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SPEECH CAPACITY IN PATIENTS WITH VOICE DISORDERS BEFORE AND AFTER SURGICAL TREATMENT OF VOCAL FOLD TUMORS

KAPACITET GOVORA KOD PACIJENATA SA POREMEĆAJEM GLASA PRE I POSLE HIRURŠKOG TRETMANA IZRAŠTAJA NA GLASNICAMA

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Summary

Inroduction. Pathological characteristics of voice and speech in persons with benign and malignant vocal fold tumors present as different variations in the voice pitch, intensity and quality. The aim of the study was to determine the speech capacity of persons with malignant and benign vocal fold tumors before and after surgical treatment and to establish if there are differences in the speech capacity in relation to the type of tumor. **Material and Methods**. The sample included 67 subjects who were divided into two groups: group I – subjects with benign tumors, vocal cord lesions (polyps, cysts) and Reinke's edema and group II - subjects with malignant tumors, aged 23 to 74 years (mean age 55.43; standard deviation 11.95). Acoustic voice analysis, maximum phonation time of the vowel /a/, analysis of temporal speech organization, and sentence melody analysis were used for measuring the speech capacity. **Results**. Before surgery, the speech capacity in both groups of patients was almost equal, without statistical significance between the compared groups. After surgery, there was a statistically significant difference between the speech capacity in the examined groups, with better speech capacity observed in group I ($t = -3.807$, $p < 0.001$). The study did not show an isolated effect of time or tumor type on the speech capacity, but showed a combined effect ($F = 10.079$, $p = 0.002$). **Conclusion.** The proposed method for the assessment of the speech capacity before and after surgical treatment of vocal fold tumors is a useful tool for the prediction of the voice outcome and in planning rehabilitation procedures.

Key words: Larynx; Neoplasms; Vocal Cords; Vocal Cord Dysfunction; Voice; Speech-Language Pathology; Speech Acoustics; Speech Production Measurement

Sažetak

Uvod. Patološke karakteristike glasa i govora kod osoba sa benignim i malignim tumorima na glasnicama sagledavaju se kao različite varijacije visine, intenziteta i kvaliteta govornog glasa. Cilj rada bio je utvrđivanje govornog kapaciteta osoba sa malignim i benignim tumorima na glasnicama, pre i posle hirurškog lečenja i konstatovanje da li postoje razlike u govornom kapacitetu u odnosu na vrstu tumora. **Materijal i metode.** Uzorak je činilo 67 ispitanika podeljenih u dve grupe: I grupa − benigni tumori (polipi, ciste) i Rajnkeovi edemi i II grupa − ispitanici sa malignim tumorima, starosti od 23 do 74 godine (prosečna starost 55,43 godine; standardna devijacija 11,95 godina). Kao mera kapaciteta govora u istraživanju je korišćena akustička analiza glasa, maksimalno vreme fonacije samoglasnika /a/, analiza vremenske organizacije govora i analiza melodije rečenice. **Rezultati.** Pre operacije govorni kapacitet u obe grupe ispitanika bio je skoro jednak, bez statističke značajnosti između upoređenih grupa. Nakon operacije uočena je statistički značajna razlika između govornog kapaciteta ispitivanih grupa, pri čemu je bolji govorni kapacitet uočen u I grupi ($t = -3,807$, $p < 0,001$). Studija nije pokazala izolovani efekat vremena ili vrste tumora na kapacitet govora, ali je pokazala kombinovani efekat ($F = 10,079$, $p = 0,002$). **Zaključak.** Predloženi način procene govornog kapaciteta pre i posle operativnog lečenja tumora glasnica predstavlja koristan alat kojim bi se moglo predvideti očekivano stanje glasa i planirati rehabilitacioni postupak.

Ključne reči: larinks; neoplazme; glasne žice; disfunkcija glasnih žica; glas; govorno jezička patologija; govorna akustika; merenje govornog kapaciteta

Introduction

Voice is a result of laryngeal sound production which is primarily an auditory component of speech that allows the expression of emotions and feelings in personal, social and professional relationships [1, 2]. As part of the speech capacity, voice can be quantified by using acoustic voice parameters, including fundamental frequency, intensity, quality, melody [3] and so on. Thus, voice is associated with prosody [4], emotions [3, 5, 6], temporal organization of speech [7–9], articulation of sounds, phonemes, and melody of speech [10].

