Resultados estroboscopicos y del análisis acústico de la voz en pacientes con nódulos vocales y pacientes con disfonias funcionales en Galicia

Laryngostroboscopic and acoustic analysis findings in patients with vocal nodules and patients with functional dysphonias in Galicia

Wasim Elhendi Halawa • Sofía Santos Perez • Antonio Caravaca García • Torcuato Labella Caballero

RESUMO

Objetivo: Evaluar los hallazgos laringoestroboscopicos y del análisis acústico de la voz en pacientes con nódulos vocales y disfonías funcionales en Galicia.

Pacientes y métodos: 97 pacientes diagnosticados de nódulos vocales y 65 pacientes diagnosticados de disfonía funcional fueron examinados mediante laringostroboscopia, siguiendo un protocolo estandarizado que incluye el análisis de cierre glotico, de la vibración de las cuerdas vocales y de la onda mucosa. Para el análisis acústico se utilizó el programa Dr. Speech Science evaluando la frecuencia fundamental media(F0) y su desviación estándar, jitter, shimmer, y la energía de ruido normalizado (NNE).

Resultados: Todos los pacientes mostraron alteración de al menos un parámetro laringostroboscopico. El análisis acústico indica que la mayoría de los pacientes mostraron una reducción de la frecuencia fundamental, un aumento de la perturbación (jitter y shimmer) y un aumento de NNE.

Conclusión: La laringoestroboscopia, sistematizada mediante un protocolo, es una técnica muy útil en el diagnóstico de las anomalías estructurales y funcionales en los pacientes con nódulos vocales y disfonías funcionales, mientras que el análisis acústico de la voz puede ser de utilidad como herramienta complementaria en el diagnóstico de estos pacientes.

Palabras clave: Laringostroboscopia; anláisis acústico, nodulos vocales ; disfonías funcionales.

ABSTRACT

Objective: To evaluate the laryngostroboscopic and acoustic analysis findings in patients with vocal nodules and functional dysphonias in Galicia.

Patients and Methods: 97 patients diagnosed of vocal nodules and 65 patients diagnosed of functional dysphonisa were examined by laryngostroboscopy, following a standardized protocol which includes: analysis of glottal closure, vocal fold vibration and the mucosal wave. For acoustic analysis we used the program Dr. Speech Science evaluating the mean fundamental frequency (F0) and its standard deviation, jitter, shimmer, and Normalized Noise Energy (NNE).

Results: All patients showed alteration of at least one laryngostroboscopic parameter.

Acoustic analysis indicated that most patients showed a reduction of fundamental frequency, an increase of perturbation (jitter and shimmer), and an increase of NNE.

Conclusion: Laryngostroboscopy, systematized through a protocol, is a very useful technique for the diagnosis of structural and functional abnormalities in patients with vocal nodules and functional dysphonia, while acoustic analysis of voice can be useful as a complementary tool in the diagnosis of these patients.

Keywords: Laryngostroboscopy; acoustic analysis; vocal nodules; functional dysphonias

INTRODUCTION

Until recently there were no objective and exact procedures for voice evaluation, and many otolaryngologists depended on their own hearing and on laryngeal mirrors. In 1992, however, the International Association of Logopedics and Phoniatrics stated that evaluation of dysphonia on the basis of the otolaryngologist's own sight was not sufficient, and that objective standardized instrumental protocols were required.[1-3] Objective evaluation protocols are necessary for monitoring of clinical course, for comparison of pre and post treatment status, for comparison between treatment groups in clinical and experimental studies, and increasingly for legal purposes.

