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Objective acoustic and aerodynamic analyses of voice after frontal anterior laryngectomy with epiglottoplasty

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ABSTRACT

Objective: In this study, we aimed to perform an objective analysis of the acoustic and aerodynamic characteristics of voice during the preoperative period and the early and late postoperative periods among patients who had undergone frontal anterior laryngectomy with epiglottoplasty (FALE) to determine the degree to which voice was affected after surgery.

Methods: The study group included 21 subjects who had undergone FALE. Subjective evaluations were performed using the Grade, Roughness, Breathiness, Asthenia, Strained (GRBAS) scale and the Turkish version of the Voice Handicap Index (VHI). Objective evaluations were performed through voice analyses of voice recordings from the preoperative, 3-month postoperative, and 1-year postoperative periods. The analyzed parameters included fundamental frequency (F0) determination, shimmer %, jitter %, noise-to-harmonic ratio (NHR), variability of the fundamental frequency (VF0), amplitude perturbation quotient (APQ), and soft phonation index (SPI).

Results: Subjective voice evaluations revealed that subjects generally reported that their voice was adequate, while physicians using the GRBAS scale generally found that patients exhibited hoarseness and weakness, which they interpreted as a moderate-to-severe voice disorder. Laryngostroboscopic evaluation revealed that most patients showed a longitudinal and irregular glottal closure defect.

Conclusion: Our results indicated that patients had a dysphonic voice during the early and late postoperative periods after FALE; however, they exhibited adequate speaking and respiratory functions. Thus, FALE can be considered a surgical technique that preserves the patient's voice to a degree acceptable to continue professional and other activities, despite voice quality disruption.

Keywords: Alaryngeal, partial laryngectomy, reconstructive anterior frontal laryngectomy, speech, voice quality

Introduction

The human voice is a very important communication tool. Physiologically, voice quality depends on the vocal folds' ability to adhere to the wave motion amplitude and the symmetry of the mucosal waves. Acoustic and perceptual analyses can be performed to evaluate voice quality. Factors that may contribute to the development of voice disorders include intensive voice use in a work environment (1) and laryngeal cancers and related surgery.

In cases of laryngeal cancer, frontal anterior laryngectomy with epiglottoplasty (FALE) is performed to ensure full continuation of the speaking, respiratory, and swallowing functions of the aerodigestive intersection, despite full tumor resection according to oncologic principles (2). This procedure, described in 1979 by Tucker et al. (3), is a form of partial laryngectomy employed in early-period glottal tumors, which carries a low complication risk with successful oncologic results.

FALE surgery is performed as follows: First, a narrow U-incision is made in the neck, and the laryngeal cartilage is exposed. Then a petiole incision is cut in the 90° plane to the larynx from the upper level of the thyroid cartilage. Subsequently, cartilage incisions of 1-1.5 cm (slightly larger on the tumor side) are cut in the vertical plane from the right and left laminae in the thyroid cartilage midline. In the side with less tumor, a full-thick-

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ness incision is made, and the larynx is entered. On the side with more extensive tumor, the glottic region is dissected from the internal aspect of the thyroid cartilage, and resection is performed under direct view. Finally, the epiglottis is dissected from the anterior and lateral surfaces and pushed downward to close the opening in front of the laryngeal cartilage to perform the reconstruction.

The protection of laryngeal functions, especially speaking, has become the main goal of laryngeal cancer surgery. In the present study, we aimed to perform an objective analysis of the acoustic and aerodynamic characteristics of voice among patients who had undergone FALE during the preoperative period and early and late postoperative periods to determine the degree to which the voice was affected after surgery.

Methods

This study was conducted at Trakya University School of Medicine's Department of Otorhinolaryngology, between 23 August 2010 and 26 November 2012. Trakya University ethics committee approval was received (TUMFEC 2010/25). Written informed consent was obtained from patients who participated in this study. The study group included 21 patients who presented to our department with a T2 glottal tumor and who agreed to undergo surgery. All patients were male, and the patients' ages varied between 45 and 79 years with a mean age of 65.6 years. All patients had a reported histopathology of squamous cell carcinoma.