Voice quality can be impaired due to various pathological conditions that occur primarily at the level of the glottis [11, 12]. Tumors on the vocal folds lead to voice quality disorders, dysphonia due to glottis occlusion disorders; disorders of vocal stiffness (mobility); discrepancies in the mechanical characteristics of the two vocal folds. Acoustic phe-

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Abbreviations
MPT a – maximum phonation time of the vowel /a/

nomena of the voice are caused by: hoarseness - asymmetry of vocal fold vibrations; roughness - sound quality that has been related to the amplitude modulation, sometimes caused by more than two sound sources; pneumophonic coordination (dominance of respiratory noise in the voice) due to greater insufficient occlusion of the glottis. Inflammatory processes, tumors, scarring and other changes may lead to the surface layer rigidity, which has very unfavorable effects on the voice [13–18].

All changes in voice quality are perceived as different variations in pitch, intensity, and spoken voice quality [19]. The development of technologies that deal with the synthesis [20] and conversion of speech today is associated with greater opportunities for quantitative speech analysis [21].

In everyday clinical practice, a simple way to measure the impact of voice and its impairment on speech production is to calculate the speech capacity, which can be expressed as a standardized summary score of variables which are the measure of speech production capacity.

The aim of the study was to determine the speech capacity of persons with malignant and benign vocal fold tumors before and after surgical treatment and to establish if there are differences in the speech capacity in relation to the type of tumor.

Material and Methods

A total of 70 subjects participated in the study, but the sample included 67 subjects who met the inclusion criteria of the study. Subjects with benign tumors, pseudo-tumors or malignant tumors of the vocal folds were divided into two groups. Group I included 36 subjects with benign tumors, vocal cord lesions (polyps, cysts) and Reinke's edema of the vocal folds, aged from 23 to 74 years (M = 52.94; SD = 13.02). Group II included 31 subjects with vocal fold malignant tumors, aged from 38 to 73 years (M = 58.32; SD = 10.03). The study was conducted from June 2016 to May 2017 at the Clinic of Ear, Nose and Throat Diseases of the Clinical Center of Vojvodina, and it was part of a PhD thesis*.

Prior to conducting the research, consents of the Ethics Committee of the Clinical Center of Vojvodina and the Ethics Committee of the Faculty of Medicine of the University of Novi Sad were obtained. Subjects were offered to participate in the study after surgical treatment of vocal fold tumors. They were given information about the course of the study in writing and a written consent to be signed by those who wanted to participate in the research. Information about the participants were taken according to the research protocol. Subjects were divided into two groups based on the nature of the vocal fold tumors. Postoperative analysis of voice and speech was performed seven days following the surgical treatment. The research was conducted as a prospective study.

To check whether they met the inclusion criteria, each subject first underwent a screening assessment of cognitive abilities using the Mini Mental State Examination by Folstein et al. 1975 [22], and only subjects with orderly cognitive functions were included. Subjects also completed an anxiety questionnaire in order to exclude subjects with severe anxiety (General anxiety disorder-7, Spitzer et al.) [23]. The quality of articulation was checked using the Triage Articulation Test, by Kostić and Vladisavljević, 1981 [24]. These tests were not performed postoperatively and they were not considered when calculating the speech capacity.

In the next phase, subjects who met the inclusion criteria were examined using the following instruments:

– Acoustic analysis of voice and speech (isolated vowel /a/), and analysis of a selected short statement - a sentence that has all the vowels of the Serbian language, "I'll be back soon" by Kašić [25]. The recording was performed using a Pioneer DM-DV 15 microphone, and the subjects were instructed to pronounce the intended vowel and the selected sentence at a comfortable intensity and pitch at a distance of 5 cm from the mouth. The analysis was performed using the Praat program for acoustic speech analysis (Praat: www.praat.org), and the following data were used: pitch, intensity, micro perturbation of pitch, micro perturbation of intensity, and the presence of noise in the voice during isolated vowel production, pitch and intensity of short statement.