Wasim Elhendi Halawa
Facultativo Especialista de ORL en el Servicio de Otorrinolaringología del Hospital Punta Europa de Algeciras - Cádiz (Espanha)

Sofía Santos Pérez
Jefe del Departamento de Otorrinolaringología de La Universidad de Santiago de Compostela (Espanha)

Antonio Caravaca García
Facultativo Especialista de ORL en el Servicio de Otorrinolaringología del Hospital Punta Europa de Algeciras - Cádiz (Espanha)

Torcuato Labella Caballero
Jefe de Servicio de Otorrinolaringología del Complejo Hospitalario Universitario de Santiago de Compostela (Espanha)

Correspondência:
Wasim Elhendi Halawa
Morada: Servicio ORL, Hospital Punta de Europa,
Avda. Del Hospital s/n, 1207 Algeciras - Cádiz (Espanha)
E-mail: wasimmai@yahoo.com
Telefone: 00.34.619.34.70.35

Although the human ear is a very useful instrument for voice analysis, subjective assessments are clearly difficult to compare between different otolaryngologists, and even a single professional may give different evaluations of a single voice sample.[4]

Carding et al.[5] point out that voice is a multidimensional phenomenon, so that any simple measure will give only partial information. The current trend is thus to use multidimensional measures of vocal function, combining perceptual and instrumental measures.

The main instrumental measures currently available for objective evaluation of voice are morphofunctional techniques, notably laryngostroboscopy, and acoustic analysis. In the present study we characterized voice by laryngostroboscopy and acoustic analysis, in patients diagnosed of vocal nodules (the most common benign lesion of the larynx) and functional dysphonias (condition characterized by the absence of organic lesions).

MATERIAL AND METHODS

The study considered a total of 162 dysphonic selected patients randomized among those referred to the Phoniatrics Unit of our hospital over the 5 year period. These patients were divided into two groups: 97 patients diagnosed, by laryngostroboscopy, of vocal nodules (mean age 33 years, range 14 - 63 years; 94 women, 3 men); and 65 patients diagnosed by laryngostroboscopy, of functional dysphonia (mean age 34 years, range 13 - 59 years; 57 women, 37 men).

The hyperkinetic functional dysphonia was characterized by the absence of organic lesion; shortened, thickened and more rigid vocal folds, a prolonged closed cycle, a default of posterior glottic closure, approximation of the vocal bands during phonation and a decrease of the amplitude and undulation of the vocal folds. In the hypokinetic dysphonia, although the vocal folds often look normal under the continuous light, under the stroboscopy we can see a large vibratory movements and a major mucosal undulation which cause a weak and sometimes incomplete glottic closure along its length.

For laryngostroboscopy we used a Storz[R] model 8010 laryngostroboscope equipped with a rigid Storz[R] model 8706 CH laryngoscope, with optic 90^{o} and 10 mm diameter. Images were visualized and recorded with an Endovision DX CAM[R] video system and a Sony monitor. Laryngostroboscopic examination and interpretation followed the standard procedure of Hirano & Bless.[6] Each case was documented by two different protocols: a protocol based on systematic subjective evaluation of the stroboscopic images (Table I), and a narrative description and video recording.

For acoustic analysis of the voice we used the Voice Assessment module of Dr. Speech Science (version 3.0 for Windows 98; Tiger Electronics), running on a 66 Mhz Pentium 100 PC with 16 Mb of RAM. For digitalization of the voice signal a digital sound card compatible with Windows 16 bit was installed (A/D Sound Blaster Pro16 bit); sampling rate was 44.1 kHz, and input via a Hitachi Electrot. Radio Shack 33-3004 unidirectional dynamic microphone with no additional pre-amplification. The subject was required to produce a sustained Spanish /e/ vowel sound (similar to the English /a/ vowel sound) for 3 sec, after normal inspiration, with volume and pitch comfortable for the subject, as recommended by Preciado et al. for the Spanish population.[7] The recordings were obtained, in a quiet room, with the microphone at about 15 cm from the subject's lips, pointing towards the mouth at an angle of 45°. All

