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A-P Positioning of Medialization Thyroplasty in an Excised Larynx Model

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Abstract

Hypothesis—Posterior positioning of medialization thyroplasty provides the best acoustic and aerodynamic outcomes.

Study Design—Ex vivo excised canine larynx.

Methods—Unilateral thyroplasty windows were cut in the thyroid cartilages of 10 excised canine larynges. Each larynx was mounted on an artificial lung and the vocal fold opposite the thyroid window was adducted by medializing its arytenoid cartilage. Then, medialization thyroplasty was simulated with a probe placed anterior, central, and posterior in the thyroid window. The glottal area, airway reduction, medialization force, phonation threshold pressure and flow, aerodynamic power, intensity, efficiency, jitter, shimmer, and signal-to-noise ratio (SNR) were measured at each medialization position.

Results—Posterior medialization probe placement minimized the glottal area, provided the best voice as determined by perturbation measures and SNR, reduced the work of phonation, and increased efficiency. Anterior and middle probe placement minimized the work of phonation but provided only modest gains in sound quality and decreased sound intensity. Medializing the vocal fold with posterior probe placement required twice as much force as central and anterior probe placement.

Conclusions—The results suggest that posterior medialization provides the greatest improvement in acoustic parameters and efficiency in patients who can tolerate the airway reduction. Middle and anterior medialization can decrease work of phonation, but in this experiment objective improvement in sound quality was limited. Subtle changes in displacement shim contour, especially in middle and anterior locations, have a substantial impact on voice outcome, affirming the value of intraoperative voice assessment.

Keywords

Thyroplasty; excised larynx; voice assessment

INTRODUCTION

Medialization thyroplasty is a commonly performed procedure for voice restoration in patients with unilateral and bilateral vocal fold paralysis or paresis.^{1,2} The technique

employs a prefabricated or custom carved implant that is positioned through a small thyroid cartilage window to directly medialize the affected vocal fold(s).^{2,3} The primary mechanism by which the technique improves phonation is thought to be through facilitating phonatory glottic closure, as demonstrated by direct correlations between glottal area and acoustic outcome in thyroplasty patients.⁴ Excised larynx studies show that the posterior region of the glottis is the most difficult to close with the medialization thyroplasty technique alone,⁵ and a persistent posterior glottic gap is the most frequent cause for thyroplasty revisions in humans.^{6,7} Consequently, the design of medialization prostheses has focused on shapes that allow for maximal displacement of the posterior glottis⁸ without objective evidence that this provides superior outcomes.

Anatomic studies show that vocal fold medialization at the midmembranous location can achieve the same glottic closure with much less force than at the posterior location.⁵ Furthermore, implants placed in the anterior or midmembranous vocal fold can be smaller, posing less risk of penetrating the inner perichondrium⁹ and consequent prosthesis extrusion. On the other hand, glottic area is only one factor in achieving optimal outcomes in thyroplasty; other considerations include matching the vocal fold edges vertically¹⁰ and matching tensions,¹¹ and it is not known how prosthesis placement affects these parameters. Our surgical experience using intraoperative voice testing has shown that midmembranous medialization can sometimes produce equivalent or better results as the posterior position. This has never been studied in more controlled environments, such as excised larynx experiments, which have an advantage over in vivo human studies as they allow direct measurement of subglottal pressure, a measure inconsistent in postoperative studies.¹² Existing excised larynx studies of thyroplasty have only looked at static anatomic considerations^{5,9} or compared dissimilar techniques.¹³ In this excised larynx study, the effect of anterior-posterior medialization prosthesis placement was investigated on the dynamic acoustic and airflow parameters of pressure, flow, intensity, efficiency, power, jitter, shimmer, and signal-to-noise ratio (SNR), as well as the static parameters of glottal area, airway reduction, and implant force.

MATERIALS AND METHODS

Thyroplasty Window

Unilateral thyroplasty windows were cut in 10 excised canine larynges in the typical manner used in thyroplasty surgery (Fig. 1).^{2,3} The superior aspect of the window was made midway between the thyroid notch and the inferior margin of the thyroid cartilage. The anterior margin was set 5 mm posterior to the anterior midline of the thyroid cartilage. The window was adjusted somewhat, depending on the size of the cartilage, to achieve a window approximately 5 mm in superior-inferior dimension and 14 mm in anterior-posterior dimension. This centered the thyroplasty window over the true vocal fold and allowed preservation of the structural integrity of the thyroid cartilage. The cuts were made using a #11 scalpel blade, and great care was taken to preserve the perichondrium, especially in the anterior cuts. The window was elevated using a blunt elevator and removed. To expose the vocal folds from above for photography, excess thyroid cartilage, epiglottis, and soft tissue were removed using scissors.

