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Evaluation of Voice Quality by Vocal Analysis in Patients Who Underwent Open Heart Surgery

Açık Kalp Ameliyatı Olan Hastalarda Ses Analizi ile Ses Kalitesinin Değerlendirilmesi

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Öz

Giriş ve Amaç: Bu çalışmada açık kalp ameliyatlarının akustik ses kalitesi ve ses aralığına etkisini bilgisayar destekli analiz yöntemi kullanarak ortaya koymayı amaçladık.
Gereç ve Yöntem: 2020-2021 yılları arasında kliniğimizde ameliyat edilen 40 hastaya ameliyat öncesi objektif ses analizi yapıldı. Ameliyat sonrası 2. ayda ölçümler tekrarlandı. Sonuçlar istatistiksel olarak karşılaştırıldı.
Bulgular: Ses handikap indeksi-10 (VHI-10) açısından gruplar arasında anlamlı fark yoktu (p>0,050). Temel frekans (F0) değeri ameliyat sonrası dönemde ameliyat öncesi döneme göre istatistiksel olarak anlamlı derecede yüksek bulundu (p=0,042). Gruplar arasında % jitter, shimmer % ve harmonik gürültü oranı (HNR) değerlerinde istatistiksel olarak anlamlı bir fark yoktu.
Sonuç: Açık kalp cerrahisi solunum sistemi üzerinde yıkıcı etkisi olabilen bir ameliyattır. Ses enerjisinin kaynağı olan akciğerlerin etkilenmesi ses kalitesinin de etkileneceğini düşündürür. Bu etkiler genellikle kısa sürede gerilerken bazen kalıcı olabilir. Bu durum daha çok mesleğinde sesini kullanan kişileri etkiler. Bu nedenle her hastaya böyle bir durum hakkında detaylı bilgi verilmeli ve ses bozukluklarına neden olabilecek faktörlerin en aza indirilmesine özen gösterilmelidir.

Anahtar Kelimeler: Açık Kalp Ameliyatı, Ses, Ses Analizi, Ses kalitesi.

Abstract

Objective: In this study, we aimed to reveal the effect of open heart surgeries on acoustic sound quality and vocal range by using computer aided analysis method.
Materials and Methods: Preoperative objective voice analysis was performed on 40 patients who were operated on in our clinic between 2020 and 2021. Measurements were repeated in the 2nd postoperative month. The results were compared statistically.
Results: There was no significant difference between the groups according to the voice handicap index-10 (VHI-10) (p>0.050). The baseline frequency (F0) value was found to be statistically significantly higher in the postoperative period compared to the preoperative period (p=0.042). There was no statistically significant difference between groups in jitter %, shimmer % and harmonic noise ratio (HNR) values.
Conclusion: Open heart surgery is an operation that can have a destructive effect on the respiratory system. The fact that the lungs, which are the source of voice energy, are affected, suggests that the voice quality will also be affected. While these effects usually regress in a short time, they can sometimes be permanent. This condition mostly affects people who use their voice in their profession. Therefore, detailed information about such a situation should be given to each patient and care should be taken to minimize the factors that may cause voice disorders.

Keywords: Complete Blood Cell, Emergency Service, Neutrophil Lymphocyte Ratio, Platelet Lymphocyte Ratio, White Blood Cell

1.Introduction

The vocal tract includes various structures that start from the vocal cords, pass through the oropharynx and end at the lips and nostrils. In this process, which ends with the vibration of the vocal cords, the characteristic of the voice is formed depending on the anatomical structures through which the air passes. The source of the air, which is the main factor that provides this vibration, is the lungs. The complex metabolic activity, which contributes to the respiratory system, musculoskeletal structures as well as hormonal factors, ensures the fulfillment of the speech function, which is one of the basic elements that defines the person in daily life. Just like fingerprints, voice is personal.

The factors that affect the voice production mechanism and lead to the distortion of the voice are very diverse. Voice abuse habits (talking loudly, shouting, singing, etc.), medical reasons (larynx removal, thyroid surgery, intubation, heart surgery, etc.), chronic diseases (respiratory problems, hormonal problems, stomach problems, allergies, etc.), habits (alcohol, cigarette smoking) or neurological disorders are the most important factors that directly affect voice quality and result in voice disorders [1, 2].

