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Acoustic analysis of voice in patients treated by reconstructive subtotal laryngectomy. Evaluation and critical review

Analisi acustica della voce in soggetti sottoposti a laringectomia parziale sopracricoidea. Valutazione e revisione critica

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Key words

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Parole chiave

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Summary

Aim of this investigation was to analyse the voice in a group of 20 patients submitted to supracricoid partial laryngectomy (cricohyoidopexy, sparing two arytenoids) by the Multi Dimensional Voice Programme acoustic analysis system. Results revealed the following sound characteristics: high rate of noise, lack of periodic component of the signal, high rate of segments with no sound signal, vocal segments with marked air-turbulent flow, variation amplitude and frequency coefficients doubled compared to normal values, average fundamental frequency, if present, extremely variable and unsteady. These results show that the phonatory ability of the residual larynx, due to the altered anatomo-physiology of the structure after surgery, has to be completely re-estimated. In fact, the residual larynx determines a definitely reduced periodic acoustic signal, rich in noise and which can not be modulated. Good phonatory results of this treatment are basically due to preservation of a still understandable (but not perfect!) speech which, by ensuring the subjects' speech ability, overcomes and has little influence on the really poor quality of the vocal signal in these patients. However, the patient obtains a "new voice" as far as concerns acoustic features and this is very important for communication and social life. Moreover, the possibility of objectively estimating acoustic vocal function ability allows monitoring of the trend and results of possible speech therapy and/or phonosurgical rehabilitation treatment which should start from new anatomical and physiological bases, as well as from the new physical acoustic mechanism of signal production.

Riassunto

Scopo di questo lavoro è stato quello di analizzare la voce di un gruppo di 20 soggetti sottoposti a laringectomia parziale sopracricoidea (cricoioidopessia con risparmio delle due aritenoidi) mediante il sistema di analisi sonora Multi Dimensional Voice Programme (MDVP). I risultati hanno messo in evidenza le seguenti caratteristiche sonore: elevata quota di rumore, scarsità di componente periodica del segnale, elevata quota di segmenti senza alcun segnale sonoro, segmenti vocalici con notevole rumore da soffio aereo turbolento, coefficienti di variazione di ampiezza e frequenza raddoppiati rispetto alla normativa, frequenza fondamentale media, quando presente, estremamente variabile ed incostante. Questi risultati indicano che va totalmente rivalutata la funzionalità della laringe residua per l'evidenza clinica dell'alterata anatomo-fisiologia della struttura che rimane dopo l'intervento, la quale determina un segnale sonoro decisamente poco periodico, ricco di rumore e non modulabile. I generici buoni risultati fonatori di tale intervento vanno pertanto ascritti essenzialmente al mantenimento di un linguaggio verbale ancora intelligibile (ma non del tutto!) che, mantenendo discrete capacità comunicative (non perfette!) del soggetto, supera e rende meno influente (ma non ininfluente) la scarsa qualità reale del segnale vocale di questi soggetti. In ogni caso il soggetto avrà "una nuova voce" sotto il profilo acustico, cosa da non sottovalutare per le sue implicazioni socio-relazionali e comunicative. La possibilità di valutare obiettivamente la funzionalità acustica vocale permette inoltre di monitorizzare l'andamento e i risultati di eventuali trattamenti logopedici e/o fonochirurgici riabilitativi, i quali devono partire dalle nuove basi anatomiche e fisiologiche, nonché dal nuovo meccanismo fisico-acustico di produzione del segnale. Queste considerazioni appaiono importanti perché il paziente ottiene una "nuova voce", differente dalla propria, e questo aspetto non è sempre considerato nelle sue implicazioni socio-relazionali. Dobbiamo ricordare che una persona viene riconosciuta dal volto o dalla voce!

