Laryngeal polyps – evaluation of treatment effects on the basis of acoustic examination of voice signals

Ocena wyników leczenia osób z polipami krtaniowymi w świetle badań akustycznych sygnału głosu

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Introduction. Laryngeal polyp, preferably treated by phonosurgery, is the most common type of benign vocal fold lesion (BVFL). Phonosurgery involves precise removal of abnormalities in the vocal folds while preserving their vocal function.

Aim. The aim of the present work was to analyse objectively, via voice acoustic examination, the results of phonosurgery in the treatment of vocal fold polyps.

Material and methods. A prospective clinical examination involved 26 patients (aged 19 to 70 years) with laryngeal polyps, treated by means of phonosurgery. The control group consisted of 25 healthy volunteers (aged 24 to 65 years). The follow-up acoustic analysis was performed before phonosurgery and after one- and six-month period. Sustained phonation of vowels "a", "e", "i" and "u", was used for the acoustic analysis of voice signals. Euclidean and Hamming metrics were applied to evaluate the acoustic results of the patients in comparison to the control group.

Results. The study revealed that voice acoustic parameters of the patients with laryngeal polyp improved significantly after phonosugery compared to the values before treatment. The greatest improvement was observed in the first month after surgery, followed by a further improvement in the following five months. The improvement of acoustic parameters was independent from the location of the polyp in the glottis.

Conclusions. The results indicate that the acoustic analysis could be used in the objective monitoring of treatment effects among subjects with benign vocal fold lesions.

Key words: *vocal fold, polyp, phonosurgery, acoustic analysis*

Wprowadzenie. Najczęstszą łagodną zmianą przerostową fałdów głosowych jest polip krtaniowy, leczony zazwyczaj fonochirurgicznie.

Cel pracy. Obiektywna analiza wyników fonochirurgii w leczeniu polipów fałdów głosowych, za pomocą akustycznej analizy sygnału głosu.

Materiał i metody. Prospektywnymi badaniami klinicznymi objęto grupę 26 osób, w wieku 19-70 lat, leczonych fonochirurgicznie z powodu polipów krtani. Grupę kontrolną stanowiło 25 zdrowych ochotników w wieku 24-65 lat. Analiza akustyczna głosu wykonywana była przed i po zabiegu fonochirurgicznym: po jednym i sześciu miesiącach. Analizowano widma samogłosek „a", „e", „i", „u" podczas ich przedłużonej fonacji. Aby ocenić i porównać sygnały akustyczne głosu osób z grupy badanej w porównaniu z grupą kontrolną posłużono się metrykami Euclidesa i Hamminga.

Wyniki. Parametry akustyczne głosu osób leczonych fonochirurgicznie z powodu polipa krtani poprawiły się istotnie po zabiegu w porównaniu z ich wartościami przed zabiegiem. Największą poprawę zaobserwowano w okresie jednego miesiąca po zabiegu, dalsza poprawa postępowała po następnych pięciu miesiącach od operacji, lecz była stosunkowo mniejsza. Parametry akustyczne poprawiały się po fonochirurgicznym usunięciu polipa niezależnie od jego lokalizacji w głośni.

Wnioski. W pracy wykazano, że metoda akustycznej oceny jakości głosu ma zastosowanie w obiektywnym monitorowaniu wyników leczenia fonochirurgicznego osób z łagodnymi zmianami przerostowymi fałdów głosowych.

Słowa kluczowe: *polip krtaniowy, fonochirurgia, analiza akustyczna*

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Abbreviations:

BVFL – benign vocal fold lesion

INTRODUCTION

Of all the methods of human communication, the articulated voice is without doubt the most important means of conveying information. The distinguishing features of the human voice, timbre, melodiousness, intonation, purity and intensity, are all expressions of personality. Therefore, the quality of the voice is of crucial importance to an individual and, as a source of information about him or her, serves a cognitive function. It is also plays a crucial role in certain occupations, such as acting, singing and radio/TV announcing [1].