Although voice analysis was performed especially in head and neck surgeries, it was not performed in surgeries where the thorax or sternum was opened. We consider that the voice will be affected after surgeries in which the integrity of the thorax and/or sternum is impaired, because open heart surgery, despite technological developments and increasing experience, has a destructive effect on all tissues and organs. It may show the same destruction in all structures in the stages of receiving, storing and transmitting the air necessary for the formation of voice. Dysfunction in the lungs where air is stored is one of the most common and most important complications after open heart surgery. The decrease in postoperative pulmonary functions is affected by many factors, which may be listed as preoperative factors (smoking, chronic obstructive pulmonary disease (COPD) and other accompanying lung diseases), phrenic or left laryngeal nerve damage caused by the effect of ice used for peroperative local hypothermia, quenching of the lungs during cardiopulmonary bypass time, blood and blood products transfusion, opening of the pleura, removal of internal mammary artery (IMA). In addition, postoperative pain due to sternotomy, prolonged intubation, pain due to mediastinal and/or chest drains are also causes of decreased pulmonary function.

After sternotomy, the compliance of the lung and thoracic wall is severely reduced. The maximum decrease is on the 3rd postoperative day and continues to decrease until the 6th day. These changes in chest wall mechanics affect forced expiratory volume. As a result, respiratory rate increases, tidal volume pressure decreases and atelectasis occurs. Thus, less air is retained in the lungs than it should be, and in direct proportion to this, the amount of air delivered to the vocal cords is less. Atelectasis, which occurs at a rate of approximately 70% in the postoperative period, is the most common pulmonary complication that causes diaphragm elevation after open heart surgery. Recently, incision forms to reduce these effects of sternotomy have been investigated and minimally invasive interventions have been emphasized [3].

The increase in the longitudinal size of the thorax is provided by the diaphragm, an important respiratory muscle that allows approximately 75% of the air to enter the lungs. Another complication that causes diaphragm elevation after open heart surgery is mechanical or hypothermic damage to the unilateral or bilateral phrenic nerve. Although the incidence of diaphragmatic paralysis is not well defined, some sources have reported that the incidence of permanent bilateral diaphragmatic paralysis after open heart surgery is less than 0.1%, and temporary diaphragmatic weakness is 4% or more [4]. Ice used for topical cooling during open heart surgery is thought to cause hypothermic phrenic nerve paralysis. Although it is rarer than phrenic nerve damage, vocal cord paralysis due to left recurrent laryngeal nerve damage and associated hoarseness and speech disorder have been documented, especially in open heart surgery for patent ductus arteriosus and transverse aorta [5]. Other rare causes of vocal cord damage and related voice disorder include; traumatic endotracheal intubation, use of an improperly sized endotracheal tube, or infrequently compression of the recurrent laryngeal nerve anterior branch of an over-inflated endotracheal tube balloon, injury of the recurrent laryngeal nerve during central venous line intervention through the jugular vein, traction of the vocal cords due to improper position of the intraoperative neck, nasogastric tube placement in a way that will damage the vocal cords, compression on the recurrent laryngeal nerve due to lateral retraction of both subclavian arteries with sternal traction after sternotomy, direct manipulation and retraction of the heart [5, 6].

After most surgeries, voice disorders may be seen due to organic or mechanical reasons. Heart surgeries are also included in the ones that are related to the anatomical structures involved in the formation of the voice. Apart from organic causes that result in voice disturbance and can be detected by laryngeal examination, many patients may have complaints such as sore throat, swallowing problems and hoarseness after heart surgery [7]. These complaints, which generally regress within 24-72 hours postoperatively, vary from patient to patient [8]. Because the complaints are short-lived and do not

cause permanent damage, they are often ignored by both the physician and the patient. However, this is much more critical for professional voice users. The hoarseness that will occur in patients (singers, teachers, lawyers, imams, theater actors, etc.) who use their voice to do their job may cause serious problems that affect their performance and success in business life. The factors that may lead to postoperative voice disorders should be well known and necessary precautions should be taken to minimize their effects. In this study, we aimed to reveal the changes in voice that may occur due to cardiac surgery and its causes.

2.Materials and Methods

This study was carried out jointly with University of Health Sciences, Adana City Training and Research Hospital Cardiovascular Surgery (CVS) and Ear Nose and Throat (ENT) Clinics between 2020 and 2021. Approval was obtained from the ethics committee of the same hospital for the study (178/28.01.2020).

Forty patients undergoing open heart surgery were included in the study. Patients with a history of an operation that may affect the voice quality (such as surgery due to a pathology in the vocal cord, upper airway surgery) and patients under the age of 18 were excluded from the study. Voice analyses of the participants were performed twice, once within 48 hours before the operation and once 2nd month after the operation when the patients gained sternum stabilization, no sternal pain with chest expansion, and temporary voice problems secondary to intubation disappeared.