Functional evaluation of the patients who had undergone FALE was performed using tests from the preoperative period, early postoperative period (3-month follow-up), and late postoperative period (1-year follow-up). Assessments included video laryngostroboscopy examination, pulmonary function tests, subjective evaluation of the voice by the physician, and the Turkish version of the Voice Handicap Index (VHI). An objective voice analysis was also performed.

We recorded the detailed history of all the 21 patients, and the results of routine ear, nose, and throat examinations. Video laryngostroboscopy was performed using a 70° rigid Karl Storz endoscope (made in Germany) and was always conducted by the same investigator and recorded in a digital format. The laryngoscopic appearance of the patients' glottal closure defect was evaluated as longitudinal, dorsal, ventral, irregular, oval, or hourglass. The subjects were also evaluated in terms of disturbance of irregularity of mucosal movements and irregularity or asymmetry of the mucosal wave on stroboscopy, which was scored as follows: 0=none, 1=mild, 2=moderate, and 3=severe. Pulmonary function tests were performed at the Department of Chest Diseases. In the subjective voice evaluation, the voice was subjectively scored by the patient between 0 and 5 with 0 = no voice, 1 =very bad, 2=bad, 3=sufficient, 4=good, and 5=very good. The physician used the Grade, Roughness, Breathiness, Asthenia, Strained Grade, Roughness, Breathiness, Asthenia, Strained (GRBAS) scale for subjective voice evaluation with 0=no voice, 1=mild, 2=moderate, 3=severe (4). Subjective voice evaluation was also performed using the Turkish version of the Voice Handicap Index (VHI) (5).

For objective voice evaluation, we conducted preoperative, 3-month postoperative, and 1-year postoperative voice recordings and voice analyses. The recordings were made using the Computerized Speech Lab Model 4500 voice analysis device (Kay Elemetrics Corporation, NJ, USA), a computer with an Intel Celeron (2000 GHz) processor, the Multi-Dimensional Voice Program Model 5105 software, and a Micromic Phantom MPA III C 420 PP microphone (Austria). This equipment was available at the Department of Otorhinolaryngology's voice analysis laboratory. The microphone was placed 10 cm from the mouth at a 45° angle. Using the software, acoustic analysis was performed for the sound "a" at a fixed tone and intensity for a duration of 10 seconds, recorded after deep inspirium. We evaluated F_0, shimmer%, jitter%, NHR, VF_0, APQ, and SPI parameters. Maximum phonation time (MPT) was determined as the longest of three attempts as measured with a chronometer of the "a" sound with maximum duration after deep inspirium.

Statistical analysis

Statistical analysis was conducted using the Statistical Package for Social Sciences version 23.0 software (IBM Corp.; Armonk, NY, USA) at Trakya University School of Medicine's Department of Biostatistics and Medical Informatics. Wilcoxon and Friedman tests were used for the intragroup comparisons of measurable data. Descriptive statistics are presented as median (minimum-maximum) values and arithmetic mean±standard deviation (SD). The significance limit was set as $p<0.05$ for all analyses.

Results

Our results showed that MPT significantly differed between the preoperative period and the 3-month postoperative period ($p<0.001$), as well as between the preoperative period and the 1-year postoperative period ($p<0.001$). In contrast, MPT did not significantly differ between the early and late postoperative periods ($p=0.317$). The preoperative MPT was 15.9 s, early postoperative MPT was 5.5 s, and late postoperative MPT was 5.3 s. Similarly, the phonation quotient (ratio of vital capacity to maximum phonation time) significantly differed between the preoperative period and early postoperative period ($p<0.001$) and between the preoperative period and late postoperative period ($p<0.001$), but it did not significantly differ between the early and late postoperative periods ($p=0.496$).