The key issue in voice production is vocal fold vibration, which converts the aerodynamic energy from the exhalation airflow into acoustic energy. Thus, from the point of view of its physical features, the larynx may be thought of as a voice generator [2,3].

Recently have been recorded an increasing number of patients with organic or functional dysphonia. Pathological vocal fold changes may interfere with the glottal vibratory pattern, cause disruption of the laminar structure of the vocal fold and change its shape or prevent full glottal approximation by the intrusion of additional surface mass [4].

Some of the patients who complain of voice dysfunction suffer from BVFL (benign vocal fold lesion). This is closely connected with social change, which has resulted in increasing numbers of people using their voices professionally. The most common type of BVFL is laryngeal polyp. Laryngeal polyps should be treated by phonosurgery, which involves the precise removal of abnormalities in the vocal folds while preserving their original microstructure [4].

Current methods of voice evaluation include subjective perceptual assessment and objective acoustic analysis of the voice signal. Schultz-Coulon and Klingholz observed that the results of acoustic analysis correlate with the condition and function of the vocal tract [5]. Polish literatures present similar observations and conclusions – Niebudek-Bogusz et al, Woźnica-Wiskirska et al [6,7].

The development of digital methods of recording and processing sound allows the use of objective acoustic voice analyses in laryngological, phoniatric and logopedical diagnosis. The possibility of applying these methods stems from the fact that all pathologies and diseases of the vocal tract affect the quality of the patient's speech signal. On the basis of the complex distinctive and essential acoustic features (mathematical and physical values) contained in the acoustic voice signal, a clear assessment can be made of the condition of the sound source, namely, the larynx. Distinguishing the features of the voice in this way is fundamental to the objective voice signal analysis of patients [2,8-10]. Acoustic analysis is a non-invasive diagnostic method which has become inexpensive and appears to be successful for monitoring changes in voice quality over time [11]. Measurements of acoustic parameters have given clinicians a better understanding of the impact of voice disorders and the monitoring of efficiency treatment [4,12-14].

Acoustic analysis of the voice signal proved to be a valuable tool in various branches of phoniatry, including differential diagnosis of the organic and functional dysphonia, diagnosis of hypertrophic vocal fold lesions and vocal fold paresis, objective evaluation of voice disorders and monitoring of voice rehabilitation [11,14].

Traditional methods comprise the calculation of jitter and shimmer [variations of fundamental frequency and amplitude, respectively] and related parameters. New promising techniques include cepstral analysis, linear predictive analysis and wavelet transform [15-19].

The purpose of the present work was to provide an evaluation of the phonosurgical treatment of patients with laryngeal polyps by means of acoustic examination of voice signals. In particular, it addressed the following two questions:

1. Is the improvement in phonatory function following phonosurgical treatment of laryngeal polyps reflected in a normalization of the acoustic parameter values of voice signals?
2. Does the location of the laryngeal polyp on the vocal fold have a bearing on the results of phonosurgical treatment as evaluated in the acoustic parameter values of voice signals?

MATERIALS AND METHODS

The study group of 26 patients with laryngeal polyps included: 10 (38.5%) women and 16 (61.5%) men), aged 19 to 70 years. All the patients underwent phonosurgical treatment at an ENT Clinic in Krakow. The control group consisted of 25 volunteers {12 (48%) women and 13 (52%) men}, aged 24 to 65 years. Laryngological examination of the volunteers showed no pathology of the voice organ. It should be also noted that, according to perceptual assessment their voices were considered average for the general population.

Patients with laryngeal polyps were divided into three groups: group A – patients with a polyp located on the 1/3 anterior part of the vocal fold (13 subjects); group B – patients with a polyp located on the 1/3 central part of the vocal fold (7 subjects); and group C – patients with a polyp located on the 1/3 posterior part of the vocal fold (6 subjects).