All subjects were informed about the study to be performed and their consent was obtained. Before the voice analysis of the patients, all otolaryngological examinations were performed to rule out organic causes of voice disorders, and the nasal cavities and laryngeal structures were evaluated. None of the patients included in the study had sinonasal discomfort. A standard general anesthesia protocol was applied to all patients with intratracheal intubation in one move. Standard cardiopulmonary bypass protocol was applied to all patients after median sternotomy. It was aimed to maintain end-tidal carbon dioxide pressures between 35-40 mmHg by ventilating the patients with intraoperative and postoperative volume-controlled mode. For this purpose, ventilator tidal volume was adjusted to 6-8 ml/kg, and its frequency to 10-12/min. In all patients, 5 cmH20 positive end-expiratory pressure (PEEP) was routinely exerted to prevent atelectasis. In cases with normal oxygenation and ventilation arterial blood gas values, the ventilator oxygen value was gradually reduced to 40% in a controlled manner [9]. Upon awakening of hemodynamically stable patients without respiratory problems, the phase of weaning from the ventilator was initiated in accordance with the weaning protocol [9].

2.1 Subjective Voice Analysis

The Turkish version of the Voice Handicap Index (VHI) -10 was used in the analyses. This questionnaire, with each question rated between 0-4 points and scored out of 40, includes 10 questions. All the patients completed the questionnaire and the results were evaluated [10].

2.2 Objective Voice Analysis

Voice recordings and measurements were made in an environment where audio insulation was applied to all patients before and 2 months after the operation. The microphone (Audio-Technica AT2020USB Cardioid Dynamic USB/XLR Microphone, Audio-Technica US, Inc.) was held 20 cm away from the patient's mouth and three permanent phonations (each phonation longer than 3 seconds) were recorded at the pitch and height that the patients most comfortable using the "a" sound. The voice amplified by the microphone's own amplifier was recorded in the computer environment at a sampling rate of 44.1 kHz. The segment analyzed is a 1-second segment in the middle of vowel production. Paul Boersma and David Weenink audio analysis system (Praat) is one of the leading audio analysis programs. The collected records were digitized and acoustic analysis was performed using the Praat (Boersma, P& Weenink, D, 2013, Version 5.2.21, www.praat.org) program. Basal frequency (F0), Jitter
%, shimmer %, harmonic-noise ratio (HNR) values were recorded. Preoperative and postoperative F0, jitter %, shimmer %, HNR and VHI-10 values of the patients were statistically compared.

2.3 Statistical Analysis

Control of compliance with the normal distribution of numerical variables obtained from the partipicants was evaluated by Shapiro-Wilk statistics. The summary statistics of the variables are given as mean±standard deviation or median and percentiles (25%-75%) according to the compliance with the normal distribution. Descriptive statistics for categorical variables are given as numbers and percentages. While error-bar and box-whisker graphics were preferred to summarize numerical variables via graphics, were used to summarize categorical variables. Parametric paired two-group t-test and non-parametric Wilcoxon Rank Sign Test were used to compare pre-operative and post-operative measurements. Statistical significance level was determined as $p<0.05$.

3. Results and Discussion

3.1.Results

The mean age of the patients included in the study was 58.60±11.98 (age range 20-73). While 17 (42.5%) of the 40 patients were female, 23 (57.5%) were male. When evaluated in terms of smoking, 17 patients (42.5%) were smoking, while 23 patients

(57.5%) were non-smokers. Eighteen (45%) of the patients had been receiving medical treatment for diabetes mellitus (DM) and 3 (7.5%) of the patients for COPD.

Coronary artery bypass graft (CABG) surgery was performed in 24 of the patients, valve replacement in 11, and CABG combined with valve replacement in 5 patients. During surgery, at least one of the thoracic cavities was opened in 34 patients (85%), and drainage was provided by tube thoracostomy. Aortic cross-clamp and total perfusion times in the course of surgery are 74.98±41.215 minutes (cross-clamp time range: 33-205 minutes) and 119.70±53.987 minutes (total perfusion time range: 55-295 minutes), respectively. The mean duration of stay in ventilation was 10.40±1.582 hours (intubation interval: 9-17 hours).

There was no statistically significant relationship between pre/post-operative groups according to VHI-10 scores (p>0.05).