TABLE 1
Protocol for the evaluation of laryngostroboscopic findings

1	Fundamental frequency (F0)	....................Hz.
2	Symmetry	☐ Symmetric ☐ Asymmetric : Amplitude - Phase
3	Regularity/periodicity	☐ Regular ☐ Irregular
4	Glottal closure	☐ Complete ☐ Incomplete
5	Amplitude	- Right: ☐ Increased ☐ Normal ☐ Reduced - Left: ☐ Increased ☐ Normal ☐ Reduced
6	Mucosal wave	- Right: ☐ Increased ☐ Normal ☐ Reduced - Left: ☐ Increased ☐ Normal ☐ Reduced
7	Cord vibration	☐ Present ☐ Absent / Abnormal
8	Non vibratory portion	....
9	Ventricular bands	....
10	Other findings	....

voice recordings were obtained in the same room, with similar environmental noise levels. For each subject we obtained and analysed three 3-sec recordings of the vowel sound, and in each case the analysis was of a homogeneous central fragment of 1-sec duration. Following digitalization, the program calculated the following parameters, as recommended by Titze[8]: fundamental frequency (F0) and its standard deviation (SdF0), jitter, shimmer, and Normalized Noise Energy (NNE).

RESULTS

Laryngostroboscopy:

The four laryngostroboscopic parameters included in analysis were glottal closure (complete or incomplete), fold vibration (present or absent), right and left mucosal wave (normal or absent/abnormal), and phase symmetry (symmetric or asymmetric). Results are listed in Table II.

All patients (vocal nodules and functional dysphonia) showed alteration of at least one of these parameters. In patients with vocal nodules, the most frequent alteration (97% of patients) was incomplete glottal closure, in most cases with hourglass morphology, followed by phase asymmetry (91%), absent or abnormal fold vibration (73%), and absent or abnormal mucosal wave (58%). In patients with functional dysphonia, the most frequent alteration was again incomplete glottal closure (91%), followed by absent or abnormal fold vibration (68%), absent or abnormal mucosal wave (59%), and phase asymmetry (25%).

Other laryngostroboscopic findings in vocal nodules group, were vocal fold haematoma (11 patients), oedema (11 patients), hypertonia (12 patients), and arythenoid oedema (7 patients). Functional dysphonias, by definition, have no associated anatomical lesions.

Acoustic analysis:

The data obtained for the five parameters analysed are summarized in Table III.

In patients with vocal nodules, mean fundamental frequency (F0) was 190.12 Hz, and mean standard deviation of F0 2.72 Hz. In patients with functional dysphonia, mean F0 was 183.22 Hz, and mean standard deviation of F0 2.73 Hz.

In patients with vocal nodules, mean jitter was 0.50% and mean shimmer 5.09%. In patients with functional dysphonia, mean jitter was 0.44% and mean shimmer 5.11%.

TABLE 2
Summary of laryngostroboscopic findings in the patients with vocal nodules (VN) and functional dysphonia (FD)

Finding	**VN** (97 patients)		**FD** (65 patients)	
Glottal closure	(incomplete)	(complete)	(incomplete)	(complete)
	94 (96.9%)	3 (3.9%)	59 (90.8%)	6 (9.2%)
Cord vibration	Absent / abnormal	Present	Absent / abnormal	Present
	71 (73.2%)	26 (26.8%)	44 (67.7%)	21 (32.3%)
Mucosal wave	Absent / abnormal	Present	Absent / abnormal	Present
	56 (57.7%)	41 (42.3%)	38 (58.5%)	27 (41.2%)
Phase symmetry	Asymmetric	Symmetric	Asymmetric	Symmetric
	88 (90.7%)	88 (90.7%)	16 (24.6%)	49 (75.4%)

TABLE 3
Summary of acoustic analysis findings in the patients with vocal nodules (VN) and functional dysphonia (FD)