– Maximum phonation time of the vowel /a/ (MPT a) measured using a stopwatch showing the longest period during which a patient can sustain phonation of a vowel sound /a/ after maximum inhale.

– The temporal speech organization was analyzed during the reading of the phonetically balanced text. First, the subjects read the whole text, and the reading time was measured with a stopwatch. The text was then read again for one minute. The number of syllables and the number of inhalations while reading the text in one minute were counted (subjects were first instructed to read the text not to express their reading ability, but speech);

– The sentence melody analysis was done using a subscale of the Test for the Assessment of Sentence Accent and Melody (quantitative speech assessment) by Kostić and Sovilj [26]. The instruments used before were also used after the vocal fold surgery. On average, the test lasted between 30 and 40 minutes.

Speech capacity is a standardized summary score of variables selected in this study as a measure of capacity. According to the theoretical framework of this research, the following variables were included in the summary speech capacity: The basic voice pitch observed during the pronunciation of the vowel /a/, isolated or during continuous speech; Rapid pitch perturbations of the isolated vowel - jitter; Voice intensity during the pronunciation of the vowel /a/, isolated or during continuous speech; Rapid perturbations of isolated voice intensity - shimmer; Harmonic to noise ratio (HNR) for iso-

lated vowel /a/ pronunciation; The MPT of the vowel /a/; The MPT ratio for sounds /s/ and /z/ - (S/Z ratio); Melody of speech.

Each of these variables is assessed from 1 – 3, where 1 means a good result and 3 - a bad (pathological) result. The values of the total capacity range from 10 to 30.

In the data processing, basic descriptive statistical parameters for qualitative and quantitative assessment of the obtained results were used. We also assessed the statistical significance of the obtained results, as well as the levels of statistical significance. Statistical data analysis was done using the SPSS version 20 for Windows, and the obtained results are presented in tables and graphs with necessary comments and analysis of the obtained results.

After checking the normality of the distribution of data obtained by measuring the variables of the speech capacity, we found that the distribution of data does not correspond to normal, so these scores were standardized before further analysis.

Results

Table 1 shows descriptive data of mean speech capacity in subjects with benign tumors, vocal cord lesions (polyps, cysts) and Reinke's edema (Group I) ranging from 19.528 to 20.528 and in subjects with vocal fold malignant tumors (Group II) with mean speech capacity ranging from 20.032 to 22.258. These data show that the speech capacity had improved in subjects with benign tumors, while in subjects with malignant vocal fold tumors (Group II), the speech capacity increased after surgical treatment, which indicates reduced speech capacity.

The Student's t-test was used to analyze the difference between the speech capacity before and after surgery in both groups of subjects. Before the surgery, subjects with malignant tumors had a slightly better speech capacity, but without a statistically significant difference. After surgery, there was a statistically significant difference between the speech capacity in the examined groups; the subjects with benign tumors, vocal cord lesions (polyps, cysts) and Reinke's edema had a better speech capacity ($t = -3.807$; $p < 0.001$).

Table 2 shows the results of the t-test for dependent samples, that is the difference between the average values of Z scores before and after surgery.

In both examined groups, there was a statistically significant difference between the speech capacity before and after surgery (**Table 3**).

In the Group I, there was a statistically significant improvement in the speech capacity after surgery ($p = 0.005$). However, in Group II, the speech capacity after surgery was statistically significantly worse compared to the measured capacity before surgery ($p = 0.007$). In the Group I, a moderate correlation was obtained between the first and second measurement ($r = 0.558$, $p < 0.001$). In the Group II, no correlation was found between the measured speech capacity before and after surgery.

A two-way analysis of variance was used to analyze the effects of interaction. **Table 4** shows the effects of interaction of dependent variables on the speech capacity.