Experimental Setup

Each larynx was mounted on a barbed fitting connected to a custom built artificial lung chamber (Fig. 2). Airflow into the lung chamber was controlled with a pressure valve and directed first through two Concha Therm III humidifiers in series (Fisher & Paykel Healthcare Inc., Laguna Hills, CA) and an FMA-1601A airflow meter (Omega Engineering Inc., Stamford, CT). An ECM-88 microphone (Sony Electronics Inc., New York, NY) was

positioned 15 cm above and 5 cm anterior to the larynx and an Ultima APX digital camera (Photron USA Inc., San Diego, CA) was mounted directly above to take photographs of the glottal areas. The pressure directly beneath the larynx was measured with a Heise 901 series digital pressure meter (Ashcroft Inc., Stratford, CT). The pressure and flow readings and the acoustic signal were recorded using custom Labview 7.1 software (National Instruments Corp., Austin, TX). A suture placed through the thyroid notch secured the thyroid cartilage anterior to an x-y-z stage. The arytenoid cartilage opposite to the thyroplasty window was adducted using a three-pronged probe on an x-y-z stage. Medialization thyroplasty was simulated by a probe 3 mm in diameter attached to a DFG60-0.5 force gauge (Omega Engineering Inc., Stamford, CT) on another x-y-z stage. The probe was advanced through the thyroplasty window to adduct the anterior, medial or posterior portion of the vocal fold. The probe was advanced just enough to allow the portion of the vocal fold it was medializing to lightly touch the opposite adducted vocal fold.

Experimental Trials

For each larynx, a photograph was taken from above with the larynx mounted and the arytenoid cartilage opposite the thyroplasty window adducted (Fig. 3). Then, the flow of air was slowly increased through the system using the pressure valve, stopping briefly at pressure multiples of 5 cm H₂O, while measuring the pressure and flow rate and recording an acoustic signal. The pressure was increased slowly to 35 cm H₂O and then decreased slowly back to zero. This was repeated 5 times and considered the unilateral paralysis condition. Then, the medialization probe was positioned to medialize the anterior portion of the vocal fold. A photograph was taken and five recordings made in the same manner as previously described. This was repeated for medialization of the middle and posterior portions of the vocal fold.

Data Analysis

The glottal area of the unilateral paralysis and three medialization positions for each larynx was extracted from the digital photographs using custom-edge detection software. The degree of airway reduction was estimated by halving the change in glottal area to account for abduction of the nonparalyzed vocal fold during breathing. Frequency against time spectrograms were made from the 20 acoustic recordings of each larynx using TF32 software (Paul Milenkovic, Madison, WI). The time point when phonation began was noted and then used to extract the phonation threshold pressure, phonation threshold flow, medialization force, and phonation threshold sound intensity from the Labview data for each recording. The acoustic data from each recording was then examined using GoldWave software (GoldWave Inc., St. John's, Canada) and 3 one-second clips were cut from the first 3 continuous seconds of steady amplitude signal after the start of phonation. Jitter, shimmer, and SNR calculations were made using CSpeech software (Paul Milenkovic, Madison, WI) run on these 3 one-second clips and averaged for each recording. All of the data was averaged for the unilateral paralysis and three medialization positions for each larynx and analyzed using ANOVA with SAS statistical analysis software (SAS Institute Inc., Cary, NC). Acoustic power was calculated from these results by multiplying pressure by flow. Efficiency was calculated by dividing intensity by acoustic power. The signal ratio is the fraction of the desired signal in the recording and was calculated by taking the inverse of $(1 + 1/\text{SNR})$. The signal intensity is the intensity of the desired signal and was calculated by multiplying the signal fraction by the intensity. The signal efficiency was calculated in a similar manner.