Patients underwent laryngological evaluation and acoustic signal voice analysis three times, each examination consisting of laryngoscopical evaluation and a recording of the acoustic voice signal. The 1st registration was performed just before phonosurgical treatment; the 2ed registration – 1 month after phonosurgey; and the 3st registration – 6 months after phonosurgical treatment. The data collected from the acoustic evaluation of voice signals were subjected to multidimensional mathematical analysis.

The acoustic voice signal examinations were performed in the Department of Mechanics and Vibroacoustics at the University of Science and Technology (AGH), Krakow, Poland in an anechoic chamber (room insulated from exterior sources of noise, designed to absorb reflections of sound) with a volume V=1051 m3. The level of interference in the waveband above 50Hz did not exceed 0 dB.

In the course of each examination, patients were asked to read aloud a prepared list of the vowels a, e, i, u. Each patient read the above sounds three times. The vowels were then pronounced once again but with extended phonation (sustained vowels). The voice signals were selected on the basis of methods found in the specialist literature [4,13,14].

During the examination of patients utterances, the recording and processing of the time pressure run of the acoustic signal was made using an Oktava MKO12 microphone.

The analogue electric signal was converted and recorded on an EMU 0404 USB portable digital recorder. Each patient was given an identification number in order to establish a data bank for further calculation. The data bank of the normal speech of the group of healthy volunteers showing no vocal pathology was used as a reference Polish speech signal. The population which provided the reference signal for individual vowels consisted of people with average, untrained voices. This method of establishing a reference has been used in similar research.

Obtaining a full set of results for the acoustic examination of speech signals in patients required the use of a considerable number of computer programs. Cool Edit Pro 1.2 (Syntrillium Software Corporation), a program enabling the visualisation of the time run of recorded speech signals, was used to record the patients' utterances and isolate the fragments corresponding to their pronunciation of the phones a, e, i, u. WAV files were then created for each patient (fig. 1).

The patients acoustic data was recorded on a digital recorder. It was then analysed using the "Speech" program in Matlab environment (The MathWorks) in the Department of Mechanics and Vibroacoustics at Krakow University of Science and Technology (AGH). Before analysis, all samples of the acoustic voice signal, both normal and pathological, were normalised to the same level. From the isolated fragments corresponding to the pronunciation of individual sounds of the list of vowels set out above, two and three-dimensional dynamic spectra (in the form of spectrograms) were obtained (fig. 2, fig. 3), as well as average dynamic spectra with the indicated confidence interval (fig. 4).

These dynamic spectra served as the basis for further presentations and calculations. From a diagnostic point of view, the dynamic spectrum contains an excess of information, which might be felt to be a hindrance when diagnosing the degree of deformation of the voice signal. To eliminate this problem, the dynamic spectrum was converted to a 14-dimensional vector of features. The coordinates for this vector are: spectrum moment, formant and coefficient of relative power.

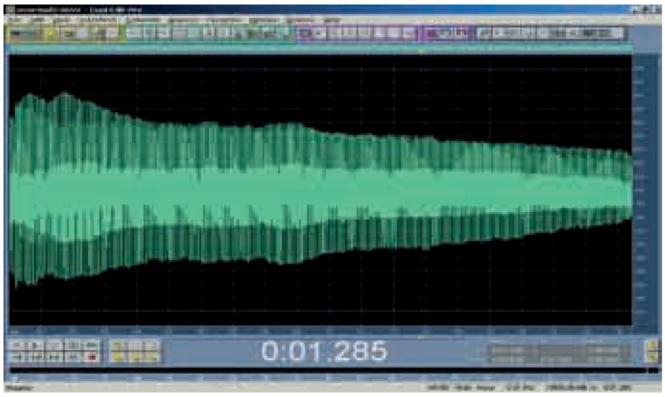

Fig. 1. Cool Edit Pro 1.2 program. Time run of the phone "a" - sustained phonation (normal voice)