Introduction

Supracricoid partial laryngectomy (SCPL) with crico-hyoido-pexy (CHP) or with crico-hyoido-epiglottopexy (CHEP) is the only remaining surgical treatment feasible prior to total laryngectomy, in order to avoid a permanent tracheostoma. The almost total resection of the laryngeal structure usually requires functional rehabilitation [1-5] which is aimed, primarily, during the post-operative period, at recovery of good sphincteric activity to determine good swallowing. Only once this has been achieved, is normal respiratory function through the natural airway (decannulation) taken into consideration. Recovery of the phonatory function is considered, first of all, a step during the rehabilitation programme and, thereafter, the last goal following decannulation. Clinical evaluation of the results of vocal function following SCPL is generally based on perceptive criteria. In clinical practice, instrumental analysis of the physical acoustic parameters of the voice are rarely carried out when conventional evaluations are performed [6-9]. The instrumental methods currently used to investigate the acoustic features of the voice provide, above all, descriptive information, as in the case of spectrography and Yanagihara's classification [10] which, although useful for "common dysphonia" do not provide objective, quantitative and qualitative parameters to evaluate the sound signal in these cases. In fact, it should not be forgotten that the ELS (European Laryngological Society) protocol defined as "substitution voices" when the vocal signal does not originate from "two vocal cords" [11-14].

This consideration is important, suggesting the need to investigate and implement "new" specific protocols in voice study, first of all, acoustic, which is obviously different from those (acoustic, perceptive, etc.) usually adopted in "common dysphonia" and evaluation of phono-surgery results [14]. In fact, after SCPL, the anatomic, functional and acoustic situation is totally different from those in "common dysphonia" and conventional phono-surgery results.

We, therefore, decided to first submit the voice of subjects treated by SCPL to acoustic digital analysis by MDVP (Multi-Dimensional Voice Programme) [15], a parametric, sophisticated software, in order to obtain reliable indications about the acoustic characteristics of vocal quality in these cases. This would also provide data which would be useful for detecting good indexes of acoustic evaluation for these patients, to be used together with traditional endoscopic and perceptive analysis. These considerations are important, because the patient acquires a "new" voice sound, which is very different from his/her own, and this aspect is not always taken into consideration for its social implications. It should not be forgotten that we recognize a person by his/her face or the sound of his/her voice!!

Material and methods

Studies have been carried out on a selected group of 20 patients (mean age 58.8 years, range 48-70), all male, affected by laryngeal carcinoma, treated by SCPL, with crico-hyoido-pexy (CHP), with preservation of both arytenoids. The vocal signal was recorded at least 3 months after decannulation (min 3 months, max 5 months). All subjects were submitted to the usual rehabilitation programme following surgery. The vocal signal was recorded and analysed using the KAY Computer Speech Lab model 4300B (Kay Elemetrics Corp., Lincoln Park, NJ, USA) [14-18], assisted by a personal computer with CSL 5.0 basic software. The software used in the analysis was the MDVP, with a microphone at a distance of 20 cm from the lips, at an angle of 45°, in a quiet room (< 30 dB background noise). Vocal samples were all digitally recorded at a sampling rate of 50 kHz. All subjects were trained to voice a vocal sample of a sustained /a/, at a conversational voice intensity, always within 55 dB and 65 dB, on average (not including recordings, the average intensity of which was out of range), as constant as possible, with no intensity or frequency variation, for the Maximum Phonation Time (MPT). In order to refer to only one constant method of study, the input microphone saturation was constantly fixed, in all cases, at (6/9) (six ninths) of CH1. This adjustment produced a fair saturation of dynamic range with no "overload" [19 20]. Investigations related to the central portion of vocalization, each sample of at least 3 seconds, after calculating MPT and observed with an average value of 5.554 and range between 4.496 and 6.711 sec.

Normal reference values were obtained from a randomised sample of 20 normal male speakers (mean age 60.4 years, range 50-70) (Table I).

It is well known that the MDVP system provides 33 measures of vocal signal, of which 3 only methodological and 30 related to acoustic features [21-23].

