid adduction (adduction) and the combined surgery (combined) groups. Voice samples were rated between 1 (normal) and 7 (severely abnormal). There was significant perceptual improvement in both groups. The extent of improvement was similar in both groups.

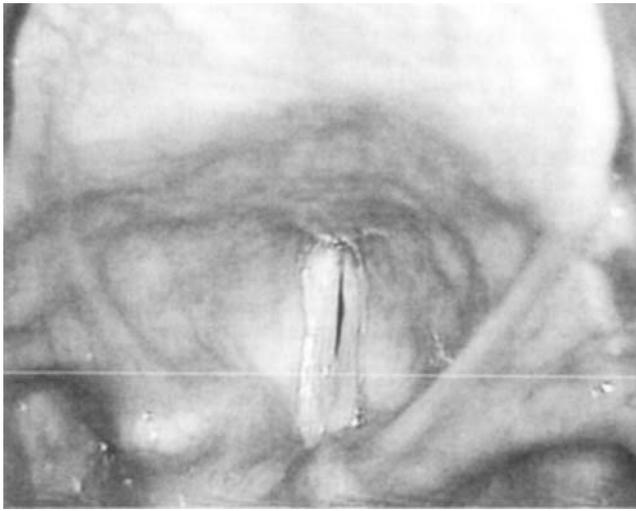


Fig. 8. Postoperative glottal configuration at maximal phonation in patient 6 of the adduction group, illustrating the contribution of the contralateral vocal cord to residual bowing. The paralyzed *left* vocal cord is nicely medialized after arytenoid adduction, but the mobile *right* vocal fold demonstrates persistent bowing.

operative bowing was observed in 21% in the adduction group and 19% in the combined group and that all cases were minimal to mild.

Stroboscopic evaluation revealed an improvement in closure and mucosal waves in both treatment groups. Glottal closure and mucosal waves are intimately related. The improved closure obtained by medialization leads to entrainment of both vocal folds with resultant improved propagation of mucosal wave on the vocal cord surface.⁹ The lack of improvement in symmetry is not surprising, because the paralyzed vocal fold is anchored in place by the adduction sutures and has limited motion. Improved closure also contributed to decreased glottic airflow that was seen in both treatment groups. Subglottic pressure was essentially unaltered in both groups. This finding has been reported previously with both thyroplasty and arytenoid adduction and is consistent with the notion that the glottis is driven by a constant pulmonary pressure system.¹⁵ Thus airflow is adjusted to maintain near-normal subglottic pressure despite the degree of glottic insufficiency.

Perceptual evaluation indicated that, while vocal quality significantly improved in both groups, the degree of improvement in both groups was identical. At this juncture, this should not be taken as evidence against our initial hypothesis that thyroarytenoid muscular tone is an essential component of a stable, good vocal quality. First, a very small sample size was present, reducing the power of the study. Second, the postoperative voice recordings were not performed at identical intervals, and the clinical scenarios for performing the vocal analysis were heterogeneous, which may have resulted in the great variability of ratings. A prospective randomized trial would be necessary for this purpose. Because reinnervation takes place only after several months, performing vocal analysis over various postoperative time periods could also assess the effects of reinnervation alone. Presumably, patients in both groups also undergo spontaneous time-related

changes such as scar contracture or resolution of edema in the postoperative period. These time-related changes probably also need to be accounted for when attributing the postoperative changes to reinnervation alone. These time-related changes could not be assessed in this retrospective study because most patients received a single postoperative vocal analysis at the various intervals presented in Table I. A future prospective trial would also be useful in this regard.

In our experience, a significant number of patients who have undergone laryngeal reinnervation have reported a perceivable improvement in their voice at 4 to 9 months after surgery, when reinnervation is expected to be established. From this clinical experience, we have concluded that there is probably a subgroup of patients who benefit from laryngeal reinnervation, and while some do not benefit, we have no way, yet, of knowing who these patients are. Therefore we continue to offer laryngeal re-