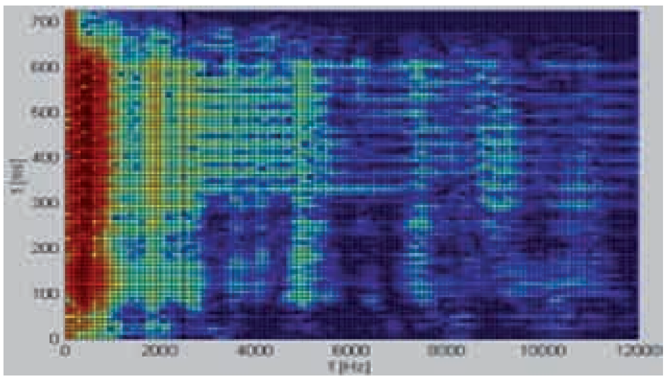

Fig. 2. Time-frequency spectrum. Two-dimensional presentation. "Speech" program in Matlab environment (normal voice)

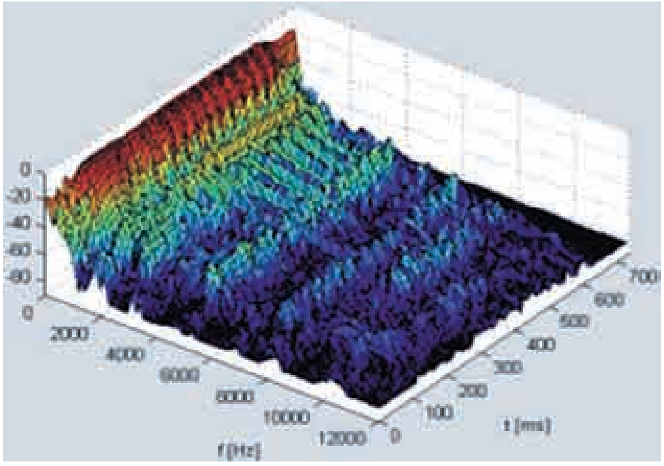

Fig. 3. Time-Frequency spectrum. Three-dimensional presentation. "Speech" program in Matlab environment (normal voice)

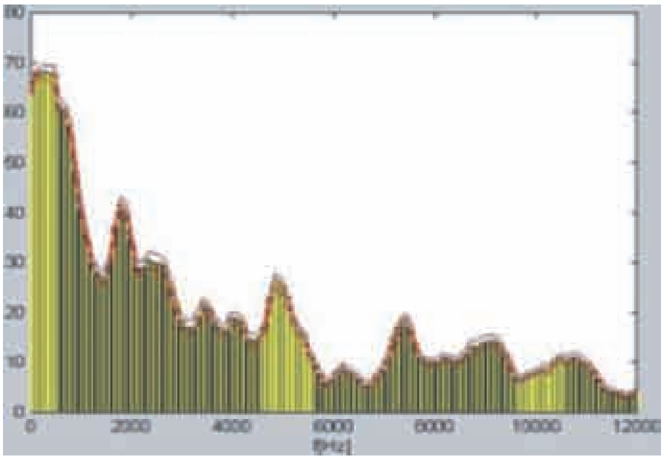

Fig. 4. Average Time-Frequency spectrum. "Speech" program in Matlab environment (normal voice)

The vector of features for the average spectrogram of speech signals appears as follows:

X = [M0 M1 M2 F1 F2 F3 F4 FF1 FF2 FF3 FF4 W1 W2 W3]

Where:

M0 - M2: spectrum moments

F1 - F4: frequencies of formants 1-4

FF1 - FF4: formants amplitude

W1 – coefficient of the relative power, defined as the signal power ratio in the band 125

– 87 [Hz] to the signal power in the whole band {0-12000 [Hz]},

W2 – coefficient of the relative power, defined as the signal power ratio in the band 750

– 2375 [Hz] to the signal power in the whole band {0-12000 [Hz]},

W3 – coefficient of the relative power, defined as the signal power ratio in the band 2000

