PHONETIC PATTERNS AFTER CO2 LASER POSTERIOR TRANSVERSE CORDOTOMY FOR BILATERAL VOCAL FOLD PARALYSIS

Stéphane Hans*°, Jacqueline Vaissière* and Daniel Brasnu°
°Department of Otolaryngology-Head and Neck Surgery,Laënnec Hospital, University Paris V
**Institute of Phonetics, University Paris III, UPRESA-CNRS 7018.*

ABSTRACT

A combination of non invasive acoustic and aerodynamic measures were used to analyze vocal function in three patients treated by CO2 Laser posterior transverse cordotomy for bilateral vocal fold paralysis. Measures included : (i) Frequency features : fundamental frequency, standard deviation, jitter, shimmer and harmonic-to-noise ratio, (ii) Several measures on the spectra of vowel /a/ : first-formant banwidths, the difference between the amplitudes of the first and second harmonics (H1-H2), the difference between the amplitude of the first harmonic and the amplitude of the first formant peak (H1-A1), the difference between the amplitudes of the first harmonic and the third formant peak was measured (H1-A3). (iii) Laryngeal aerodynamic parameters include maximum phonation time (MPT), mean air flow rate in « sustained phonation » (MFRs), phonation quotient (PQ) and mean air flow rate in « comfortable phonation » (MFRc). These measures are discussed to examine relationships among acoustic and laryngeal aerodynamic parameters, and to evaluate the degree of breathiness.

1- INTRODUCTION

Surgical management addressed bilateral vocal fold paralysis (BVFP) in patients with severe obstruction, should aim at a compromise between respiratory and phonatory performance. In the past decade, endoscopic CO2 laser arytenoidectomy has become perhaps the most commonly used surgical procedure for enlarging the glottis airway in patients whith BVFP [1] (Figure 2). Endoscopic CO2 Laser posterior transverse cordotomy (PTC) was initially reported by Dennis and Kashima in 1989 [2, 3] (Figure 3). Using the surgical properties of the CO2 Laser, the vocal ligament is sectionned just anterior to the vocal process of the arytenoid cartilages. Dennis and Kashima reported that the CO2 Laser PTC enlarges the posterior glottic aperture « respiratory glottis » and preserves close approximation of the anterior membranous vocal cord for phonation « phonatory glottis » (Figure 1). In retrospective study, we recently reported the safety and efficiency of this technique in 25 patients with BVFP [4].

Many normal subjects configure the vocal folds so that the glottis is never completely closed throughout a cycle of vibration. In normal subjects, « breathy voice » is defined as the modifications introduced by fixed opening between the arytenoid cartilages : (i) an increase in the bandwidth of the first formant, (ii) an increased tilt in the spectrum at high frequencies, and (iii) emergence of a turbulence noise source (glottis) [5-8]

The aims of this study were to analyze vocal function and phonetic patterns after CO2 Laser posterior transverse cordotomy (PTC) in bilateral vocal fold paralysis.

2- METHODS AND RESULTS

Four patients were included in this prospective study and recorded preoperatively and postoperatively at 1, 3, 6, 12 and 24 months. The etiologies included two cases of BVFP following surgical trauma (total thyroidectomy) and two cases of central nervous system disease. Distribution by sex was two male (M1 : 77 years and M2 : 69 years) and two female patients (F1 : 74 years and F2 : 52 years). CO2 Laser PTC was previously described [2, 4]. All patients were recorded under similar conditions. Pretreatment measurements were not available for one patient (M2) because he has been treated in emergencies.

2.1. Methods

2.1.1. Acoustic parameters. Two tasks were completed as part of this project. Patients were recorded in a quiet room and instructed to produce a number of sustained vowels /a/ at habitual conversational pitch and loudness.

In the first task, frequency features were analyzed with the Computerized Speech Lab and the Multidimentional Voice Program (Kay Elemetrics, NJ, USA). The frequency features automatically recorded were the average fundamental frequency (FO) in Herz, the FO standard deviation (SD) in Herz, the jitter in percent, the shimmer in percent, and the harmonic-to-noise ratio (HNR) in percent.

In the second task, several data were extracted on the spectra of vowels /a/ at 24 months after Laser procedure. Measures for a given patient are averages across five repetitions for each vowel. Before 24 month, instability of the vibration pattern was too higher, and it was not possible to measure data on the spectra of vowel /a/. The following data were extracted. (i) First-formant banwidths, (ii) The difference between the amplitudes of the first and second harmonics (H1-H2). H1-H2 was measured at the same points where F1 bandwidth was estimated. (iii) The difference between the amplitude of the first harmonic and the amplitude of the first formant peak (H1-A1). (iv) The difference between the amplitudes of the first harmonic and the third formant peak was measured (H1-A3). A non parametric Wilcoxon test was used for each comparison among preoperatively and postoperatively for M2, F1 and F2.