Parameter	Jitter		Shimmer		N.N.E.		Fo		SdFo	
	VN	FD	VN	FD	VN	FD	VN	FD	VN	FD
Mean	0.50	0.44	5.09	5.12	-7.13	-8.46	190.12	183.22	2.72	2.73
Median	0.35	0.33	4.98	4.95	-6.52	-7.88	193.03	193.32	2.29	2.20
Standard desviation	0.38	0.38	1.71	2.09	4.06	4.04	27.59	45.92	1.61	2.99
Minimum	0.18	0.16	1.87	2.35	-18.36	-16.77	82.93	81.33	0.99	0.22
Maximum	2.01	2.17	10.26	15.41	-0.77	-1.06	241.57	298.65	8.34	24.29
95% C.I.	0.42 – 0.57	0.34 – 0.53	4.75 – 5.46	4.60 – 5.63	-7.95 – -6.31	-9.46 – -7.45	184.56 – 195.68	171.84 – 194.60	2.40 – 3.05	1.99 – 3.47
Standard error of mean	0.04	0.05	0.17	0.26	0.41	0.50	2.8	5.70	0.16	0.37

Mean NNE was -7.13 in patients with vocal nodules, and -8.64 in patients with functional dysphonia.

DISCUSSION AND CONCLUSIONS

Laryngostroboscopy is nowadays generally considered to be the most useful technique for diagnosis of vocal disorders, since it allows detailed examination of the vocal folds and (through detailed analysis of video recordings) detection of dysphonias, vibratory asymmetries, structural alterations, small masses, submucosal scarring and other alterations that are not visible under normal light. It is also extremely sensitive for the detection of paresias and paralyses of the vocal folds due to minimum laryngeal neoplasms.[9,10]

The "normal" voice is characterized, during stroboscopy, by a regular and uniform vibration in amplitude and time, a symmetric behavior of both vocal folds in opening and closing time and in the extension of the separation movement. The amplitude is considered normal if it is about one third of the width of the visible part of vocal fold. Glottal closure should be complete and we should observe a normal mucosal wave (when it clearly passes through at least the half of width of the visible part of vocal fold during phonation at normal pitch and intensity).

There is no consistent relationship between a specific disease and a specific vibration pattern, since it depends not only on the disease itself but also on its size, extension, location and on the phonation type of the patient and his compensation mechanisms. However, there are general tendencies of vibration, so that usually typical patterns can be associated to a particular disease.[6]

Sataloff et al.[9] analysed 1876 laryngostroboscopic procedures performed over a 5 year period in "professional voice users" with dysphonia and known diagnosis. They found that in 29% of patients stroboscopy not only confirmed the existing diagnosis but also supplied additional diagnostic information, while in 18% of patients stroboscopy indicated that the existing analysis was incorrect.

Dejonckere et al.[11] compared evaluations of laryngostroboscopic videos by various phoniatrists, and found good inter observer and intra observer consistency for all parameters.

However, it is certainly the case that laryngoscopic findings need to be interpreted with caution, since some apparently abnormal findings are commonly seen in patients without any sort of voice problem. Elias et al.[12] performed a stroboscopic study of a sample of 65 professional singers without voice problems, obtaining "abnormal stroboscopic findings" (potentially confusable with six different pathological entities) in 58% of patients. Such abnormalities may be mistakenly identified as the cause of voice problems at a patient's first consultation. Heman Ackah et al.[13] performed laryngostroboscopic exams in 20 singers, 7 of whom reported voice problems, and 13 of whom perceived their voice as normal. The results obtained indicated that the presence of a "mass" on the vocal folds was more common among the subjects who considered their voice to be normal, while hypomobility of the vocal folds was more common in the subjects who reported voice problems.

We thus consider that reliable diagnostic use of stroboscopic data requires the phoniatrist to be aware of the range of laryngeal behaviours that may occur in normal subjects, and that a degree of caution needs to be applied. This may be particularly important when we are dealing with minor voice problems in professional voice users.