After checking the compatibility with the normal distribution, the mean pitch F0 values were evaluated via the parametric paired t test. The paired t test showed that the mean preoperative value was 188.095±48.939 and the mean postoperative value was 196.922±51.098 in terms of Mean pitch F0 measurement, and there was a statistically significant difference between these values (p=0.042) (Table 1).

Table 1: Comparison of the sound analysis parameter results of the patients in the preoperative and postoperative period.

	Preoperative		**Postoperative**		
	***Mean*±SD**	***Median***	***Mean*±SD**	***Median***	**p**
Mean pitch F0	188,095±48,939		196,922±51,098		0,042
Jitter %		0,258		0,308	0,288
Shimmer %		2,759		2,999	0,707
HNR Db		23,136		21,711	0,221

HNR: Harmonic-noise ratio

It is observed that the mean value in the postoperative period is higher than the preoperative value (Fıgure 1). In the group where the mean pitch F0 value is high; It was observed that the gender distribution was equal and there was no significant increase in the total perfusion times (122.72±52.326).

After checking for compatibility with normal distribution, non-parametric Wilcoxon rank sign test was used for Jitter %, Shimmer % and HNR Db values. The nonparametric Wicoxon rank sign test revealed that there was no statistically significant difference between the preoperative and postoperative evaluation processes in terms of Jitter %, Shimmer % and HNR Db measurements (p>0.05) (Fıgures 2, 3, 4).

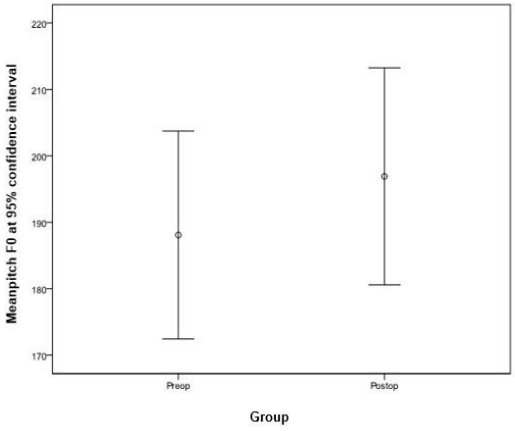

Figure 1. Error bar graph with visual evaluation of patients' mean pitch F0 results at 95% confidence interval.

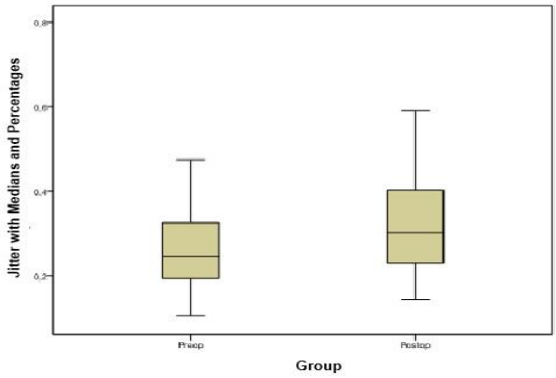

Figure 2. Box-plot graphy in which the Jitter % results of the patients were evaluated visually in the preoperative and postoperative period.

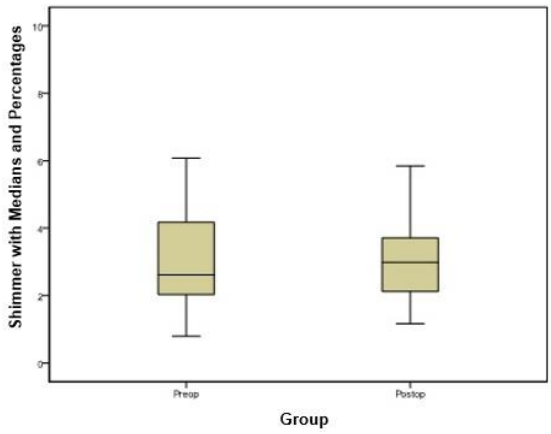

Figure 3. Box-plot graphy in which the Shimmer % results of the patients were evaluated visually in the preoperative and postoperative period.

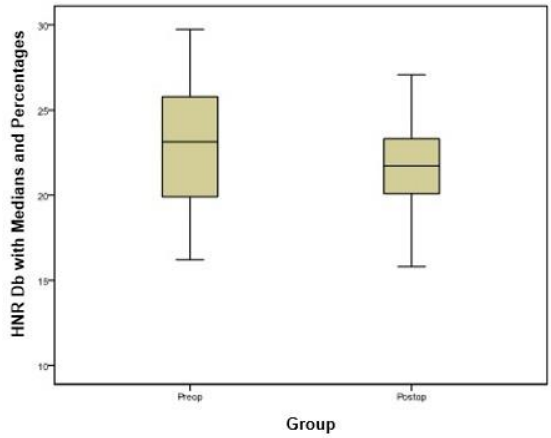

Figure 4. Box-plot graphy in which the HNR Db results of the patients were evaluated visually in the preoperative and postoperative period.