The obtained results show that there is no isolated effect of time or type of tumor on the speech capacity, but there is a combined effect ($F = 10.079$, $p = 0.002$) **(Graph 1)** showing the difference in the obtained scores between the groups and the interac-

Table 1. Speech capacity of subjects before and after surgery in relation to the type of tumor
Tabela 1. *Izmerene vrednosti kapaciteta govora ispitanika pre i nakon operacije u odnosu na izraštaje*

Group/*Grupa*	Time/*Vreme*	N/*Br.*	Min/*Min*	Max/*Maks*	Mean/*Srednja vrednost*	Standard deviation *Standardna devijacija*
Group I/*Grupa I*	Before/*Pre*	36	15	25	20.528	2.602
	After/*Posle*	36	14	25	19.528	3.184
Group II/*Grupa II*	Before/*Pre*	31	17	25	20.032	2.198
	After/*Posle*	31	16	28	22.258	2.594

Legend: Group I – benign tumors, vocal cord lesions (polyps, cysts) and Reinke's edema; Group II – malignant tumors
Legenda: Grupa I – benigni tumori, lezije glasnica (polipi, ciste) i Rajnkeovi edemi; Grupa II – maligni tumori

Table 2. Relationship between the tumor type and measurement time
Tabela 2. *Interakcija između vrste izraštaja i vremena merenja*

Time/*Vreme*	Tumor Type *Vrsta izraštaja*	N/*Br.*	Z Mean *Z Srednja vrednost*	Standard deviation *Standardna devijacija*	t/*t*	p/*p*
Before/*Pre*	Group I/*Grupa I*	36	0.095	1.076	0.834	0.407
	Group II/*Grupa II*	31	-0.110	0.909		
After/*Posle*	Group I/*Grupa I*	36	-0.393	0.991	-3.807	0.000
	Group II/*Grupa II*	31	0.457	0.808		

Legend: Group I – benign tumors, vocal cord lesions (polyps, cysts) and Reinke's edema; Group II – malignant tumors
Legenda: Grupa I – benigni tumori, lezije glasnica (polipi, ciste) i Rajnkeovi edemi; Grupa II – maligni tumori

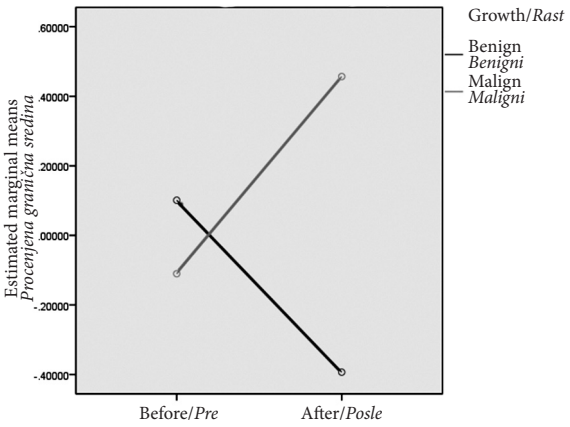
Table 3. Differences between the speech capacity of subjects before and after surgery
Tabela 3. *Razlike između kapaciteta govora ispitanika pre i posle operacije*

Group/*Grupa*	Time/*Vreme*	N/*Br.*	Z Mean *Z Srednja vrednost*	Standard deviation *Standardna devijacija*	r	p (r)	t/*t*	p/*p*
Group I/*Grupa I*	Before/*Pre*	36	0.095	1.076	0.558	0.000	3.006	0.005
	After/*Posle*	36	-0.393	0.991				
Group II/*Grupa II*	Before/*Pre*	31	-0.110	0.909	0.197	0.288	-2.894	0.007
	After/*Posle*	31	0.457	0.808				

Legend: Group I – benign tumors, vocal cord lesions (polyps, cysts) and Reinke's edema; Group II – malignant tumors
Legenda: Grupa I – benigni tumori, lezije glasnica (polipi, ciste) i Rajnkeovi edemi; Grupa II – maligni tumori

Table 4. Interaction of variables of the speech capacity
Tabela 4. *Interakcija varijabli u kapacitetu govora*

	Mean Square/*Prosečan kvadrat*	F	p	Eta
Before – After/*Pre – posle*	0.043	0.047	0.829	0.000
Tumors/*Izraštaji*	3.376	3.653	0.058	0.028
Before – After *tumors/*Pre – posle *izraštaji*	9.315	10.079	0.002	0.072



Graph 1. Total speech capacity before and after surgery of vocal fold malignant tumors and vocal fold benign tumors, vocal cord lesions (polyps, cysts) and Reinke's edema
Grafikon 1. *Ukupni kapacitet govora pre i posle operacije kod malignih izraštaja na glasnicama i benignih izraštaja na glasnicama, lezija glasnica (polipa, cisti) i Rajnkeovih edema*

tions of the variables. Since the lines in the graph intersect, it can be concluded that there is a combined effect of the type of tumor and time of measurement on the speech capacity.