– 3125 [Hz] to the signal power in the whole band {0-12000 [Hz]},

Maintaining a database of reference and pathological voice signals in the form of 14-dimensional vectors of features requires a quantitative evaluation of the degree of similarity or difference. This can be achieved by appropriate metrics of the acoustic voice signals under examination. As a result of calculation, it is possible to obtain a scalar value which describes the degree of similarity between pathological and reference samples. This value will be the determinant of correct or incorrect voice. Metrics (Euclidean, Generalized Euclidean, Hamming and Generalizes Hammning) allowed a one-dimensional space to be accessed during comparison instead of the whole vector of features [2,20,21].

In the present study the following metrics were used:

1. Euclidean metrics

$$Q_1 = \sqrt{\sum_{j=1}^{K}\sum_{i=1}^{N}(x_{ij}^{w} - x_{ij}^{p})^2}$$

2. Generalized Euclidean metrics

$$Q_2 = \sqrt{\sum_{j=1}^{K}\sum_{i=1}^{N}a_i(x_{ij}^{w} - x_{ij}^{p})^2}$$

3. Hamming metrics

$$Q_3 = \sum_{j=1}^{K}\sum_{i=1}^{N}| x_{ij}^{w} - x_{ij}^{p} |$$

4. Generalized Hamming metrics

$$Q_3 = \sum_{j=1}^{K}\sum_{i=1}^{N}a_i | x_{ij}^{w} - x_{ij}^{p} |$$

The results of the calculations were combined in sets according to the division of patients into groups A to C, as described above. These measurements made it possible to evaluate whether the speech signal was correct or incorrect. This was followed by an analysis of sustained vowels, which was prompted by the fact that it is precisely during the utterance of sustained vowels that the most stationary signal is obtained and the periodicity and stabilization of the basic laryngeal tone are revealed. Finally, a complete statistical analysis was carried out based on the metrics for the sustained vowel "a". The Generalized Euclidean metric values and Fisher test [F – value of the coefficient of the variance analysis test for which statistical differences are assessed].

RESULTS AND ANALYSIS

In order to simplify statistical calculation and to present the results in the form of diagrams in a clear way (Fig. 5,6,7,8), the values of metrics based on acoustic voice signals for control group (patters) are standardized at zero.

Values of metrics for the sustained vowels a, e, i, u obtained from three consecutive acoustic analyses were collected in charts for individual patients (Table I). Average metric values for the sustained vowel "a" (registered during 1st, 2nd and 3rd examination) and their standard deviations were then calculated for the whole group of patients and for group A – patients with a polyp located on the 1/3 anterior part of the vocal fold; group B – patients with a polyp located on the 1/3 central part of the vocal fold; and group C – patients with a polyp located on the 1/3 posterior part of the vocal fold (Table II).

For the whole group of patients with polyps, there was a statistically significant difference (F=6.37) for the Generalized Euclidean metric values occurring between 1st and 2nd examinations, 1st and 3rd examinations and 2nd and 3rd examinations. The period of monitoring of the phonosurgeric effects lasted at least 6 months.

The study showed that after phonosurgery the improvement in the examined acoustic parameters of voice signals assessed using the Generalized Euclidean metric values was observed after 1st month and lasted at least 6 months. An improvement in the acoustic parameter of voice signals assessed using the Generalized Euclidean metric was noted in the third examination compared with the second examination, which was performed a month after surgery (Fig. 5).