In the present study, only 11 out of the 30 parameters implemented by the software, have been considered. These parameters are the more representative and significant in describing restored vocal functional in these cases: Fo, vFo, vAm, Jitt, Shim, NHR, VTI, SPI, DVB, DSH, DUV [16].

Fo (Hz). Average Fundamental Frequency for all extracted pitch periods.

vFo (%). Fundamental Frequency Variation represents the relative standard deviation (SD) of the period-to-period calculated fundamental frequency. It reflects the very long-term variations of Fo for all the analysed voice sample.

Table I. Standard reference values.

	Parameter	Range	Mean	SD
Fo	Average Fundamental Frequency (Hz)	85.055-164.823	117.515	20.630
vFo	Fundamental Frequency Variation (%)	0.419-2.332	0.895	0.375
vAm	Peak-Amplitude Variation (%)	4.332-22.091	8.897	2.897
Jitt	Jitter percent (%)	0.134-1.939	0.538	0.371
Shim	Shimmer percent (%)	1.656-6.727	2.900	1.010
NHR	Noise to Harmonic Ratio	0.089-0.201	0.125	0.019
VTI	Voice Turbulence Index	0.004-0.124	0.057	0.020
SPI	Soft Phonation Index	1.793-14.141	5.822	3.473
DVB	Degree of Voice Breaks (%)	0	0	0
DSH	Degree of Sub-harmonics (%)	0	0	0
DUV	Degree of Unvoiced Voice (%)	0	0	0

vAm (%). Peak Amplitude Variation represents the relative SD of the period-to-period calculated peak-to-peak amplitude. It reflects the very long-term amplitude variations within the analysed voice sample.
Jitt (%). Jitter Percent provides an evaluation of the variability of the pitch period within the analysed voice sample. It represents the relative period-to-period (very short-term) variability.
Shim (%). Shimmer Percent provides an evaluation of the variability of the peak-to-peak amplitude within the analysed voice sample. It represents the relative period-to-period (very short-term) variability of the peak-to-peak amplitude.
NHR. Noise-to-Harmonic Ratio is an average ratio of energy of the inharmonic components in the range 1500-4500 Hz to the harmonic components energy in the range 70-4500 Hz. It is a general evaluation of the noise presence in the analysed signal (such as amplitude and frequency variations, turbulence noise, sub-harmonic components and/or voice breaks).
VTI. Voice Turbulence Index is an average ratio of the spectral inharmonic high frequency energy in the range 2800-5800 Hz to the spectral harmonic energy in the range 70-4500 Hz in areas of the signal where the influence of the frequency and amplitude variations, voice breaks and sub-harmonic components are minimal. VTI measures the relative energy level of high frequency noise. It correlates primarily? with the turbulence caused by incomplete or loose adduction of the vocal folds.
SPI. This parameter is not a measurement of noise, but rather the harmonic structure of the spectrum. Soft Phonation Index is an average ratio of the lower frequency harmonic energy (70-1600 Hz) to the higher frequency (1600-4500 Hz) harmonic energy (compare to NHR and VTI). An increased value of SPI may be an indication of incomplete or loosely adducted vocal folds during phonation. SPI is very sensitive to the vowel formant structure, because vowels with lower high frequency energy will result in higher SPI. Only values computed for the same vowel can be compared. The vowel /a/ is recommended.
DVB (%). Degree of Voice Breaks shows, in percent, the ratio of the total length of areas representing voice breaks to the time of the complete voice sample.
DSH (%). Degree of Sub-Harmonics is an estimated relative evaluation of sub-harmonic to Fo components in the voice sample.
DUV (%). Degree of Voiceless is an estimated relative evaluation of non-harmonic areas (where Fo cannot be detected) in the voice sample. In the case of non-sustained phonation from the beginning to the end of the data acquisition, DUV will evaluate also the pauses before, after and/or between the voice sample(s).
The MDVP does not provide results when the analysed signal is totally formed by non-harmonic areas.
The results were submitted to statistical evaluation by comparing mean values of each parameter in the normal and "surgery" group, using Student's t test, at $p = 0.05$ significance level.