F_0, NHR, and SPI. For example, the acoustic analysis parameters in tests conducted with the "a" sound all increased from the preoperative period to the early and late postoperative periods. However, statistical analyses revealed that these parameters did not significantly differ between the groups ($p=0.220$). Evaluation in terms of jitter%, VF_0, shimmer%, and perturbation APQ revealed significant differences between the preoperative period and the early postoperative period ($p<0.001$), and

Main Points:

- FALE is an oncological surgery.
- After the FALE operation objective parameters show patients have distorted voice.
- Although postoperative acoustic and aerodynamic data revealed a moderately severe dysphonic voice, the patients retained adequate speaking and pulmonary functions.

Table 1. Mean values of acoustic analysis parameters with the "a" sound during the preoperative period, early postoperative period, and late postoperative period

Parameters	Preop Mean±SD Median (min-max)	Postop, 3rd month Mean±SD Median (min-max)	Postop, 1st year Mean±SD Median (min-max)	*p
F0, Hz	163.2±51.0 155.5 (85.3-271.0)	176.0±63.4 171.1 (70.4-286.2)	189.6±60.1 195.0 (76.8-291.6)	>0.05
Jitter %	3.5±2.5 3.0 (0.6-10.0)	8.1±5.1 7.2 (1.4-21.7)	8.1±6.2 7.0 (2.5-23.6)	<0.05
VF0, Hz	11.0±13.7 3.9 (1.0-47.5)	18.2±13.6 18.4 (2.5-43.8)	22.1±18.1 18.0 (2.5-52.6)	<0.05
Shimmer %	7.4±6.0 5.3 (1.7-25.1)	14.6±6.8 13.3 (5.8-34.7)	15.9±7.2 14.7 (4.3-32.4)	<0.05
APQ	5.5±4.6 4.1 (1.2-19.8)	10.5±4.7 9.4 (3.7-23.2)	11.8±5.1 11.2 (3.2-22.1)	<0.05
NHR	0.2±0.1 0,17 (0.07-0.8)	0.4±0.2 0.5 (0.1-1.0)	0.51±0.3 0.45 (0.1-1.0)	>0.05
SPI	26.0±17.6 21.5 (4.5-59.2)	15.0±11.3 10.9 (2.7-42.8)	13.9±8.3 11,6 (1.9-30.2)	>0.05

*Wilcoxon and Friedman Test.
SD: standard deviation; F0: fundamental frequency; VF0: variability of fundamental frequency; APQ: amplitude perturbation ratio; NHR: noise harmonic ratio; SPI: soft phonation index; Preop: preoperative period; Postop 3rd month, early postoperative period; Postop 1st year, late postoperative period

Table 2. Voice handicap index

	Preop Mean±SD Median (min-max)	Postop, 3rd month Mean±SD Median (min-max)	Postop, 1st year Mean±SD Median (min-max)	*p
Functional	9.29±2.0 9 (6-13)	14.8±0.9 15 (13-17)	14.8±1. 15 (13-17)	>0.05
Physical	12.9±1.8 13 (10-17)	14.3±1.0 14 (12-16)	14.1±1.1 14 (12-16)	>0.05
Emotional	12.7±1.3 13 (10-15)	14.6±0.6 15 (13-16)	14.3±0.6 14 (13-15)	>0.05
Total	34.9±3.2 35 (30-40)	43.9±1.4 44 (42-47)	43.2±1.8 43 (40-47)	>0.05

*Wilcoxon and Friedman Test.
SD: standard deviation; Preop: preoperative period; Postop 3rd month, early postoperative period; Postop 1st year, late postoperative period

Table 3. Subjective voice evaluation

Voice	Preop Number (%)	Postop 3rd month Number (%)	Postop 1st year Number (%)
None	0	0	0
Very Poor	0	0	0
Poor	5 (23.8)	4 (19.04)	3 (14.2)
Adequate	10 (47.6)	15 (71.4)	14 (66.6)
Good	6 (28.5)	2 (9.5)	4 (19.04)
Very good	0	0	0

Preop: preoperative period; Postop 3rd month, early postoperative period; Postop 1st year, late postoperative period

between the preoperative period and late postoperative period ($p<0.001$). However, jitter%, VF_0, shimmer %, and perturbation APQ did not significantly differ between the early and late postoperative periods (respectively, $p=0.243$, $p=0.376$, $p=0.546$, $p=0.334$) (Table 1).