2.1.2. Aerodynamic parameters. Aerodynamic parameters were performed with the Aerophone II (Kay Elemetrics, NJ, USA). Two tasks were completed as part of this project. The patients produced the vowel /a/ for as long as possible after a maximal inspiration, in « maximum sustained phonation », or following comfortable inspiration « comfortable phonation ». The maximum phonation time (MPT), the mean air flow rate (MFRs) and the phonation quotient (PQ) were measured in « maximum sustained phonation ». The PQ is defined as the vital capacity divided by the MPT. The mean air flow rate (MFRc) was determined in « ²comfortable phonation ». For the two tasks, the patients repeated the test several times (minimum three attempts), resting between each attempt. The method was first demontrated by the experimenter.

Data from each recordings of the one male and two female patients were compared with the male and female reference group data by calculating Z scores according Holmberg [9]. Group reference data were obtained from 60 male and 50 female patients [10]. The Z score was defined as the ratio of the observed value minus the group mean value divided by the group standard deviation. Z score calculations were based on data for the separate male and female reference groups [10].

These measures are used to examine relationships among laryngeal aerodynamic parameters and acoustic characteristics of voice for M1, F1 and F2.

2.2. Results

Frequency features and laryngeal aerodynamic parameters for one male (M1) and two female (F1, F2) patients are presented in Table 1.

Measures on the spectra of the vowel /a/, first-formant bandwidth, H1-H2, H1-A1, H1-A3, differed significantly among postoperatively and preoperatively patients (M1, F1 and F2).

Frequency features	Preoperative	1 and 3 months	6 months	12 and 24 months
Average F0 in Herz	N	ND	N	N
SD F0 in Herz	N	ND	+	+
Jitter in percent	N	ND	+	+
Shimmer in percent	N	ND	+	+
HNR ratio in percent	N	ND	+	+
Aerodynamic parameters				
MPT in seconds	N	+	+	N
MFRs in liters/second	N	+	+	N
PQ in liters/second	N	+	+	N
SPL in decibels	N	-	-	N
MFRc in liters/second	N	+	+	N

Table 1. Frequency features and laryngeal aerodynamic parameters (three patients)

MPT : maximum phonation time
MFRs : mean air flow rate in «sustained phonation »
PQ : phonation quotient (liters/second)
SPL : intensity levels
MFRc: mean air flow rate in « comfortable phonation »

N : normal value
+ : Z score for data value > 2
- : Z score for data value < 2

3- DISCUSSION

Numerous surgical treatment options are available in patients with severely compromised airway due to bilateral vocal fold paralysis (BVFP). The most physiologic motion to the paralyzed larynx has been introduced by Tucker, who reported in 1976 a technique of reinnervation by insertion of a neuromuscular pedicle [11]. Despite initial reports of good results, long-term outcome has been disappointing [12]. CO2 Laser arytenoidectomy described by Ossof [1] achieve successful restoration of the airway (Technique 1) (Figure 2). CO2 Laser endoscopic posterior transverse cordotomy (PTC) has been introduced by Dennis and Kashima in 1989 (Technique 2) (Figure 3). They presented respiratory and phonatory findings documenting that the CO2 Laser PTC was effective in relieving airway obstruction [2, 3]. Lawson et al. compared the vocal results after CO2 Laser PTC and CO2 Laser arytenoidectomy. Although the mean values of the maximum phonation time and phonation quotient were higher if a CO2 Laser procedure was performed. Lawson et al. could not demonstrate any significant statistical differences between the two techniques [13]. Eckel compared the results of two techniques with a view to respiratory and phonatory function. He reported that phonatory function after Laser demonstrated considerably compromised maximum phonation time, peak sound pressure levels and phonational frequency range [14].

Recordings performed preoperatively and at 1, 3, 6, 12 and 24 months postoperatively in our study allowed analysis of the evolution of voice parameters. At 1 and 3 months after CO2 Laser procedure, the patients were capable only « whispering », and after 6 months postoperatively, the voice may be subjectively described as « breathy ».

At 1 and 3 months after Laser procedure, the glottic incompetence was reflected in the impossibility to automatically detect the F0, jitter, shimmer and harmonic-to-noise ratio and also in the limited sound pressure level range. Incomplete glottic closure was reflected in the limited MPT, the high mean airflow rates (MFRs and MFRc).