Table I. Patient no. 1. – metric values for sustained vowels a, e, i, u after three consecutive acoustic analyses

Patient no. 1 Registration 1	Euclidean	Generalized Euclidean	Hamming	Generalized Hamming
a1	0.3323	0.228	0.8071	0.3952
e1	0.2322	0.1489	0.6764	0.3214
i1	0.2918	0.1501	0.9207	0.3534
u1	0.7248	0.3454	1.8895	0.7922
Patient no. 1 Registration 2	Euclidean	Generalized Euclidean	Hamming	Generalized Hamming
a2	0.2309	0.0969	0.4921	0.1852
e2	0.1401	0.0680	0.3559	0.1606
i2	0.2633	0.1578	0.8245	0.3711
u2	0.7063	0.3144	0.9300	0.6911
Patient no. 1 Registration 3	Euclidean	Generalized Euclidean	Hamming	Generalized Hamming
a3	0.2098	0.0855	0.4124	0.1784
e3	0.1238	0.0580	0.3366	0.1269
i3	0.1413	0.0908	0.4079	0.2170
u3	0.1648	0.0958	0.5022	0.2167

Table II. Average metric values and standard deviation for sustained vowel "a"

Whole group with laryngeal polyp	Average value			Standard deviation		
Registration	a1	a2	a3	a1	a2	a3
Euclidean metrics	0.4742	0.4102	0.3810	0.1690	0.1814	0.1431
Generalized Euclidean metrics	0.2986	0.2475	0.1931	0.0759	0.1205	0.0390
Hamming metrics	1.2832	1.0647	1.0584	0.4548	0.5016	0.4890
Generalized Hamming metrics	0.5176	0.3936	0.3516	0.0981	0.1941	0.1035
Group A	Average value			Standard deviation		
Registration	a1	a2	a3	a1	a2	a3
Euclidean metrics	0.4558	0.1812	0.1617	0.1382	0.0854	0.0680
Generalized Euclidean metrics	0.2875	0.0854	0.0711	0.0709	0.0384	0.0204
Hamming metrics	1.1956	0.4563	0.3465	0.4045	0.0245	0.0931
Generalized Hamming metrics	0.5016	0.1637	0.1482	0.1123	0.0845	0.0427
Group B	Average value			Standard deviation		
Registration	a1	a2	a3	a1	a2	a3
Euclidean metrics	0.3284	0.2215	0.1798	0.0055	0.0133	0.1142
Generalized Euclidean metrics	0.2424	0.1058	0.0455	0.0205	0.0125	0.0353
Hamming metrics	0.8674	0.5362	0.2124	0.0852	0.0624	0.0390
Generalized Hamming metrics	0.4440	0.2126	0.1284	0.0689	0.0387	0.0801
Group C	Average value			Standard deviation		
Registration	a1	a2	a3	a1	a2	a3
Euclidean metrics	0.4719	0.3578	0.4122	0.1103	0.2114	0.1210
Generalized Euclidean metrics	0.3269	0.1727	0.1407	0.0399	0.0030	0.0410
Hamming metrics	1.8721	1.0165	1.1040	0.3714	0.5017	0.3841
Generalized Hamming metrics	0.5463	0.3475	0.3248	0.0914	0.0375	0.0874

The analysis of phonosurgery effects depending on the location of polyps on vocal fold, leads to the following observations. Among the patients with polyps located on the 1/3 of the anterior part of the vocal fold, there was a statistically significant difference (F=10.54) for the Generalized Euclidean metric values occurring between 1st and 2nd examinations, and 1st and 3rd examinations. The follow-up improvement of the values of the acoustic parameters was also observed between the 2nd and 3rd examinations. However, there was no statistically significant difference. The study indicated that the greatest improvement in the examined acoustic parameters of voice signals in patients with laryngeal polyps located on the 1/3 anterior part of the vocal folds assessed using the Generalized Euclidean metric values was achieved in the first month after surgery, followed by a further improvement in the following 5 months (Fig. 6).

In the group of the patients with polyps located on the 1/3 central part of the vocal fold, there was a statistically significant difference (F=7.31) for the Generalized Euclidean metric values occurring between 1st and 2nd examinations, 1st and 3rd examinations. This shows that the greatest improvement in the examined acoustic parameters of voice signals in patients with laryngeal polyps located on the 1/3 central part of the vocal folds assessed using the Generalized Euclidean metric values occurred after 1 month of the post-treatment period and lasted at least 6 months after surgery. It should also be noted that in the evaluation using the Generalized Euclidean metric, there was an improvement in the acoustic parameters of voice signals in 3rd examination (remote) compared with 2nd examination (early), which was performed one month after surgery (Fig. 7).