Results

Standard reference values, in normal subjects (normative), are shown in Table I.
Results in subjects submitted to SCPL are shown in Table II.
A variable amount of harmonic areas was found in all cases. In fact, MDVP does not provide results when the signal is totally formed by non-harmonic areas. The results are recorded as average, min, max, range values and SD.

Table II. Values of treated patients.

	Parameter	Range	Mean	SD
Fo	Average Fundamental Frequency (Hz)	70.083-526.13	179.825	134.113
vFo	Fundamental Frequency Variation (%)	2.976-45.313	17.379	12.088
vAm	Peak-Amplitude Variation (%)	14.278-48.451	27.469	11.004
Jitt	Jitter percent (%)	3.479-23.627	11.157	6.707
Shim	Shimmer percent (%)	7.254-41.835	20.009	9.183
NHR	Noise to Harmonic Ratio	0.183-0.702	0.635	0.357
VTI	Voice Turbulence Index	0.141-1.535	0.499	0.470
SPI	Soft Phonation Index	0.722-7.609	3.561	2.609
DVB	Degree of Voice Breaks (%)	0-97.244	27.657	36.673
DSH	Degree of Sub-harmonics (%)	0-9.756	0.696	2.607
DUV	Degree of Unvoiced Voice (%)	0-98.148	69.271	39.673

Table III. Statistical results.

	Parameter	Normal speakers Mean values	Treated pts. Mean values	t value	p value
Fo	Average fundamental frequency	117.515	179.825	2.054	0.047
vFo	Fundamental Frequency Variation	0.895	17.379	6.096	0.000
vAm	Peak-Amplitude Variation	8.897	27.469	7.299	0.000
Jitt	Jitter percent	0.538	11.157	7.070	0.000
Shim	Shimmer percent	2.900	20.009	8.282	0.000
NHR	Noise to Harmonic Ratio	0.125	0.635	6.380	0.000
VTI	Voice Turbulence Index	0.057	0.499	4.202	0.000
SPI	Soft Phonation Index	5.822	3.561	2.458	0.019
DVB	Degree of Voice Breaks	0	27.657	3.407	0.002
DSH	Degree of Sub-harmonics	0	0.696	1.194	0.240
DUV	Degree of Unvoiced Voice	0	69.271	7.809	0.000

With significance level at 0.05, values exceeding 1.684 (established-t), obtained by means of Student t test (calculated), should be statistically significant.

Results were then submitted to statistical evaluation by comparing mean values of each parameter with normal reference values.

Using Student's t test with p = 0.05 significance level after evaluating the t value in each parameter, all variations between standard parameters and those in patients who underwent surgery, except for DSH (Table III), were statistically significant.

Discussion

The clinical evidence of a change in residual laryngeal anatomo-physiology, following SCPL, causes reasonable doubt that most parameters and traditional methods used in vocal evaluation, cannot, from a physiological, physical and acoustic standpoint, be taken into consideration after this type of surgery.

Cabrera Trigo [24] pointed out that such treatment causes an alteration in the endolaryngeal tract characterised by an irregular air passage and a new vocal production mechanism which appears very different from that of the normal larynx. Namely, non-adductive and muscular fascicular movements, subglottic expiratory air vector with very low subglottic pressure [25], turbulent air flow along irregular laryngeal margins.

In fact, Dejonkere et al. [13], adopting the ELS protocol in "common dysphonia", refers to "substitution voices" when the signal does not originate from two vocal chords, and suggests the use of specific protocols [26 27].