Evaluation of each individual case in terms of the VHI and functional, physical, and emotional parameters revealed no statistically significant differences between any time periods. While no differences were statistically significant, we found that the functional index was most affected, while there were more limited increases in the functional and emotional indices (Table 2).

Between the preoperative period and the early and late postoperative periods, a decreased number of patients subjectively described their own voice as poor while an increased number of patients described their voice as adequate. Although a decreased number of patients found their voice to be adequate in the late postoperative period, this decrease may be explained by the increased number of patients who found that their voice was good. We also observed that the number of cases with a coarse or wheezing voice increased between the preoperative period and the early and late postoperative stages (Table 3).

Discussion

In the present study, we investigated MPT, F_0, jitter %, VF_0, shimmer %, APQ, NHR, and SPI to determine the degree to which the voice was affected in the early and late postoperative periods after FALE and compared these acoustic analysis parameters between preoperative, early and late postoperative period . We used the GRBAS scale and VHI for subjective analysis. For the evaluation of subjective and acoustic characteristics, acoustic analysis was performed using the "a" vowel.

Comparison of MPT, jitter%, VF_0, shimmer%, and APQ between the preoperative period, early postoperative period, and late postoperative period revealed statistically significant differences between the two postoperative periods compared to the preoperative period. We found no significant differences between the early and late postoperative periods (Table 1). F_0, NHR, and SPI did not significantly differ between the preoperative and postoperative periods (Table 1).

The mean MPT was 15.9 seconds in the preoperative period and 5.5 seconds in the postoperative period. On average, MPT is 22-34 sec in healthy males and 16-25 sec in healthy females (6). After FALE, loose and irregular neoglottal closure causes large amounts of air leakage during phonation causing the observed decrease of MPT (7).

We observed a postoperative increase in the F_0 value, but this change was not statistically significant. F_0 is the number of glottal cycles occurring in one second. A change in the glottal cycle rate typically indicates change in the mechanical characteristics of the vocal cords. Glottal tumors directly affect the mechanical characteristics of the vocal cords and would thus be expected to change F_0; therefore, the lack of a statistical difference between the preoperative and postoperative F_0 values could indicate that F_0 was already changed preoperatively by the tumor. Crevier-Buchman et al. (8) also found no statistically significant difference in mean F_0 or F_0 standard deviation values before and 6 months after a supracricoid partial laryngectomy cricohyoidoepiglottopexy (SCPL-CHEP) operation.

Topaloğlu et al. (9) evaluated SCPL-CHP patients one year after operation and found higher postoperative jitter and shimmer results compared to that of the control group. As in our study, Yagiz et al. (10) and Giovanni et al. (11) found high jitter and shimmer measurements in patients who had undergone FALE. Horii (12) reported that jitter analysis can be used for the evaluation of glottis vibration efficiency. During FALE, resection is performed in the paraglottic field and intrinsic muscle structure, and the tissue remaining after operation no longer has the tension and compliance ability of normal glottis muscles. These anatomic changes may explain the unbalanced vibrational patterns and increased jitter and shimmer values in the glottis after FALE (13).

The VF_0 value can be increased by any random regular short-term or long-term changes in voice pitch. Normative limit values presume that the F_0 does not change during constant phonation; thus, all changes in F_0 values are reflected in VF_0 measurements. We also found that VF_0 values were high during the early and late postoperative periods due to the lack of a stable cord structure.

APQ defines the irregularities between the peak amplitudes in short-term voice. A voice's amplitude can show variability for various reasons. Intercycle amplitude irregularity can occur because the cords cannot provide periodic vibration or due to the occurrence of irregular noises in the voice signal during certain periods. Breathy and hoarse voices usually show a high APQ value. The GRBAS scale indicated that our patients had breathy rough voices after FALE, which is in accordance with the increased APQ values.