For patients with polyps located on the 1/3 posterior part of the vocal fold, there was a statistically significant difference (F=11.39) for the Generalized Euclidean metric values occurring between examinations 1st and 2nd examinations and 1st and 3rd examinations. Analogically, as in the patient's groups with anterior localisation of polyp there was no statistically significant difference between 2nd and 3rd examinations (Fig. 8).

In connection with the above it should be concluded that removing laryngeal polyps with the use

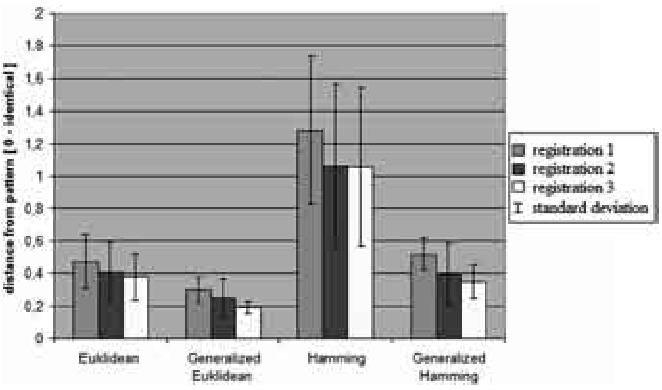

Fig. 5. Metrics for whole group of patients with laryngeal polyps [level 0 – control group (pattern)]

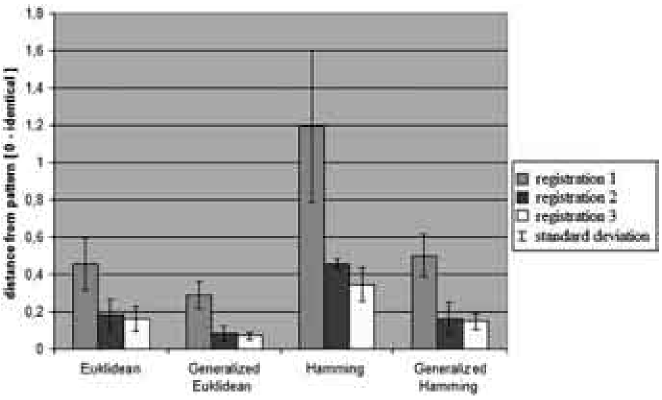

Fig. 6. Metrics for group A – polyp located on the 1/3 anterior part of the vocal fold [level 0 – control group (pattern)]

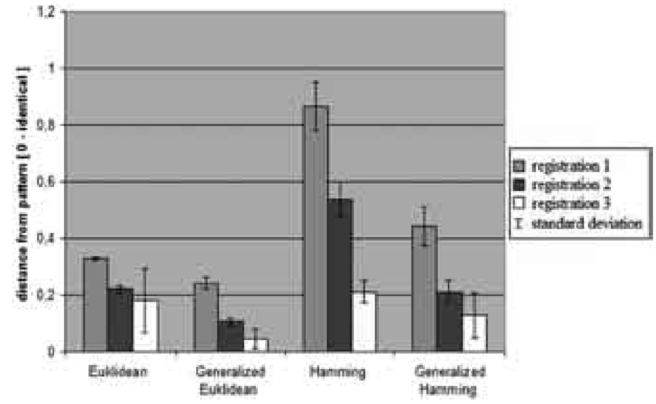

Fig. 7. Metrics for group B – polyp located on the 1/3 central part of the vocal fold [level 0 – control group (pattern)]