As far as concerns that same protocol, the technical nature of the equipment and software, for voice analysis, needs to be taken into further consideration, since most of them, except for those like MDVP, if not highly sophisticated and carefully handled, can easily produce unreliable results when measuring a fundamental frequency or other parameters in a sound signal, the periodicity of which is no longer regular [15 23].

Clearly, the acoustic evaluation of this voice requires objective and quantitative acoustic parameters and methods of the vocal product to investigate results and upgrade phonatory aspects in surgery. To this end, the modern acoustic digital analysis of the vocal sound (noise, harmonics, frequency and intensity short-term variations, etc.) can still be used. This application is of considerable clinical interest on account of the possibility of obtaining various measures of the vocal sample as well as information on the "neoglottic" functional results. These methods then allow easier and less subjective comparison of acoustic functional results in surveys [28].

Acoustic features of the voice in patients submitted to SCPL are related to anatomical structures and functional abilities of the residual restored phonatory system. Hence, the "neoglottis" vibrational pattern appears rather "unstable" and not-always-periodic, because of the anatomical characteristics of vibrating structures [29 30]:

1. arytenoid mucosa with no structure "which can be modulated" lying below;
2. tongue base/pharynx/epiglottis;
3. T-shaped neoglottis (with 2 arytenoids);
4. upside-down L-shaped (with 1 arytenoid);
5. closure modes (sagittal, front, mixed);
6. incomplete closure.

This obviously entails completely "new" functional and acoustic consequences. Many Authors have compared vocal characteristics after SCPL with CHP or CHEP, from both a quantitative and qualitative point of view. Now, we first analysed studies in which qualitative evaluation of phonatory results, after this type of surgery, consisted in assigning, following simple subjective criteria, a more or less positive judgement of evaluation of phonatory and vocal function, in general (Table IV).

In 103 patients submitted to CHP, Labayle and Dahan [31] observed improvements occurring over months. This was often related to the decision of the patient to undertake rehabilitation, aiming at good results. These improvements, following rehabilitation, were really surprising.

Piquet et al. [32] studied a group of 117 patients, of whom 71 submitted to CHP and 46 to CHEP. Vocal quality was good in 80% of cases, better and with a sound production intensity higher than that prior to treatment and with a low-pitched timbre. In 20% of cases, the restored voice kept on being unvoiced even after vocal rehabilitation.

Prades and Martin [33] observed 19 patients submitted to CHP and referred to the quality of the voice as always being good. As far as concerns this result, an essential role was played by the mobility of the arytenoids and by the fact that, despite a reduced antero-posterior diameter, the width and height of the laryngeal canal are preserved, thus allowing better vibration of the structures when the air column passes.

Ferri and Bottazzi[34], in 21 patients with SCPL, observed: good recovery of phonatory quality in 5 (23%); sufficient in 10 (47%); poor in 6 (30%).

Pech et al. [35] evaluating phonatory function in a group of 49 patients, 17 of whom following CHEP and 32 following CHP, observed good recovery of the voice in all CHEP-treated patients, while in the 32 CHP-treated patients voice quality was poor. Albeit, as the Authors stressed, the worst voice, in these patients, is always better than the oesophageal voice, certainly in function of the absence of a tracheostoma.

Guerrier et al. [36] studied functional ability in 58 patients, all affected by laryngeal glottic carcinoma, submitted to CHEP. After a minimum observation of at least 4 months, results demonstrated good phona-

Table IV. Phonatory functional results with subjective evaluation

Author (ref.)	No. pts	Treatment CHP	CHEP	Good voice (%)	Sufficient voice (%)	Poor voice (%)
Labayle [31]	103	103	–	100	–	–
Piquet [32]	117	71	46	80	–	20
Prades [31]	50	48	2	38	62	–
Bottazzi [31]	21	21		23	47	30
Pech [31]	49	32	17	35	–	65
Guerrier [31]	58	–	58	100	–	–
Marandas [31]	57	57	–	72	–	28
Vigneau [31]	60	8	52	68	27	5
Traissac [31]	122	25	97	23	58	19
Total	637	365	272	60	21.5	18.5

tory recovery in all patients. Factors influencing voice quality, besides preservation of the arytenoids, are motivation, but above all, patient's educational ability allowing him/her gain the greatest profit from the various orthoepical rehabilitation manoeuvres.

