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Aerodynamic Analysis in Quantitative Evaluation of Voice Disorders

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Abstract

The aim of this study is to characterize the aerodynamics measures of subjects with functional dysphonia. By comparing such technique with spectrography and videolaryngoscopy, correlation between these methods and aerodynamic measurements can be evaluated. This prospective study contained 23 dysphonic patients without organic lesions of the larynx. In addition to laryngeal endoscopy, patients were underwent to spectrographic and aerodynamic analysis of the voice. Aerodynamic evaluation demonstrated the possibility of distinguishing between three functional categories: hypofunctional, hyperfunctional and hypofunctional dysphonia with supraglottic compensation. Finally, comparing the G component of the GRBAS scale to glottic resistance, the result was a negative correlation index equal to -0918 for subjects with hypofunctional dysphonia with supraglottic contracture. In the other two groups of samples (hypofunctional dysphonia, hyperfunctional dysphonia) this correlation was not found. It was given particular emphasis on the aerodynamic evaluation because this technique allows measurement of glottic effort and monitoring during therapy. The obtained data suggest that it would be desirable to increase the use of aerodynamic parameters in the phoniatric diagnosis.

Keywords

Aerodynamic evaluation; Voice disorders; Spectrography

Introduction

Voice production is a multidimensional phenomenon, it would be necessary to determine a multiple approach to detect the presence of a lesion and/or a functional disorder. It also should be necessary to use perceptual and self-evaluation analysis to determine the consequences that such disorder has during ordinary daily activities [1]. Comparing objective investigations and the perceptual ones, the latter is still the most followed to document the severity of voice disorders [2] but not to quantify itself.

To overcome the subjectivity of the perceptual analysis, several authors identified a pool of acoustic and aerodynamic indexes correlated to the perceptual evaluation and were able to quantify the severity of the disorder [2-4].

More positive were the results obtained by Yu P [5]. Combining a set of 6 acoustic and aerodynamic indices, they allowed a discriminant analysis of the different severity levels approximately in 86% of cases. Since such study was carried out in voice samples of exclusively male patients, the goal is limited to only the overall dysphonic population. A successive study [6] determined voice evaluation protocols including aerodynamic and acoustic (linear and nonlinear) measurements. In particular, indexes included fundamental frequency, intensity, jitter, signal-to-noise ratio, oral airflow, subglottic pressure, maximum phonation time and vocal range. The results derived from a comparative analysis of voice samples based on a four point scale according to the G component of the GRBAS. The study revealed a correlation between objective and subjective measurements of 81% in female samples and 84% in male ones.

Therefore, since actually doesn't exist an objective protocol able to allow a discriminant analysis of the different type of dysphonia, perceptual and instrumental measurements should be included both in a clinical assessment protocol to evaluated phonatory efficiency.

The aerodynamic voice study evaluates how the airflow stimulates the glottal oscillator which determines phonation. The main purpose of such technique is to estimate the efficient functioning of the laryngeal transducer involved in the conversion from aerodynamic to acoustic energy allowing to detect whether or not there is an adequate pneumo-phonic coordination. Among the aerodynamic parameters most often considered in literature [7-14] there is the subglottic pressure (P_{sub}) defined as the relative amount between the force produced by the bellows lung and the glottis arranged in phonation setting.

Sundberg [15] tried to better understand the physiological mechanisms underlying the variation of vocal frequency and loudness during voice and / or singing source. A group of 10 professional singers participated in this study. The test consisted of singing the syllable / pae :/ for 5 consecutive times to 4 different sound intensity levels (pianissimo-piano-forte-fortissimo) and on a frequency range of one octave. The aim was to understand how the P_{sub} may be altered by the intensity and mode of phonation. This study detected that a doubling of P_{sub} corresponds to an increase of about 10 dBSPL. The increase of the SPL to a doubling of P_{sub} suggests that this relationship is influenced by the mode of phonation which is in turn, conditioned by the glottis adduction. From flow to normal or pressed mode of phonation there is a decrease in the peak flow and an increase of P_{sub} with consequential decrease of sound intensity. In another study by Sundberg [16], the author described the differences between the modal and the falsetto registers, comparing the performances among three different groups of singers consisting of tenors, baritones and countertenors. This research revealed that the $P_{sub,}$ appears to be about twice the modal register than the falsetto in all categories considered. Tenors and baritones used higher values (50 cm $H_2$0) than countertenors that contract less thyroarytenoid muscles, showing a higher mobility of the vocal folds and therefore required lower P_{sub} values .