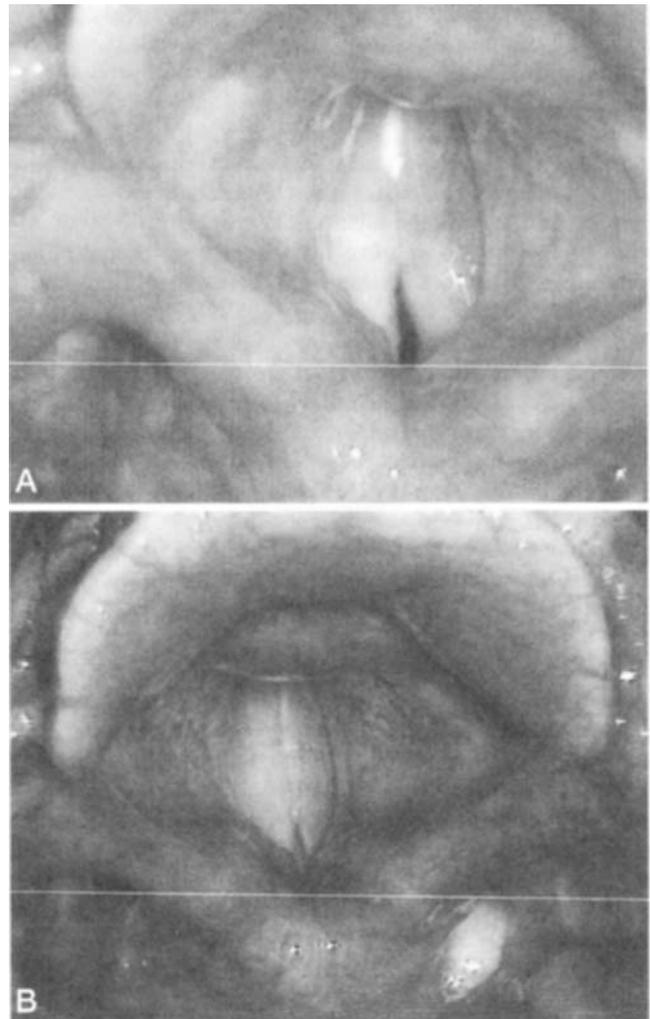


Fig. 9. Preoperative (A) and postoperative (B) glottal configuration at maximal phonation in patient 6 of the combined group. The paralyzed *right* vocal cord has undergone type I thyroplasty, but persistent large posterior chink remains (A). Complete closure and great improvement in the perceptual quality of voice were achieved after removal of the thyroplasty implant and completion of arytenoid adduction with reinnervation (B).

innervation to our patients. Intraoperative electromyography of the thyroarytenoid has been added to select truly denervated vocal cords that would theoretically benefit from reinnervation. The additional morbidity and increase in operative time from adding reinnervation to medialization is minimal. As far as we know, objective assessment of combined arytenoid adduction and ansa cervicalis to recurrent laryngeal nerve anastomosis for unilateral vocal cord paralysis has not been reported. Netterville et al.⁵ mentioned performing a few cases, but a predicted follow-up study has not been published.

The indications and optimal timing of laryngeal reinnervation have not been defined. In cases of idiopathic paralysis or when the extent of nerve injury is not clear, an adequate time interval should be allowed for return of function. When laryngeal framework surgery is performed, intraoperative electromyography is useful for distinguishing truly denervated vocal folds that would benefit from reinnervation, from those which have established a synkinetic reinnervation after a period of axonotmesis and would not benefit from nonspecific laryngeal reinnervation. The question of "After how long a wait is reinnervation unlikely to add any benefit?" could probably be definitely answered by a prospective study using preoperative and postoperative electromyography and perceptual analysis data. In this study, patient 6 (combined group) had reinnervation 2 years after a vagal schwannoma resection and failed medialization thyroplasty. The perceptual improvement was excellent, and he was one of the patients who noted a further improvement of voice quality around 6 months after surgery (Fig. 9). Patient 9 (combined group) had a 4-year history of progressive idiopathic paralysis and had also failed thyroplasty. Postoperative electromyography and magnetic stimulation studies were performed at the National Institute on Deafness and Other Communication Disorders (C. Ludlow, personal communication, May 1992) 15 months after reinnervation. The results showed not only that the vocal cord was reinnervated, but also that the activation pattern was normal in its timing pattern, indicating that the thyroarytenoid muscle was activating correctly for speech gestures.

CONCLUSION

Combined laryngeal reinnervation and medialization for treatment of unilateral vocal cord paralysis is feasible and provides theoretical advantages over medialization alone. We compared the combined procedure with arytenoid adduction in a small group of patients. No significant differences were found in the videostroboscopic parameters, aerodynamic measures, and perceptual ratings between the two groups. Prospective studies are required before the role of laryngeal reinnervation is definitely established in the treatment of vocal cord paralysis.

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