RESULTS

Medialization Area and Force

The reduction in glottal area correlated very closely with medialization probe position (Table I). Anterior, middle, and posterior probe placement resulted in areas $\sim\frac{3}{4}$, $\frac{1}{2}$, and $\frac{1}{4}$ of the simulated unilateral paralysis area, respectively. With abduction of the nonparalyzed vocal fold during breathing, this corresponds to a reduction of airway area of 11%, 29%, and 37% for the anterior, middle, and posterior medialization positions, respectively. The force required to medialize the vocal fold at anterior and middle locations was very similar and around half the force required at the posterior location.

Aerodynamic Results

Anterior and middle medialization both lead to a slight decrease in phonation threshold pressure (9% and 4%, respectively), while posterior medialization increased the phonation threshold pressure by around 25%. Phonation threshold flow decreased uniformly with anterior, middle, and posterior medialization, resulting in 24%, 27%, and 34% reductions in flow compared to unilateral paralysis.

These changes in pressure and flow resulted in an overall decrease in calculated aerodynamic power (or rate of work) with medialization (Table II). The greatest decrease was with anterior and middle medialization, both giving a 30% reduction in power consumption, whereas posterior medialization resulted in a 20% reduction in power consumption.

Acoustic Results

Anterior and middle medialization offered a modest 10%–20% reduction in jitter and an approximate 10% reduction in shimmer compared to unilateral paralysis. Posterior medialization showed a far greater reduction, 45% reduction in jitter and 28% reduction in shimmer.

Noise was very significant in these experiments due to the high flow of air resulting from the large glottic gaps. SNR improved by 16% and 7% with anterior and middle medialization, respectively, and by 28% with posterior medialization.

Intensity at phonation threshold decreased by approximately 50% with anterior and middle medialization compared to unilateral paralysis. Posterior medialization produced an overall intensity just 7% less than unilateral paralysis and equal signal intensity.

Combining the intensity results with the calculated aerodynamic power provides efficiency data. Anterior and middle medialization showed a 30% and 20% decrease in efficiency, respectively. Posterior medialization resulted in a 15% improvement in overall efficiency and a 23% improvement in signal efficiency.

DISCUSSION

The anatomic, acoustic and aerodynamic parameters measured in this study all showed significant changes when the medialization probe was advanced from anterior to posterior. Some of these changes were likely a consequence of changing geometry while others probably indicate improved phonatory conditions. Glottal area decreased in a predictable manner matching the shortening of the hypotenuse of the triangular glottic opening (Fig. 3). Medialization force doubled likely due to increased force dissipation from higher amounts of tissue between the medialization probe and the posterior vocal fold as well as losses from moving the arytenoid cartilage (Fig. 3). Phonation threshold flow decreased likely not only

from increased friction due to airway narrowing, but also from improvement in phonatory conditions that lower phonation threshold, such as symmetry, tension or glottic closure.

Phonation threshold pressure showed a more complicated pattern. It decreased with anterior and middle medialization, but greater pressures were required for posterior medialization. This translated to anterior and middle medialization requiring less aerodynamic power than posterior medialization, although the resulting intensity and efficiency at phonation threshold were also much lower than seen with posterior medialization. This may be explained by considering that anterior and middle medialization require less displacement to achieve effective approximation to the contralateral vocal fold. Vocal fold entrainment and focal oscillation can thus be rendered even though there is a residual glottic gap posterior. The ensuing vibration will tend to be asymmetric and of lower amplitude, producing a less efficient signal of lower intensity. Posterior medialization requires greater aerodynamic power due to substantially smaller glottic area and entrainment of a longer vocal fold length. Once phonation is achieved with posterior medialization, because of better efficiency a greater signal intensity is possible than with more anterior shim locations.

The perturbation measures and SNR showed that posterior displacement also offers superior acoustic results to anterior and middle displacement. This is likely a reflection of the more even distribution of tension in posterior medialization combined with improved symmetry. These factors decrease the irregular and, at times, chaotic behavior that creates jitter, shimmer, noise, and hoarseness.

The results can be summarized in terms of the goals of medialization thyroplasty: to improve sound quality, intensity, ease of phonation, efficiency, and airway protection. Sound quality is subjective, and in this study we used objective acoustic measures of percent jitter, percent shimmer, and SNR to best describe this perceptual entity. Sound intensity was measured at the start of phonation, providing a measure of the intensity of sound with minimal effort. Aerodynamic power was calculated from phonation threshold pressure and flow and is a measure of the ease of phonation to produce minimal sound. Efficiency combines intensity and aerodynamic power. Airway protection is a function of the ability to reduce glottal area with maximal vocal fold adduction.