The present study we also analyzed the acoustic analysis of the voice, a non invasive diagnostic technique that provides quantitative information on voice quality. Results are obtained in digital form, and thus readily managed, processed and stored on personal computers. The first problem arising in the evaluation and comparison of different voices is to define what is understood by "normal" voice. In fact normal voice cannot be defined in purely objective terms, but various authors in recent years have considered that normal voice can be defined as that of a non smoker who is not a professional voice user, with no history of vocal disorder, with normal hearing, and without respiratory, neurological, nasosinusal or pharygolaryngeal or allergy problems.[3,4,14]

Having defined "normal voice", the next problem is to obtain a control group (with voice normal according to the selected criteria) allowing meaningful assessment of pathological groups. There have been very few studies of acoustic characteristics of the voice in our region (northern Spain), with most available data coming from other regions.

Normal given mean values of F0 are 217 Hz +/- 35 Hz in women (206 Hz for Takahashi and Koike, 200 Hz for Kent and 193 Hz for Bless) and 117 Hz +/- 30 Hz in men (114 Hz for Hollien and 106 Hz for Bless). Van Lierde offers normal values of SdF0 of 1.4 Hz in men and 2.6 Hz in women. Normal values of jitter are considered below 0.25% and as slight alteration if below 0.5%, but it seems to be accepted as normal jitter till 0.68%. Van Lierde considers normal jitter's values of 0.57% in women and 0.48% in men. Casado Morente provides an average value of jitter and shimmer in healthy subjects of 0.24% and 2.10% respectively and of -13, 62 +/- 4, 27 of N.N.E.[1,8,15]

It should be noted that several studies have found that the values of acoustic parameters may vary rather markedly depending on the software used for analysis. For example, most software packages for acoustic analysis of the voice determine fundamental frequency (F0); however, both the type of signal used for estimation of this parameter (microphonic or laryngographic) and the calculation algorithm may differ from one software package to another. The standard deviation of F0, considered a valuable indication in neurologic diseases, is another widely cited parameter, though it is not so widely used in the study of vocal pathologies because it is influenced by variation in pitch.

Casado et al.[15] report a mean fundamental frequency of 127 Hz in Spanish men with vocal nodules and 241 Hz in Spanish women with vocal nodules. The great majority of our patients with vocal nodules were women, and mean fundamental frequency in these patients was 190 Hz, markedly lower than the 241 Hz obtained by Casado et al. Reduced F0 in patients with vocal nodules is attributable to the increased mass of the vocal cords. Mean standard deviation of F0 was also lower than in Casado et al.'s study. Reduced standard deviation of F0 in patients with vocal nodules is probably attributable to increased cord tension.

Kotby et al.[16] reported that variations in F0 tend to be unimodal in normal subjects, but bimodal or multimodal in patients with functional dysphonias, due to the presence of subharmonics. Such variation patterns appear to be more closely related to the severity of the dysphonia than to its aetiology.

Both disturbances of fundamental frequency (jitter) and of its intensity (shimmer) reflect the degree of instability of the phonation system during voice production. It seems reasonable to suppose that vocal cords with some sort of structural or functional alteration will tend to show more erratic vibration. Some researchers[17-19] have tried to use these perturbation measures for identifying various types of laryngeal pathology; unfortunately, however, these studies have used very different methodologies (different recording devices, differences in signal digitalization, different software and algorithms for parameter estimation). It is thus difficult to meaningfully compare the results obtained by different groups.

In the present study, as in some previous studies[17,18], we found that jitter and shimmer were markedly increased in both patients with vocal nodules and patients with functional dysphonia. Casado et al.[15,22] likewise found significantly higher jitter and shimmer in their vocal nodules group (jitter 0.35% and shimmer 3.25%) than in their control group; though note that these values are rather lower than obtained in the present study. Preciado et al.[22] performed a case control study, and found that jitter and shimmer showed statistically significant differences between dysphonic and normal vowels.