According to such findings, the effort of this study is to characterize the aerodynamics measures of subjects with functional dysphonia by means of the phonatory aerodynamic test

Materials and Methods

The study contained 23 subjects with functional dysphonia (11

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adult males, 12 females, from 38 to 59 years of age, mean of 50.4) exclusion criteria, were the appearance of organic lesions of the larynx, smoking, laryngo-pharyngeal reflux. After a preliminary visit, the recruited

The evaluation included: Flexible laryngostroboscopy, for a clear observation of the vocal tract, by means of a 3.2mm endoscope (Olympus ENF P3); Spectrography: voice analysis was performed during a sustained vocalization with the /a/ vowel positioning the microphone at 30cm from the mouth in a silent room, setting the amplification level at 3/10; Aerodynamic Analysis (Aerophone II, F-J Electronics).

In particular, aerodynamic evaluation consisted of two procedures

Articulatory Test (AT): Its the most frequently employed and standardized. The patients were instructed to pronounce, after a deep inspiration, and in their voice conversation, a sequence of occlusive bilabial phonemes /I-PI-PI/ within a face mask which was linked to a tube of silicone used to detect the intraoral pressure. The sequence was repeated until the point of maximum phonation time, avoiding any erroneous inspirations during the test. From the three basic parameters recorded together (Intensity, Flow, Pressure), other indices were extrapolated, including those most useful to explain the aerodynamic performances, that is glottal resistance, phonatory efficiency and intensity.

Particularly, Glottic Resistance in Ns/M5 (relation between subglottic pressure and average phonatory airflow), Phonatory Power (product of subglottic pressure and phonatory airflow) in Watts just as the appropriate software required.

Running Speech (RS): Its a sustained vowel anticipated by bilabial consonant (/m /) until maximum phonation time. Subjective evaluation of voice, by the GRBAS scale which stands for Grade, Roughness, Breathy, Astenicity and Strain, performed by a phoniatrician and a speech therapist, both having ten years' experience. Self-evaluation of the patients using the Voice Handicap Index (VHI) developed by Jacobson [17] in 1997 and validated in 2002 by the Agency for Health Care Research. Auditory, spectrographic and endoscopic ratings were not blind to the aerodynamic analysis. Aiming to a statistic analysis, the Spearman's Nonparametric Correlation Coefficient was performed, whose possible values vary in the range of [-1, +1]. In particular, values close to -1 indicate a type of inverse correlation, while values close to +1 a direct correlation.

Finally we have compared the G component of the GRBAS scale to glottic resistance (corresponding to the relative amount between subglottic pressure and oral airflow) obtained from Running Speech.

Results

Flexible laryngostroboscopy

23 samples were analyzed and divided as follows: 7 with hyperfunctional dysphonia with no laryngeal pathologies; 9 with hypofunctional dysphonia, with glottic insufficiency associated with mechanisms of supraglottic compensation; 7 with glottic hypofunctional configuration.

Spectrography

Results demonstrated an aspecific spread of noise on the voice spectrum, not being able to detect any indicative data to trace the movement and the strain of the vocal folds. Some patients had areas with no voice in addition to the noise, but still evenly distributed between several groups of subjects examined. It was also not possible to identify a setting of the noise corresponding to hypo or hyper vocal cord adduction.

Aerodynamic evaluation

The aerodynamic evaluation was carried out on 23 subjects organized into three functional categories: hypofunctional dysphonia (Group A-7 subjects), Hypofunctional dysphonia with supraglottic compensation (Group B- 9 subjects), Hyperfunctional dysphonia (Group C-7 subjects)

A comparison of data was as follow, first related to AT (Pronunciation of IP in quick succession) and then to RS (sustained phonation). Concerning to derivate measurements of AT (Table 1),

Group A showed as follows: Glottic Resistance values ranging from a minimum of 15.75 to a maximum of 64.06 Ns/m^5 with a mean of 45.31Ns/m^5; Phonatory Power ranges from a minimum of 0162 to a maximum of 0577 Watts with a mean of 0.400.

Group B data showed as follows: Glottic Resistance ranges from a minimum of 55.74 Ns/m5 to a maximum of 256.98 Ns/m^5 with a mean of 96.90 Ns/m^5; Phonatory Power is instead between a minimum of 0028 Watts and a maximum of 0600 Watts with an average of 0.28 Watt.

Recorded values in Group C revealed as follows: Glottic Resistance ranges from a minimum of 36.71 Ns/m^5 to a maximum of 1285.30, with a mean of 206.79 Ns/m^5; Phonatory Power ranges from 0018 Watt to 0507 Watt, with a mean of 0.24. Phonatory Power is correlated to an higher subglottic pressure and an inefficient phonatory flow (Table 1).