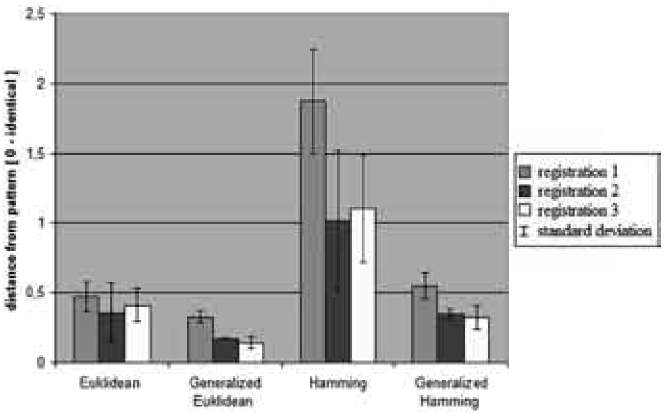

Fig. 8. Metrics for group C – polyp located on the 1/3 posterior part of the vocal fold [level 0 – control group (pattern)]

of extirpation phonosurgery leads to permanent improvement in acoustic voice signal parameters during six month's period of post-treatment observation. The maximum improvement in acoustic voice signal parameters was reached during one month after surgery for all groups of analyzed patients.

Nevertheless, the values of parameters of acoustic voice signals in patients undergoing phonosurgery treatment were still different from acoustic voice signal parameters in the control group.

DISCUSSION

The aim of phonosurgical management of laryngeal polyps is to remove them and to restore and maintain the proper phonatory function of the larynx.

According to Zeitels et al [22,23], extirpative phonosurgery is based on the techniques of endoscopic microsurgery and on the appreciation of the role of the mucosal wave of the vocal folds in the theory of voice production proposed by Hirano [9,24,25]. The authors emphasise in their works that optimization of the voice in patients following phonosurgical procedures can only be achieved when the complex "cover-body" of the vocal folds is maintained or reconstructed. This fact is crucial to the vibratory function of the voice.

It should be also be emphasized that the function of the human voice is complex in nature. Therefore, it is impossible to define voice on the basis of one or more parameters arising from a single type of investigation; this can only describe the phonatory function of the voice organ in a fragmentary rather than holistic way.

In evaluating the results of phonosurgical treatment of laryngeal polyps, the present work conducted acoustic analysis of reference and pathological voice signals using 14-dimensional vectors of features. The examined spaces were then metrized, enabling a quantitative evaluation of the degree of similarity or difference. The presented results of the speech signal acoustic analysis are consistent with the findings of the other authors who research the function of the glottis. These observations confirm also the study of Zeitels et al underlying the role of the extirpative phonosurgery in the protection of the phonatory function [22]

It should be noted that the maximum improvement in acoustic voice signal parameters was achieved up to one month after phonosurgery. This view is shared by other authors who report that the healing process of vocal folds after phonosurgery lasts from 2 to 4 weeks [22,23].

Polyps located in the central part of vocal folds have a major impact on acoustic voice signal disturbances as compared with polyp located in the posterior part of vocal folds. This observation is confirmed by Titze, who points out that the central part of the glottis has a major impact on voice quality and efficiency [26]. This view is complemented by Södersten et al., who state that posterior part of vocal folds does not considerably affect voice quality [27,28].

In the paper the usefulness of acoustic examinations of the voice signal for multilayer analysis of the laryngeal phonatory function was shown in the diagnostic and therapeutic procedures in the patients treated phonosurgically because of the laryngeal polyps.

CONCLUSIONS

1. Acoustic examination of voice signals and analysis of the Generalized Euclidean metrics showed improvement in the phonatory function in subjects with laryngeal polyps treated by means of phonosurgery.
2. Acoustic parameters improved after phonosurgery regardless of the polyp's localisation in the glottis.
3. The maximum improvement of acoustic results was observed one month after phonosurgical treatment of laryngeal polyps.
4. The study carried out by means of objective parameters, confirmed the effectiveness of phonosurgery in the improvement of phonatory function of patients with BVFL.

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