The results show that posterior placement was superior in terms of acoustic measures, efficiency, and airway protection (Table III) at a moderate cost in airway reduction. Middle placement had minimal improvement in sound quality but a larger reduction in the work of phonation. Anterior placement had similar sound quality and work of phonation results as middle placement but with poorer efficiency and airway protection, although consequently, the least reduction in airway caliber.

These findings are in agreement with the design preference of most preformed prostheses, such as the Montgomery® Implant System (Boston Medical Products, Boston., MA) and the Kurz Titanium Implant (Kurz Medical, Norcross, GA), which favor posterior displacement.⁸ They are also similar to findings in human postoperative thyroplasty studies. Jitter, shimmer, and SNR universally improve with thyroplasty.^{4,14,15} In a study by Omori et al. these improvements correlated with reduction in glottal area.⁴ This also occurred in this study but showed a more substantial improvement when factors such as symmetry and equalization of tension (expected in posterior medialization) were also present. The decrease in airflow seen in this study also agrees well with human studies and is a consequence of airway narrowing and improved phonatory conditions.^{12,16} Pressure estimates in humans show mixed results with most studies reporting a decrease in intraoral pressure,¹² an indirect estimate for subglottal pressure. In this study, subglottal pressure showed a complicated pattern that decreased with anterior and middle medialization but increased with posterior medialization.

As explained previously, this was likely due to differences in mechanics between anterior and posterior medialization.

The results in this study show some differences with previous excised larynx studies of medialization thyroplasty. In a study by Green et al., jitter, shimmer, and SNR worsened with medialization thyroplasty alone but improved the results of arytenoid adduction when combined with that procedure.¹³ The authors concluded that the poor results they experienced with medialization thyroplasty alone were likely due to the large posterior chink present between the vocal processes in dogs. In this study, we were able to achieve improvement in jitter, shimmer, and SNR without complete glottic closure by using a small probe that medialized a portion of the vocal fold until it touched the opposite fold instead of the triangular shaped shim used in the afore-mentioned study. This highlights the importance of displacing the vocal fold adequately enough to entrain the opposite vocal fold, while avoiding too much displacement, especially in anterior and middle locations, that could potentially impede vibration. As in the anatomic study by Noordzij et al., we observed that posterior medialization required a greater force to adequately medialize the vocal fold. Unlike that study, we could not achieve the same glottic closure with displacement of the middle vocal fold as we could with displacement of the posterior vocal fold.⁵ This was again likely due to the smaller probe used in this study compared to the large shims used in previous studies.

There are limitations in applying an excised canine larynx model to human glottic insufficiency, such as the aforementioned differences in anatomy and lack of compensatory behavior; however, these differences should not significantly affect the trends observed in the various medialization positions. Another potential limitation in our model is that all of the measurements were made at phonation threshold or slightly above in the case of jitter and shimmer. This was designed to detect the changes in aerodynamic and acoustic parameters with different medialization positions at the point of minimal effort in phonation. For higher pressures and flows, the parameters will likely maintain the relationships observed in this experiment; however, this is not certain. For example, the poor efficiency seen with anterior and middle medialization may be present only at low aerodynamic power and may improve with higher pressures, leading to higher intensities.

In applying the findings in this study, it appears that prosthesis design may be tailored to patient goals. Prostheses that emphasize posterior glottis medialization could be used in patients with good respiratory reserve. The surgeon can feel confident that additional prosthesis size and force of medialization can be translated into effective medialization of the membranous vocal fold. When intraoperative monitoring fails to show the desired result, additional medialization might be achieved through judicious anterior and midmembranous displacement. Arytenoid adduction remains an option when all of these measures prove ineffective and especially if the plane of correction is not matched to the opposite vocal fold. Prostheses emphasizing middle and anterior medialization could be chosen for patients who cannot tolerate any airway compromise. Effective displacement should be possible using only gentle force and small displacement prostheses. With care to avoid irregularities such as an approach should prove particularly useful for patients with significant bilateral pathology or poor respiratory reserve.

A final important point is that many of the larynges did not display the final pattern seen in the averaged results as evident by the large standard deviations in the data. This reaffirms the importance of intraoperative voice assessment performed by many surgeons.¹⁷ Under ideal circumstance this should guide how the particular patient will respond to different probe placements. When intraoperative testing is not possible due to bleeding or edema¹⁸ or

in the occasional patient done under general anesthesia, the data presented in this study give surgeons a general idea of what they can expect with different medialization positions.