After 6 months after technique 2, SD of F0 was significantly wider postoperatively than preoperatively in the three patients. Titze, in an analysis of the control of F0 in normal subjects, stressed the relationship between the lung pressure and the vocal folds length, the tension of the intrinsic laryngeal muscles, and the mucous membrane passive stress relationship [15]. These parameters could be modified after CO2 Laser PTC, explaining, therefore, the wider F0 SD.

After 6 months after technique 2, our study showed instability of the vibration pattern results in the addition of aperiodic components (jitter and shimmer). Voice perturbation was measured by jitter percent, representing the very short-term (period-to-period) irregularity of the pitch, and shimmer percent, representing the very short-term (period-to-period) irregularity of the peak-to-peak amplitude of the voice. Horii reported that shimmer and jitter values allowed for analysis of the vibrational action of the glottis [16]. Such CO2 laser technique 2 explains the unstable vibrational pattern of the glotttis.

The higher rates of airflow (MFRs and MFRc) in this study are considerably outside the physiologic range for normal function. Mean airflow rate is a rather variable measure, even in normal subjects. Like other authors, we reported that TMP, PQ , MFRs and MFRc showed a great inter-individual variation [10, 17]. Like Holmberg, we reported, also, mean airflow rate was a rather variable measure, even in repeated recordings of normal subjects, and it is only sensitive to relatively dramatic changes in mechanisms related to glottal closure [9,10]. In normal subjects, a significant increase in mean flow rate could be explained by the posterior opening of the glottis. The membranous part of the vocal folds closes but airflow can be shunted through the posterior cartilaginous portion of the glottis which has been found to account for 35-45 % of the entire glottis length and 50 to 65 % of the entire glottis area [18] (Figure 1).

After CO2 Laser PTC, the increase in mean air flow rate could be explained by the posterior opening of the glottis : the maximum airflow values could result from letting air pass via posterior glottal gap.

Abnormally large values for mean airflow rates (MFRs and MFRc) can contribute energy loss, and can add significantly to the first-formant bandwidth. An increase in the bandwidth of the first formant may be a characteristic of the spectra of breathy voice. Measurement of the bandwidth can provide an indirect method to estimate the area of the glottis.

Another acoustic consequence of glottal gap is the generation of turbulence noise. The effect of turbulence noise at the glottis can be seen in the spectrum of vowels, particularly in the F3 region. Breathiness may be positively correlated with a high spectral level in frequency bands above about 5 kHz. In this study, we reported for all patients, high harmonic-to-noise ratio (HNR). The spectra of breathy voice are often reported to be characterized by a relatively high HNR in normal subjects [5]. The results of higher levels airflow rates, acoustically, is a source that has relatively less energy in higher frequency harmonics and elevated levels of turbulence noise. A positive relation between listener rated breathiness severity and high-frequency spectral noise has been reported in several studies [5-8].

It seems that the concept of an anterior, « phonatory glottis » as opposed to a posterior, « respiratory glottis » should be reconsidered for patients withe BVFP (Figure 1). The posterior cricoarytenoid (PCA) muscle acts as the respiratory muscle of the larynx but also increases phonatory glottal width. Hirose reported the function of PCA muscle in speech. He found a marked elevation of PCA muscle activity for the production of voiceless consonants and the PCA activity has a different pattern depending of the language[19].

Further future studies involving a combination of aerodynamic and stroboscopic measurements may provide important kinematic explanations about the role of the posterior glottis. Additional studies are required to examine the relationship between acoustic and aerodynamic and the perceptual parameters.

Nevertheless, we hope to have shown in this limited study, (1) acoustic and aerodynamic measures confirmed subjectively listener breathiness and (2) the posterior glottis cannot be regarded only as a respiratory glottis.

REFERENCES

[1] Ossof, R.H., Sisson, G.A., Duncavage, J.A., Moselle, H.I., Andrews, P.E., McMillan, W.G. 1984. Endoscopic laser arytenoidectomy for the treatment of bilateral vocal cord paralysis. *Laryngoscope, 94 : 1293-7.*

[2] Dennis, D. P., Kashima, H. 1989. Carbon dioxide laser posterior cordectomy for treatment of bilateral vocal cord paralysis. *Ann Otol Rhinol Laryngol, 98 : 930-4.*

[3] Kashima, H.K. 1991. Bilateral vocal fold motion impairment : pathophysiology and management by transverse cordotomy. *Ann Otol Rhinol Laryngol, 100 : 717-21.*