The results obtained are even more evident in the following aerodynamic evaluations. As a matter of fact, during a sustained phonation of /a/ for the subjects of the group A, the use of Running Speech modality showed as follows (Table 1): Glottic Resistance ranges from 1.77 to 10.84 watts, with a mean of 4.97 watts; Phonatory Power ranges between 0,009 and 0,054 watts, with a mean of 0.028.

Moreover, Group B showed as follows: Glottic Resistance value between 3:45 and 15.75 Ns/m^5 Ns/m^5 with a mean of 6:56; Phonatory Power between 0006 and 0027 Watts with a mean of 0.016.

The group C lists the following values: Glottic Resistance ranges from a minimum of 1.22 to a maximum of Ns/m^5 22:37 Ns/m^5, with a mean of 7.15; Phonatory Power ranges from a minimum of 0.005 to a maximum of 0039 watts, with a mean of 0014 watts.

Like for the articulatory test, measurements derive from subglottic pressure and airflow variations (Table 2).

Voice Handicap Index (VHI) and GRBAS scale : the tables report results of the voice self-evaluation test (VHI) and GRBAS scale based on subjects evaluated and classified according to their functional categories (Table 3-5).

Finally, comparing the G component of the GRBAS scale to glottic resistance obtained from Running Speech, the result was a reverse correlation index equal to -0918 for subjects with hypofunctional dysphonia with supraglottic compensation. In the other two groups of samples (hypofunctional dysphonia, hyperfunctional dysphonia) this correlation was not found. Such result was confirmed in the Articulatory Test modality as well.

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Table 1: Articulatory Test and Running Speech in three groups analyzed.

Articulatory Test	Phonatory Power Watt	Glottic Resistance Ns/m^5	**Running Speech**	Phonatory Power Watt	Glottic Resistance Ns/m^5
Hypofunctional Dysphonia	0.400	45.31	Hypofunctional Dysphonia	0.028	4.97
Hypofunctional Dysphonia with compensation	0.28	96.90	Hypofunctional Dysphonia with compensation	0.016	6.56
Hyperfunctional Dysphonia	0.24	206.79	Hyperfunctional Dysphonia	0.014	7.15

Table 2: Estimated P_{sub} and aerodynamic flow in three groups analyzed (Articulatory Test and running speech).

Articulatory Test	Oral airflow l/s	Subglottic pressure (mean) cmH_2O	Subglottic pressure (peak) cmH_2O	**Running speech**	Oral airflow l/s	Subglottic pressure (mean) cmH_2O	Subglottic pressure (peak) cmH_2O
Hypofunctional Dyphonia	0.306	3.97	11.09	Hypofunctional Dyphonia	0.281	1.18	2.08
Hypofunctional Dyphonia with compensation	0.198	4.70	12.09	Hypofunctional Dyphonia with compensation	0.175	1,18	2,92
Hyperkinetic dysphonia	0.169	4.76	14.60	Hyperkinetic Dysphonia	0.166	2.28	2.02

Table 3: (Group A) VHI and GRBAS scale for subjects with hypofunctional dysphonia.

PZ	**VHI**			**G**	**R**	**B**	**A**	**S**
	physical area	functional area	emotional area					
1	9	0	2	2	1	2	2	1
2	30	27	14	2	0	2	2	1
3	14	3	5	1	0	1	1	0
4	16	6	5	1	1	0	1	1
5	33	17	7	2	0	2	2	1
6	19	13	10	1	1	0	1	1
7	18	2	12	2	0	2	2	1
M	**19.8**	**9,7**	**7.8**	**1.57**	**0.42**	**1.28**	**1.57**	**0.85**

The Voice Handicap Index (VHI) and GRBAS scale

Results of the voice self-evaluation test (VHI) and GRBAS scale based on subjects evaluated and classified according to their functional categories.

Table 4: (Group B) VHI and GRBAS scale for subjects with Hypofunctional dysphonia with supraglottic compensation.

PZ	**VHI**			**G**	**R**	**B**	**A**	**S**
	physical area	functional area	emotional area					
1	4	27	15	2	2	1	1	2
2	21	9	0	3	2	2	1	2
3	20	14	12	1	2	1	0	0
4	3	0	0	2	2	0	0	2
5	20	3	7	2	2	1	1	1
6	5	14	1	2	2	0	0	1
7	21	26	8	2	1	1	1	1
8	2	3	0	2	2	1	1	2
9	23	0	15	2	2	2	1	0
M	**13,2**	**10,6**	**6,4**	**2**	**1.8**	**1**	**0.6**	**1.2**

Considerations

The aim of our study was to determine a multiparametric voice evaluation that may provide to the clinician useful information both for a correct diagnosis and for an adequate management of the voice disorder.