Increased NHR values are considered to indicate increased spectral voice due to changed amplitude or frequency (i.e., shimmer and jitter), irregular noise, sub-harmonic factors, and/or voice breaks. Yagiz et al. (10) found a statistically significant increase in harmonic noise ratio following FALE, and Topaloglu et al. (9) reported similar findings in patients after SCPL-CHP. However, both these studies included healthy individuals as the control group. In our present study, we also identified an increased NHR after FALE; however, this difference lacked statistical significance, possibly due to our use of preoperative values as the control group.

The SPI is an indicator of how tightly and completely the vocal cords are closed during phonation. Increased SPI values usually indicate that the vocal cords are loosely or incompletely closed during phonation. SPI values did not show a postoperative increase in our study, possibly because the vocal cords were already unable to close sufficiently due to the glottal tumors preoperatively.

While objective measurements do not evaluate the biopsychosocial impact of a voice disorder, the VHI measures how voice problems impact a patient's quality of life (14). We did not observe substantial changes in the physical and emotional scores during the postoperative period, indicating that the patients were not significantly affected by the surgical changes. However, we found a significant increase in the functional index (Table 2), indicating functional loss following surgery in accordance with the other objective and subjective measurements. Saito et al. (15). reported V-RQOL (voice-related life quality) scores in patients following SCPL (mean physical factor area, 67; social-emotional area, 77.8; and total score, 71.3), which indicated an acceptable post-SCPL voice-related life quality. The physical factor and total score results exhibited no particular relationship with the duration after surgery. Notably, since life quality is affected by psychological, ethnic, social, and cultural factors, studies conducted in different countries may find different VHI scores.

Subjective voice evaluation by the physician was performed using the GRBAS scale. The voice was evaluated in terms of general characteristics, hoarseness, murmur, blowing, strain, and weakness parameters. In general, all three groups exhibited a moderate or severe voice disorder. Since voice hoarseness is related to an irregular glottal stroke, it is expected that this perceptual feature of the voice will exhibit a postoperative change in patients with glottal carcinoma (8). During the preoperative period, 9 patients did not exhibit wheezing and blowing. A moderate blowing sound was observed in 15 patients during the early postoperative period, and in 5 patients during the late postoperative period. Wheezing and blowing increased in the early postoperative period because the larynx was unable to fully close due to its disturbed anatomy after the FALE operation. The decrease of wheezing in the late postoperative period was likely due to compensation of the neoglottis. Moderate weakness was observed in 5 patients during the preoperative period, 12 patients during the early postoperative period, and 10 patients during the late postoperative period. During the postoperative periods, patients generally presented with a straining, weak, and hoarse voice. We found a correlation between the acoustic analysis parameters and video laryngostroboscopic results.

During all three periods, patients exhibited an oval- or hourglass-shaped glottis closure defect. Since normal cord structure is absent after FALE, the longitudinal closure defect was found to increase in the newly formed larynx during the early and late postoperative periods compared to in the preoperative period. From the early postoperative period to the late postoperative period, the longitudinal closure defect decreased. The glottal voice is formed by the transmission of vibrations in irregular mucosal structures, which intensifies in the narrowest part of the glottic region (16).

Evaluation of mucosal wave movements revealed moderate mucosal wave irregularity during all three periods. Moderate asymmetry was present in 10 cases during the preoperative period. The number of cases with moderate asymmetry increased in the early postoperative period (20 cases) and late postoperative period (19 cases).

In conclusion FALE is an oncologic surgery, not a surgery chosen for phonation. Our present results indicated that postoperative phonation continued in a manner that did not disrupt the patients' quality of life or hinder communication. Although neoglottal incompliance caused a distorted voice quality, the patients were still able to adequately communicate by speaking. Overall, although post-FALE acoustic and aerodynamic data revealed a moderately severe dysphonic voice, the patients retained adequate speaking and pulmonary functions. We conclude that this surgical technique preserved an acceptable voice for the patients' occupational and other activities, despite disruption of voice quality.

Ethics Committee Approval: Ethics committee approval was received for this study from the ethics committee of Trakya University (TUMFEC 2010/25).

Informed Consent: Written informed consent was obtained from patients and the parents of the patients who participated in this study.

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