CONCLUSION

This is the first study examining the influence of medialization thyroplasty prosthesis design, specifically, the anterior-posterior point of maximal medialization on acoustic and aerodynamic parameters during phonation. The results show that posterior medialization reduces the glottal area most and offers the best sound quality and efficiency. Anterior and middle medialization show only modest improvement in sound quality but place much less force on the medialization prosthesis and offer the greatest reduction in work of phonation. Subtle changes in displacement shim contour, especially in anterior and middle location, have a substantial impact on voice outcome, affirming the value of intraoperative voice assessment.

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BIBLIOGRAPHY

1. Isshiki N, Okamura H, Ishikawa T. Thyroplasty type I (lateral compression) for dysphonia due to vocal cord paralysis or atrophy. *Acta Otolaryngol.* 1975; 80:465–473. [PubMed: 1202920]
2. Ford, CN. Thyroplasty: indications, techniques, outcome. In: Fried, MP.; Ferlito, A., editors. *The Larynx*. San Diego, CA: Plural Publishing Inc.; 2008. p. 243-252.
3. Koufman JA. Laryngoplasty for vocal cord medialization: an alternative to Teflon. *Laryngoscope.* 1986; 96:726–731. [PubMed: 3724322]
4. Omori K, Kacker A, Slavitt DH, Blaugrund SM. Quantitative videostroboscopic measurement of glottal gap and vocal function: an analysis of thyroplasty type I. *Ann Otol Rhinol Laryngol.* 1996; 105:280–285. [PubMed: 8604889]
5. Noordzij JP, Opperman DA, Perrault DF Jr, Woo P. The biomechanics of the medialization laryngoplasty (thyroplasty type I) in an ex vivo canine model. *J Voice.* 1998; 12:372–382. [PubMed: 9763188]
6. Koufman JA, Postma GN. Revision laryngoplasty. *Op Tech Otolaryngol.* 1999; 10:61–65.
7. Woo P, Pearl AW, Hsiung MW, Som P. Failed medialization laryngoplasty: management by revision surgery. *Otolaryngol Head Neck Surg.* 2001; 124:615–621. [PubMed: 11391250]
8. Montgomery WW, Blaugrund SM, Varvares MA. Thyroplasty: a new approach. *Ann Otol Rhinol Laryngol.* 1993; 102:571–579. [PubMed: 8352479]
9. Kojima H, Hirano S, Shoji K, Isshiki N. Anatomic study for posterior medialization thyroplasty. *Ann Otol Rhinol Laryngol.* 1999; 108:373–377. [PubMed: 10214785]
10. Ford CN. Advances and refinements in phonosurgery. *Laryngoscope.* 1999; 109:1891–1900. [PubMed: 10591344]
11. Isshiki N. Progress in laryngeal framework surgery. *Acta Otolaryngol.* 2000; 120:120–127. [PubMed: 11603755]
12. Hartl DM, Hans S, Vaissiere J, Brasnu DF. Laryngeal aerodynamics after vocal fold augmentation with autologous fat vs. thyroplasty in the same patient. *Arch Otolaryngol Head Neck Surg.* 2005; 131:696–700. [PubMed: 16103301]
13. Green DC, Berke GS, Ward PH. Vocal fold medialization by surgical augmentation versus arytenoid adduction in the in vivo canine model. *Ann Otol Rhinol Laryngol.* 1991; 100:280–287. [PubMed: 2018285]

14. Lundy DS, Casiano RR, Xue JW, Lu FL. Thyroplasty type I: short- versus long-term results. *Otolaryngol Head Neck Surg.* 2000; 122:533–536. [PubMed: 10740173]
15. Lu FL, Casiano RR, Lundy DS, Xue JW. Longitudinal evaluation of vocal function after thyroplasty type I in the treatment of unilateral vocal paralysis. *Laryngoscope.* 1996; 106:573–577. [PubMed: 8628083]
16. Janas JD, Waugh P, Swenson ER, Hillel A. Effect of thyroplasty on laryngeal airflow. *Ann Otol Rhinol Laryngol.* 1999; 108:286–292. [PubMed: 10086623]
17. Netterville JL, Stone RE, Luken ES, Civantos FJ, Ossoff RH. Silastic medialization and arytenoid adduction: the Vanderbilt experience. A review of 116 phonosurgical procedures. *Ann Otol Rhinol Laryngol.* 1993; 102:413–424. [PubMed: 8390215]
18. Maves MD, McCabe BF, Gray S. Phonosurgery: indications and pitfalls. *Ann Otol Rhinol Laryngol.* 1989; 98:577–580. [PubMed: 2764438]

Fig. 1. Schematic showing the dimensions and position of the thyroplasty window cut into the thyroid cartilage of each larynx. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

Fig. 2. Schematic of the experimental apparatus. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

Fig. 3.