Marandas et al. [37], in a survey of 57 patients submitted to CHP, at the Institute Gustave Roussy, observed poor phonatory results in 16 patients (28%) and good in 41 (72%).

Prades et al. [38] analysed 2 patients who underwent CHEP, concluding, from the results, that phonation is basically a source of complaint among the patients, as well as a strain due to closure of the glottis. These two functions of the neolarynx are, as a rule, of poor quality. Moreover, there is little difference between the results of the various surgical techniques, and even these are very difficult to define.

Vigneau et al. [39] analysed functional results, in a survey of 64 patients submitted to SCPL from 1975 to 1985, 52 underwent CHEP and 8 CHP, with 4 patients who underwent total laryngectomy a few weeks after surgery on account of a resection considered oncologically insufficient. Acccording to the rehabilitation protocol, the beginning of orthoepical retraining was programmed to begin 10 days after surgery, together with external massage. A good, perfectly understandable, and satisfactory voice was achieved in 69% of CHEP speakers and in 60% of CHP speakers. In 21% and 22%, respectively, of CHEP speakers and CHP speakers, the voice was slightly voiced, low intensity but understandable and considered satisfactory by the patients. The remaining 10% of the CHEP speakers and 11% of the CHP speakers had a residual voice which was hardly understandable and, in general, of poor quality.

Traissac et al. [40] analysed 122 cases, of which 97 following CHEP and 25 CHP. A good voice was achieved in 25% of patients treated with CHEP and in 17% of those treated with CHP. The voice was unvoiced in patients treated according to SCPL-CHEP and in 60% of those who underwent SCPL-CHP. Finally, in 17% and 23% of patients treated, respectively, with CHEP and CHP, an understandable voice was noted. No big differences between results, obtained shortly after surgery and those after a rehabilitation programme, were noted which is in contrast with other Authors' experience. In fact, to this end, Minni et al. [41] reported that it is because of the continuous rehabilitation exercises that the intensity of vocal production becomes more and more dynamic, continuous and regular after surgery and, furthermore, in the opinion of these Authors, early treatment of speech defects, by guaranteeing fast recovery of laryngeal physiological function, allows a more rapid return to social life of patients submitted to SCPL.

Pastore et al. [42] submitted the recorded phrases of 14 patients, following reconstructive subtotal laryngectomy treatment, to the attention of trained listeners. This study proved that vocal quality after surgery, although little voiced, permits an understandable and socially acceptable communication.

Genovese et al. [43] reported that, although the new voice, achieved through SCPL, is less sonorous, it is perfectly understandable, socially acceptable, speech.

Moreover, there are other studies in which phonatory function of patients submitted to SCPL was evaluated by a semi-objective method, mainly by spectography.

Demard and Demard [44] reported that the voice, after reconstructive subtotal laryngectomy, is low-pitched and resembles a good esophageal voice. The acoustic structure of the vocal signal is the result of a combination between the vibration of mucosa at the reconstructed site and a noise component produced by the pharyngeal constriction and by the turbulent air flow. These Authors hypothesised the possibility of an improvement in vocal quality, by rehabilitation, consisting in reducing pharyngeal constriction which produces noise by suppressing the cervical vocal strain.

Minni et al. [41] analysed 149 patients submitted to SCPL. The functional evaluation included phonation and return to social life, as well as an analysis of vocal quality, by means of spectography. Although, in all cases, phonatory recovery was considered sufficient, typical phonatory features were observed in patients treated with this procedure, resulting in: slowing down of the speaking rate constant, lowering of the fundamental frequency, constant increase in the component of noise compared to that of the fundamental signal. The Authors stressed the importance of post-operative rehabilitation which implies the reduction in noise in favour of the harmonics.