[4] Laccourreye, O., Paz Escobar, M.-I., Gerhardt, J., Hans, S., Biacabe, B. and Brasnu D. Carbon dioxide laser endoscopic posterior partial transverse cordotomy for bilateral paralysis of the vocal fold – A 10-year experience-. *Laryngoscope (in press).*

[5] Klatt, D., Klatt, L. 1990. Analysis, synthesis, and perception of voice quality variations among female and male talkers. *JASA, 87 : 820-57.*

[6] Hillenbrand, J., Cleveland, R.A. and Erickson, R.L. 1994. Acoustic correlates of breathy voice quality. *J Speech Hear Res, 37 : 769-78.*

[7] Ladefoged, P. 1983. The linguistic use of different phonation types. *In : Bless, D., Abbs,J., eds. Vocal folds physiology. Contemporary research and clinical issues. San Diego : College-Hill Press., 351-60.*

[8] Ladefoged, P. 1986. Discussion of phonetics : a note on some terms for phonation types. *In Fujimara, O., eds. Vocal folds physiology. Voice production, mechanisms and functions. Raven Press., Ltd., New York, 373-5.*

[9] Holmberg E.B., Hillman R.E., Perkell J.S., Gress C. 1994. Relationships between intra-speaker variation in aerodynamic measures of voice production and variation in SPL across repeated recordings. *J Speach Hear Res, 37 484-95.*

[10] Hans, S., Vaissière, J., Laccourreye, O., Brasnu, D. Evaluation of laryngeal aerodynamic parameters in normal subjects using non invasive, commercially available equipment. *data submitted for publication*

[11] Tucker, H.M. 1976. Human laryngeal innervation. *Laryngoscope 86 : 769-99.*

[12] May, M., Lavorato A.S., Bleyaert, A.L. 1980. Rehabilitation of the crippled larynx : application of the Tucker technique for muscle-nerve reinnervation. *Laryngoscope 90 : 1-18.*

[13] Lawson, G., Remacle, M., Hamoir, M., Jamart, J. 1996. Posterior cordectomy and subtotal arytenoidectomy for the treatment of bilateral vocal fold immobility : functional results. *J of Voice 10 : 314-9.*

[14] Eckel, H.E., Thumfart, M., Vossing, M., Wassermann, K., Thumfart, W.F. 1994. Cordectomy versus arytenoidectomy in the management of bilateral vocal cord paralysis. *Ann Otol Rhinol Laryngol, 103 : 852-7.*
[15] Titze, I.R., 1991. Mechanisms underlying the control of fundamental frequency. *In : Gauffin, J., Hammarberg, B., eds. Vocal folds physiology. Stockholm, Sweden : Singular Group, 1991 : 123-38.*
[16] Horii, Y. 1980. Jitter and shimmer differences among sustained vowel phonations. *J Speech Hear Res, 23 : 202-9.*
[17] Holmberg, E.B., Hillman, R.E., Perkell, J.S. 1988. Glottal airflow and transglottal air pressure mesurements for male and female spekers in soft, normal and loud voice. *JASA, 84 : 511-29.*
[18] Hirano, M., Kurita, S., Kiyokawa, K., Sato, K. 1986. Posterior glottis. Morphological study in excised human laynges. *Ann Otol Rhinol Laryngol, 95 : 576-81.*
[19] Hirose, H. 1976. Posterior cricoarytenoid muscle as a speech muscle. *Ann Otol Rhinol Laryngol, 85 : 334-42.*

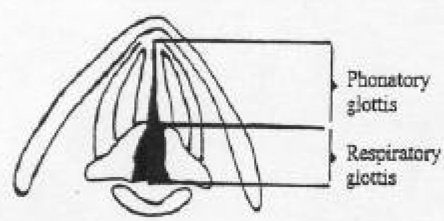

Figure 1. Axial section of normal larynx at glottis. The phonatory glottis extends from vocal process to anterior commissure. The respiratory glottis extends from vocal process to posterior commissure.

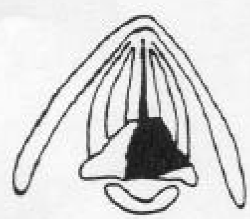

Figure 2. Endoscopic CO2 Laser arytenoidectomy (Technique 1).

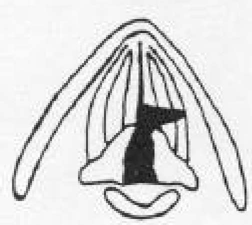

Figure 3. Endoscopic CO2 Laser posterior transverse cordotomy (Technique 2).