Photographs and schematic of the four different conditions examined in this study. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

TABLE I

Measured Parameters Averaged Over All Larynges.

Measured Parameters	Unilateral Paralysis	Position of Medialization Thyroplasty				P Value*
		Anterior	Middle	Posterior		
Glottal area (pixels)	4110 ±1599	3210 ±1926 (78.1%)	1700 ±1470 (41.4%)	1080 ±869 (26.3%)	<.001	
Force (g)	1.35 ±2.96	4.44 ±3.12 (100%)	4.77 ±2.23 (107.4%)	9.06 ±4.02 (204.1%)	<.001	
PTF (ml/min)	98.9 ±27.2	75.7 ±19.7 (76.5%)	72.6 ±23.5 (73.4%)	64.9 ±22.5 (65.6%)	.008	
PTP (cm H ₂ O)	9.31 ±2.8	8.49 ±3.4 (91.2%)	8.98 ±3.6 (96.5%)	11.5 ±4.7 (123.5%)	.048	
PTI (dB)	70.1 ±5.1	66.8 ±6.7 (46.8%)	67.6 ±7.0 (56.2%)	69.8 ±8.5 (93.3%)	.196 [‡]	
Jitter (%)	8.63 ±3.80	7.78 ±3.56 (90.2%)	6.8 ±2.45 (78.8%)	4.72 ±2.45 (54.7%)	.028	
Shimmer (%)	26.7 ±7.5	23.4 ±9.8 (87.6%)	23.7 ±9.7 (88.8%)	19.2 ±11.3 (71.9%)	.065 [‡]	
SNR	2.44 ±0.92	2.83 ±1.37 (116.0%)	2.62 ±1.37 (107.4%)	3.13 ±1.30 (128.3%)	.168 [‡]	

PTF = phonation threshold flow; PTP = phonation threshold pressure; PTI = phonation threshold intensity; SNR = signal-to-noise ratio.

The numbers in parentheses give the percentage change from unilateral paralysis, except for force which is percentage change from anterior medialization. For the values given in dB, the numbers in parenthesis give the actual percentage change, not the percentage change in dB.

* Analysis of variance.

[‡] $P < .05$ for unilateral paralysis vs. anterior medialization and unilateral paralysis vs. posterior medialization if animal 4 is excluded.

[‡] $P < .05$ for unilateral paralysis vs. posterior medialization in all animals. $P < .05$ for anterior vs. posterior medialization if animal is 4 excluded.

TABLE II

Parameters Calculated From Averaged Measured Parameters.

Calculated Parameters	Position of Medialization Thyroplasty			
	Unilateral Paralysis	Anterior	Middle	Posterior
Power (mW)	1.47	1.03 (69.8%)	1.04 (70.8%)	1.19 (81.1%)
Efficiency (dB)	68.4	66.7 (67.0%)	67.4 (79.4%)	69.0 (115.1%)
Signal ratio	0.71	0.74 (104.2%)	0.72 (102.0%)	0.76 (106.8%)
Signal intensity (dB)	68.6	65.5 (48.7%)	66.2 (57.4%)	68.6 (99.7%)
Signal efficiency (dB)	66.9	65.4 (69.8%)	66.0 (81.0%)	67.8 (123.0%)

The numbers in parentheses give the percentage change from unilateral paralysis. For the values given in dB, the numbers in parenthesis give the actual percentage change, not the percentage change in dB.

TABLE III

Summary of Results.

Medialization Location	Sound Quality	Intensity	Ease of Phonation	Efficiency	Airway Protection
Anterior	+	-	+++	-	+
Middle	+	-	+++	-	++
Posterior	+++	±	++	++	+++

Each + represents ~10% increase, each - represents ~10% decrease, except for airway protection, where each + represents ~25% increase.