Voice samples from 23 dysphonic subjects were assessed and divided into three functional categories according to their glottic appearance: Hypofunctional Dysphonia, Hypofunctional Dysphonia with supraglottic compensation, Hyperfunctional Dysphonia.

Objective evaluation included flexible laryngostroboscopy, spectrographic and aerodynamic voice recordings. This diagnostic procedure was also performed by the perceptual evaluation (GRBAS) and VHI in order to obtain a complete clinical framework of the subjects' voice condition. Resulting data lead to interesting conclusions. In particular, the spectrographic test gave indications extremely generic, since it showed non-specific signs of spreading noise with not a clear position on the spectrum. Some authors [18-20] have previously reported the noise presence on high frequencies in the hypofunctional, and on lower frequencies in the hyperfunctional.

In contrast, the data derived from this study showed a random distribution of the noise in order to confirm these findings. Spectrography revealed its use to be too generic to distinguish several types of alteration and functional compensation.

On the other hand, aerodynamic analysis was performed in the Articulatory Test (AT) and Running Speech (RS) procedure and it turned out as follows:

A clear increase in glottic resistance (corresponding to the relative amount between the subglottic pressure peak and oral airflow) from subjects with hypofunctional dysphonia to those with self compensation, and to subjects with hyperfunctional dysphonia , while phonatory power showed an inverse tendency. These results derive from a subglottic pressure that was more consistent, and from a phonatory flow that was decreasing. Thus, the various parameters considered seem to vary in order to the functional alteration showed in flexible endoscopy. The Running Speech modality allows us to assess the pressure performance of the flow during the production of a sustained phonation. This phonatory aerodynamic test provided results according with those observed with the AT (Articulatory Test).

A comparison was performed between the glottic resistance (G / F) and the judgment given to each patient in relation to the G component (Grade of Dysphonia) of the GRBAS scale in order to note a possible correlation between the resulting data from the aerodynamic assessment and the voice perceptual evaluation. Results showed an inverse correlation between the two variables mentioned above for subjects with hypofunctional dysphonia with supraglottic contracture compensation. This finding is interesting because dysphonia with glottic compensation is regarded to be the one that lasts the longest time and is therefore defined as chronic (most severe). This indicates that high levels of glottic resistance have low scores in the other variable. This correlation has emerged only in the "Running Speech" (RS), and is equal to -0.918. There was no evidence

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Table 5: (Group C) VHI and GRBAS scale for subjects with hyperfunctional dysphonia.

PZ	VHI			G	R	B	A	S
	physical area	functional area	emotional area					
1	31	26	23	3	3	0	3	3
2	28	19	34	2	1	0	0	0
3	22	7	2	3	3	0	0	2
4	21	6	7	2	2	0	1	2
5	20	0	0	0	0	0	0	0
6	24	14	12	2	2	0	0	1
7	22	6	2	1	1	0	0	1
M	**24**	**11,1**	**11,4**	**1.8**	**1.7**	**0**	**0.5**	**1.2**

of any correlation between the parameters considered (the G index of GRBAS scale and glottis resistance, given by the ratio between G / F ratio) in the other two groups of patients (hypofunctional and hyperfunctional dysphonic patients) both for A.T. and R.S.

Finally, for all three groups the analysis of the scores given by each subject to the various items of the voice self-evaluation test shows a greater impairment on the voice perceptual area than the functional and the psychological framework. In particular, higher values were observed for subjects with hyperfunctional dysphonia. According to the aerodynamic evaluation this finding shows a great vocal effort due to a vocal mechanism that is spontaneous and immediate but not satisfactory.

Conclusion

This study gives emphasis on the aerodynamic evaluation because, although not used in daily clinical practice, this is best suited to the type of structure observed by video laryngoscopic exams and better correlated with the type of phonation. A phonatory aerodynamic test makes it possible to accurately quantify the glottis dysfunction and monitor its progress in therapy. It would therefore be desirable to make more frequent use of aerodynamic parameters in order to better and more effectively understand not only the processes underlying the physiological production of the voice, but also how these are modified according to the different glottic and overglottic assessment. The daily use of such indexes along with a more developed and conscious interpretation of them would help the clinicians handle dysphonic patients and realize a certainly more appropriate rehabilitation project.

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