Although initially subjects in Group I had an equal speech capacity as subjects in Group II, after surgery the speech capacity was statistically significantly better in the Group I, while in Group II the speech capacity was statistically significantly worse.

Discussion

Before surgery, the speech capacity in both groups of subjects was almost equal; the subjects in the Group I had slightly better speech capacity, but without statistical significance in the compared groups. Pathological values of voice pitch in subjects in the Group I and uniform values of other variables that were taken into account when calculating the speech capacity gave a slightly better overall result in the Group II. Similar results in terms of pitch were reported by other authors. Martins et al. [27] reported that subjects with Reinke's edema of the vocal folds before surgery (M = 149.8 Hz) had lower values of pitch. Results of voice pitch in subjects with benign and pseudo-tumors of the vocal folds are shown by Coyle et al. [28] who found that fundamental frequency is within the reference values, with an average of 124.32 Hz. A study by Chotigavanich et al. [29] examined the acoustic characteristics of the voice in subjects with vocal fold malignant tumors before and after endoscopic surgery of T1 glottis carcinomas and found an average voice value of 147.32 Hz before surgery. Klauznicer [30] found an increase to 235.8 Hz in subjects with malignant tumors of the vocal folds. Increased rigidity of the fixed vocal folds affects the increase in pitch. Therefore, the voice pitch in subjects with vocal fold benign tumors is reduced and the voice pitch in subjects with vocal fold malignant tumors is increased; there is an approximation in voice pitch in men and women and between the examined groups.

In terms of pitch and intensity micro-perturbations of voice before surgery, the groups are uniform and similar results are reported by other authors. Martins et al. [27] found that before surgery, voice pitch micro-perturbations were 2.9% on average. The jitter parameter values before surgery of vocal fold polyps were also examined by Petrović-Lazić et al. [31] who found that before surgery in patients with vocal fold polyps the mean value of this parameter was 1.873% and that there was a statistically significant deviation of this parameter compared to the control group of healthy subjects. Pathological values of jitter were found by Verma et al. [17] in a study conducted pre-operatively in 100 subjects with dysphonia caused by benign and pseudo-tumors of the vocal folds. The reason for this finding was explained by the existence of inadequate periodicity

in the vibration of the vocal folds due to the existence of tumors. The jitter parameter values were also pathological in patients with vocal fold malignant tumors, as confirmed by Staníkova et al. [32]. The melody of speech is closely related to the pitch, that is, the fundamental frequency of the voice. It depends on the speed of vibration of the vocal folds, their tension and the change in tension [33].

Due to all the above, the speech capacity in the examined groups is uniform before surgery. In patients with polyps, Sahin et al. [12] found that voice therapy before surgery can increase the results of surgical outcome and lead to the improvement of the speech capacity.

After surgical removal of vocal fold tumors in the Group I, there was a statistically significant improvement in the speech capacity. However, in the Group II, after unilateral cordectomy, the speech capacity was statistically significantly worse compared to the measured capacity before surgery. The reason for this is greater loss of vocal fold tissue than in subjects with benign tumors, vocal cord lesions (polyps, cysts) and Reinke's edema in line with the principle of surgical radicalism that puts the phonation function off, through the possibility of reconstruction of the remaining laryngeal tissue, postoperative edema of reconstructed tissue, length of general anesthesia, postoperative pain, sparing voice and speech in order not to burden the structures of the reconstructed larynx. Similar postoperative results, in terms of changes in voice pitch, in both benign and malignant tumors are reported by other authors [29, 31, 34].

In our research, voice in the Group I was still partially disturbed after surgery, while the speech capacity values in the Group II changed from borderline values to pathological values after surgery, so the speech capacity deteriorated.