Some authors, such as Klingholz & Martin[20], consider that jitter is generally reduced in hyperkinetic functional dysphonias, due to the high tension of the vocal cords. However, Hall[21] compared various acoustic parameters between a group of 10 healthy women and another group of 10 women with vocal nodules, but did not find any significant difference between normal and pathological voices in any of the parameters studied.

NNE is the most widely used measure of glottal noise in Japan, China and Europe. It is an index of the relative magnitude of the laryngeal noise energy resulting from incomplete glottal closure during phonation. The perception of "breathy" voice in the pathological larynx is closely related to the amount of glottal noise present in the vocal signal. In the present study we obtained high mean NNE values, both in patients with vocal nodules and patients with functional dysphonia. This is in line with the findings of previous authors who have likewise observed that NNE is generally higher in pathological subjects than in normal subjects. Casado et al.[15] reported a mean NNE of 13.62 in normal subjects and 10.65 in patients with vocal nodules. Kasuya et al.[23] investigated the efficacy of NNE for detecting diverse laryngeal pathologies in a sample of 186 patients, finding that this is an especially useful parameter for detecting glottal cancer, vocal fold paralysis and vocal nodules.

It should be stressed that acoustic analysis of the voice has various disadvantages, including difficulties in comparing results obtained in different studies because of the use of different algorithms in the various software packages available. Furthermore, most software packages were originally developed for analysis of English language phonetics, and may not give entirely equivalent results in analysis of other languages; for example, the Spanish /e/ sound is similar but not identical to English /a/ sound. We consider that each clinic or research group should stick to a constant methodology, given the possible influence of diverse variables on the different parameters. Certainly we consider it important that research studies should clearly specify the methodology used.

Pruszewicz et al.[24] defend the utility of acoustic analysis for differential diagnosis of functional and organic dysphonias. Callan et al.[25] present a multidimensional scheme including various acoustic parameters (jitter, shimmer, standard deviation of F0, HNR), which offers an easy procedure for multivariate data visualization for voice evaluation. However, Holmberg et al.[26] give less importance to acoustic analysis. They consider that aerodynamic measures reflect the presence of vocal pathology more effectively than acoustic measures in the case of vocal nodules, and recommend the routine use of aerodynamic measures for the diagnosis of these pathological entities.

In conclusion, we believe that the laryngostroboscopy, systematized through a protocol, is a very useful technique in the diagnosis of structural and functional abnormalities in patients diagnosed of vocal nodules and functional dysphonias, detecting at least some alteration in the parameters most commonly studied. However it should not be the only technique used for the diagnosis given the high percentage of abnormal stroboscopic findings in healthy people.
The acoustic analysis of voice, the program Dr. Speech, despite its limitations, can be a useful complementary tool in the diagnosis of vocal nodules and functional dysphonias.

References:

1. Bless DM. Measurement of vocal function. Otolaryngol Clin North Am. 1991; 24(5):1023-33.
2. Lockhart MS. Objective assessment of voice intervention: a clinical audit. IntJ Lang Commun Disord. 1998; 33 Suppl: 316-21.
3. Di Nicola V, Fiorella ML, Luperto P, Staffieri A. Objective evaluation of dysphonia. Possibilities and limitations. Acta Otorhinolaryngol Ital. 2001;21(1); 10-21.
4. Rabinov CR, Kreiman J, Gerratt BR, Bielamowicz S. Comparing reliability of perceptual ratings of roughness and acoustic measure of jitter. J Speech Hear Res. 1995; 38(1):26-32.
5. Carding P, Carlson E, Epstein R, Mathieson L. Re: Evaluation of voice quality.Int J Lang Commun Disord. 2001; 36(1):127-34.
6. Hirano M, Bless DM. Videostroboscopic examination of the larynx. Singular Publishing Group, Inc. San Diego. 1993; 15-32.
7. Preciado Lopez JA, Calzada Uriondo MG, Zabaleta Lopez M, Garcia Cano FJ. Variability in the digital voice analysis depending on the analyzed vocal, in normal patients and in patients with dysphonia. Acta Otorrinolaringol Esp. 2000; 51(7):618-28.
8. Titze IR. National Center for Voice and Speech. Workshop on Acoustic Voice Analysis. Summary Statement, Denver, 1994; 1-30
9. Sataloff RT, Spiegel JR, Hawkshaw M. Strobovideolaryngoscopy: results and clinical value. Ann Otol Rhinol Laryngol. 1991; 100(9):725-7.
10. García-Tapia Urrutia R (2). Estroboscopia. in: García Tapia R, Cobeta Marco I. Diagnóstico y Tratamiento de los Trastornos de la Voz. Editorial Garsi, S.A. Madrid. 1996; 111-124.
11. Dejonckere PH, Crevier L, Elbaz E, Marraco M. Quantitative rating of video-laryngostroboscopy: a reliability study. Rev Laryngol Otol Rhinol (Bord). 1998; 119(4):259-60.
12. Elias ME, Sataloff RT, Rosen DC, Heuer RJ. Normal strobovideolaryngoscopy: variability in healthy singers. J Voice. 1997; 11(1):104-7.
13. Heman-Ackah YD, Dean CM, Sataloff RT. Strobovideolaryngoscopic findings in singing teachers. J Voice. 2002;16(1):81-6.
14. Aronson AE. Clinical Voice Disorders: An Interdisciplinary Approach. Third Edition. Thieme Inc., New York. 1990; 20-28, 41-75, 102-128.
15. Casado Morente JC, Adrian Torres JA, Conde Jimenez M. Objective study of the voice in a normal population and in dysphonia caused by nodules and vocal polyps. Acta Otorrinolaringol Esp. 2001; 52(6):476-82.
16. Kotby MN, Titze IR, Saleh MM, Berry DA. Fundamental frequency stability in functional dysphonia. Acta Otolaryngol. 1993; 113(3):439-44.
17. Wolfe V, Fitch J, Cornell R. Acoustic prediction of severity in commonly occurring voice problems. Speech Hear Res. 1995;38(2):273-9.
18. Martin D, Fitch J, Wolfe V. Pathologic voice type and the acoustic prediction of severity. J Speech Hear Res. 1995; 38(4):765-71.
19. Wolfe V, Fitch J, Martin D. Acoustic measures of dysphonic severity across and within voice types. Folia Phoniatr Logop. 1997; 49(6):292-9.
20. Klingholz F, Martin F. Quantitative spectral evaluation of shimmer and jitter. Speech Hear Res. 1985; 28(2):169-74.
21. Hall KD. Variations across time in acoustic and electroglottographic measures of phonatory function in women with and without vocal nodules. J Speech Hear Res. 1995; 38(4):783-93.
22. Preciado JA, Garcia Tapia R, Infante JC (2). Prevalence of voice disorders among educational professionals. Factors contributing to their appearance or their persistence. Acta Otorrinolaringol Esp. 1998; 49(2):137-42.
23. Kasuya H, Ogawa S, Mashima K, Ebihara S. Normalized noise energy as an acoustic measure to evaluate pathologic voice. J Acoust Soc Am. 1986;80(5):1329-34.
24. Pruszewicz A, Obrebowski A, Swidzinski P, Demenko G. Usefulness of acoustic studies on the diffrerential diagnostics of organic and functional dysphonia. Acta Otolaryngol. 1991; 111(2):414-9
25. Callan DE, Kent RD, Roy N, Tasko SM. Self-organizing map for the classification of normal and disordered female voices. J Speech Lang Hear Res. 1999; 42(2):355-66.
26. Holmberg EB, Hillman RE, Hammarberg B, Sodersten M. Efficacy of a behaviorally based voice therapy protocol for vocal nodules. J Voice. 2001; 15(3):395-412.