In addition to these subjective and semi-objective analyses, the voice, following SCPL, was evaluated also by instrumental analyses of physical-acoustic parameters of the vocal product.

Bonnet et al. [45] analysed the main physical features of the voice produced by the neoglottis, in 43 CHP speakers and in 68 CHEP speakers. All cases were considered sufficient and with a maximum intensity of 50-90 dB and a variable fundamental of approximately 120 Hz.

Laccourreye et al. [46 47] estimated functional results in 104 patients following SCPL (68 CHP and 36 CHEP). All patients showed good recovery of phonatory function thanks to the preservation of at least one arytenoid and early rehabilitation, which are, as already pointed out, the two main features of this treatment.

Laccourreye et al. [48], again, revealed, by means of acoustic analyses, a considerable reduction in MPT, Speech Rate (number of words per minute), Phrase

Grouping (number of words per breath), as well as an excessive Fo variability, a statistically significant increase in jitter, shimmer and NHR.
De Vincentiis et al. [17] submitted 153 subjects to acoustic analysis, 83 underwent CHP, 70 CHEP. All were submitted to perceptive analysis of the voice, vocal extension by means of the Fo indicator of the stroboscope and maximum intensity evaluation using a phonometer. The study showed better vocal recovery after CHEP, but the most important information was related to the maximum phonation intensity which provided most patients with a socially appreciable and useful phonation.
Finally, according to Vigili et al. [49], assessment of quality of life [50 51] and satisfaction with care are particularly important in the field of oncology and it is generally accepted that it is a multidimensional concept involving three different domains: physical, psychological and social. In fact, in conservative laryngeal surgery (also SCPL), the Authors [49] stressed subjective-objective evaluation of speech (computerized spectrographic analysis of fundamental frequency, percentage of noise and intensity and logopaedic evaluation of speech). Analysis of the results obtained confirmed the need to set up an evaluation protocol combining both the subjective perceptions of the patient, as well as a more objective evaluation of the functions that are impaired following surgery.
According to Jemmi et al. [10], SCPL associated with CHP, makes speech continuity possible. Such subjects have mixed vocal output (periodic components together with noise) although, overall, the voice produced has the fundamental requirements for intelligibility (i.e., intensity, pitch, harmonic structure, emission time) and may thus be considered valid for interpersonal verbal communication.
After evaluating the investigations, mentioned above, an early outline of the phonatory function in patients treated with this type of laryngeal surgery can be traced, both for qualitative and quantitative features, the latter only when supported by a physical-acoustic analysis of the vocal signal.
The voice of subjects with SCPL displays the following characteristics: low-pitched tonality, remarkable reduction of MPT, of speech rate and of speech fluency, measured by the phrase grouping, high noise to harmonics ratio, due partly to the turbulent flow through the freshly restored structure, increase in physical acoustic parameters, such as jitter and shimmer with respect to normal subjects, increase in fundamental frequency. However, it is possible to observe, on the basis of a perceptive "qualitative" evaluation, that, in more than 80% of the subjects analysed in the literature (Table IV), the vocal functional ability is sufficient [10-43]. This is an important consideration, within a "minimal normal conversational ability" permitted by the sound signal still present, favouring a fair speech articulation and also its "social value" to be still preserved.
A different evaluation is made following a technical quantitative analysis of the sound signal quality, produced by the residual laryngeal structure, after SCPL. In fact, Dejonkere et al. [13], proposing the ELS protocol for the functional assessment of the voice in "common dysphonia", define "substitution voices" those when the signal does not originate from the two vocal cords; they suggest to re-address the specific protocol, after acoustic analysis. In fact, the most important acoustic finding is the high variability of the fundamental frequency (when a nearly – periodic signal is generated!) caused by the radical anatomical change after SCPL. Except for pressure generated by pulmonary air flow, all that produces the voice physiologically is altered. The signal with all its periodic and aperiodic (noise) components is generated by mucosa vibration which may change from time to time in site and encounter mode. These vibrating structures (arytenoids, tongue base, pharyngeal walls), are visibly, structurally and functionally, very different from vocal cords. According to this viewpoint, the analytical protocol of this voice must be conceptually different from that for "common dysphonia".
Moerman et al. [27] have suggested that "Substitution voicing" cannot be evaluated accurately by the GIRBAS perceptual rating scale, and a valid alternative is needed.
According to Bron et al. [52], the restoration of laryngeal function after SCPL with CHEP is satisfactory. Although most of the patients seem to recover normal swallowing function, severe voice alterations appear to be inevitable.
Recently, Yuceturk [53] performed a multidimensional assessment of voice and speech after supracricoid laryngectomy with CHP; the study evaluated vocal function in patients with SCPL compared with that in normal subjects. The acoustic parameters were found to be significantly different from those of normal subjects. The values of perceptual scores were within approximately 50% of the normal range. The number of arytenoids spared did not affect either acoustic or perceptual measurements. A rough, breathy, unpleasant, but intelligible and acceptable, voice could be obtained after SCPL with CHP.
Analyses of our data, obtained using a special hi-tech system, suitable for the analysis of small periodic vocal signals, showed a high DVB parameter which displays the rate of absence of both periodic and aperiodic sonority, averaging from one quarter to almost the entire duration of the sound signal. In the remaining sound portions, DVU, which represents a measure of non-harmonic sound portions, i.e., where no Fo could be measured, shows an irregular periodic phonation with a range between 0