The reason why there is no significant improvement in the speech capacity in the Group I can certainly be found in the fact that these are changes in the vocal folds that disrupt phonation automatism over time. Spontaneously, in the short postoperative time in which the measurements were performed as part of this research, phonation automatism cannot be changed, regardless of the fact that the anatomical preconditions for better occlusion and vibration are significantly better than after removal of one vocal fold due to a malignant tumor.

Removal of vocal folds in patients with malignant tumors disrupts the "phonation valve", which turns partially impaired speech capacity into pathological.

Postoperatively, there was a statistically significant difference between the speech capacity in the examined groups, with better speech capacity in the Group I. Tissue loss after surgery of malignant tumors is greater because it aims to remove the malignant process that has affected the vocal fold. Unilateral cordectomy is the removal of one vocal fold, which prevents early postoperative occlusion of the remains of the glottis and the reconstructed part of the larynx, which results in shorter tone phonation, a greater number of pauses during reading and speech production, poorer melody, soundless segments of speech after surgery, as well as incomprehensible speech production. Some subjects from this group used whispering speech. On the other hand, the advancement of surgical treatment techniques in the Group I, aims to preserve the existing and improve the phonation function of the vocal folds. Less invasive techniques provide better overall voice quality. Also, reconstruction techniques of tissue excision sites, such as the "flap technique" after removal of Reinke's edema, significantly improve the postoperative voice parameters [35].

When observing the overall speech capacity in all 67 subjects included in the study, regardless of the type of tumor and comparison of the results before and after surgery, there is no statistically significant correlation in terms of the speech capacity. Also, the comparison of overall results of the speech capacity in 67 subjects with benign and malignant vocal fold tumors, without analyzing the variables before and after surgery, showed no statistically significant correlation between the speech capacities in all the examined subjects. This is due to the fact that the speech capacity before surgery was equal in both groups of subjects, and after surgery, the speech capacity in the subjects with malignant tumors worsened, and the speech capacity in subjects with benign tumors has improved. So, the obtained results suggest that there is no isolated effect of time or type of tumor on the speech capacity, but that there is a combined effect.

These results were expected, because vocal fold tumors of any origin cause loss of glottis occlusion to a greater or lesser extent, increasing the mass of the vocal folds and affecting the vocal fold vibratory cycle. The research shows that voice quality is affected by the extent and localization of glottis surgery [32]. Pseudo-tumors, such as Reinke's edema, increase the vocal fold mass and affect the vibration process [27]. On the other hand, surgical treatment of benign tumors, vocal cord lesions (polyps, cysts) and Reinke's edema is less invasive than surgical treatment of malignant lesions, the structure of the vocal folds remains preserved, and surgical techniques used to treat these changes on the vocal folds aim to preserve the phonation function. Mechanical injuries that occur during microsurgery may lead to structural changes in the layers of the vocal cords [36]. In cordectomy, as a treatment option for early glottic carcinoma, and due to vocal fold scarring, the parameters that we examined as components of the speech capacity were consequently deteriorating [37].

Malignant tumors have a greater impact on pathological perturbations of vocal fold vibration (jitter) in the early stage, and invasion of tumors into deeper layers causes vocal fold stiffness with the existence of a-vibration segment of the vocal fold [18]. After surgical treatment of vocal fold malignant tumors, when they are removed together with the pathological tissues the normal architecture of the glottis is disturbed and there is an increased incompatibility between the two hemi-larynxes. After surgery of malignant tumors, changes in phonation are inevitable, regardless of whether the vo-

cal folds are reconstructed or neo-folds are formed during voice therapy. In order to provide fast and complete vocal fold recovery after surgery, early inclusion of vocal therapy with mechanical stimulation is suggested [37].

Conclusion

Preoperatively, the speech capacity in subjects with benign tumors, vocal cord lesions (polyps, cysts) and Reinke's edema as well as in subjects with malignant tumors is partially impaired or pathological. After surgical removal of benign tumors, vocal cord lesions (polyps, cysts) and Reinke's edema, there is a statistically significant improvement in the speech capacity. There is no isolated effect of time or type of tumor on the speech capacity, but there is a combined effect. The proposed method for the assessment of the speech capacity before and after surgical treatment of vocal cord tumors is a useful tool for the prediction of the voice outcome and in planning rehabilitation procedures.

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