and 98% of the samples examined, the mean value of which was about 70%. This percentage implies a sound signal production which, for over two thirds of its duration, is only noise. On the contrary, it was always possible to detect an almost periodic part of the signal (minimum value: 2%). Hence, it is obvious that Fo evaluations, when measured, are very irregular and unpredictable, as the Fo parameter shows, because of the very wide range of values and the high percentage of the Fundamental Frequency Variation (vFo).
The signal has a high Noise to Harmonic Ratio (NHR), and the important turbulent air passage (incomplete closure) is described by the increased VTI value. Amplitude is not constant: tripled variation amplitude coefficient (vAm) and, finally, considerably increased amplitude and frequency perturbations, are fully confirmed.
All these features describe a very slight periodic, instable, signal, and explain the large percentage of high grade dysphonia in perceptive evaluations [54].

Conclusions

In conclusion, the residual larynx produces a slight sonorous, almost completely aperiodic signal with a variable and inconstant Fo, when and if it is generated. These observations clearly show that the "post-reconstructive-surgery voice" is to be reconsidered, not only as a product of a different functional anatomical configuration of the residual larynx, but also from the resulting acoustic physical product standpoint. In other words, the new laryngeal physiology produces a "different" signal which can never be compared to the "normal" one. This consideration is the most important as the patient gets a "new" voice sound, which is very different from his/her own, and this aspect is not always considered for its social implications. We must remember that we recognize a person by his/her face or the sound of his/her voice!
These evaluations involve new parameters of study and of the real physical acoustic features. To this end, MDVP parameters are indicated for their accurate, direct and quantitative information on some acoustic aspects of functional ability and quality of vocal production, limiting the uncertain subjective, perceptive (GIRBAS scale) or spectrographic interpretations (Yanagihara classification), still improperly used in this situation. Our results, according to Marioni et al. [26], help us in defining guidelines to evaluate the functional results of SCPL and facilitate interstudy comparison. These studies will be integrated by investigations on speech intelligibility [9].
These evaluations, together with both direct and stroboscopic endoscopic visualisation, will likely provide useful suggestions to improve "vocal performance", in these patients, by future phonosurgical and/or speech therapy rehabilitation programmes.

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