3. 2. Discussion

The human voice occurs as a result of the whole body working in a great harmony. Speech is particularly related to the respiratory system, but also to special speech centers in the cerebral cortex, respiratory control centers in the brain, articulation, and resonator structures in the oral and nasal cavities. The air inhaled from the mouth and nose to the lungs, the source of voice energy, is compressed by the contraction of the chest, back, abdomen and diaphragm muscles, and is first transmitted to the vocal cords, where it vibrates, then it is processed in the upper airway and comes out of the mouth. If there is a problem at one of the stops during the passage, then we will talk about the deterioration of the voice quality [1, 8]. The most common complaints in people with voice disorders are soreness in the throat, a feeling of pain or tension during speech, a feeling of stuck in the throat, hoarseness that does not heal or that is frequently experienced, complete loss of voice, difficulty in speaking, breathlessness, inability to maintain speaking for a long time, higher (thin) or low (thick) voice than normal, cracking/roughness in the voice, difficulty speaking/singing loudly, and worsening of the voice during the day or towards the weekend [11]. It is important to use computer-aided programs that allow acoustic analysis of the voice in the objective evaluation of voice disorders. Acoustic analysis provides the opportunity to evaluate the voice objectively. There are many programs that are used for this purpose. In our study, we used the Praat voice analysis program, which is a noninvasive method that can be easily applied in objective voice analysis. Although there are many parameters to evaluate the voice analysis, we used fundamental frequency (F0): the number of vibrations of the vocal folds per second, jitter: the involuntary frequency irregularity in the fundamental frequency, that is, it refers to the variation in each period, shimmer: indicates the change between the amplitudes of the sound wave, and HNR: a scale that measures the amount of additional noise in the audio signal.

Subramaniam et al. reported that F0 values varied in various age groups in a prospective study examining the acoustic parameters of the voice in patients who had undergone tonsillectomy [12]. While the postoperative F0 value increased significantly in the 5-10 age group, it showed a statistically significant decrease in the 11-16 age group. These changes reflect the variable behavior of postoperative F0.

In the meta-analysis of Lang et al., in which the acoustic voice parameters before and after thyroidectomy were compared, they did not find a statistically significant difference in HNR and jitter values, but they found a statistically significant decrease in F0 and shimmer values in the first 3 months postoperatively [13].

Ng et al. Also published their analysis of voice change in patients who underwent medialization tyroplasty.[14] The postoperative F0 value was found to be significantly increased in female patients with malignant etiology, whereas it was found to be significantly decreased in male patients. Physiologically, a higher F0 corresponds to faster vibration of the vocal cords, possibly as a result of higher laryngeal tension. The increased tension is probably also more pronounced in male patients because their usual F0 values are lower than in female patients. It has been stated that this difference in the findings between genders may be related to the difference in respiratory support.

"Fast-track" applications in open heart surgeries have a rapidly increasing popularity. In this way, the intubation time was reduced for early mobilization. Recently, side effects of intubation have been avoided completely by performing surgery on the awake patient without intubation so that vocal cord damage and edema can be prevented [3]. We applied standard general anesthesia protocol to all patients. There was no significant difference in terms of intubation times in the group with increased F0. However, compared to studies in which voice analysis was performed after head and neck surgeries, intubation times were found

to be longer in our study. We think that the increase in the postoperative F0 value in our study is an increase independent of the intubation time, since we know that the vocal cords of our patients did not suffer postoperative permanent damage and that the effect of intubation on the voice passed in a short time.

It is known that pulmonary functions are severely affected in patients whose left internal mammary artery (LIMA) is removed [3]. The effect may be due to disruption of pleural integrity, injury to the LIMA region, or sternum traction. In our study; LIMA was removed in 24 of the CABG patients, and at least one pleura was opened in 34 of the total patients. During open heart surgeries; some inflammatory system activations (activation of the complement system, neutrophil sequestration in the pulmonary microvascular bed, release of free oxygen radicals) disrupt the alveolar structure, the effect of sternotomy on the lung capacity in a restrictive manner, and the exposure of the lungs to direct trauma due to the deterioration of pleural integrity; postoperative vital capacity, total lung capacity, and diffusion capacity decrease, and it may take several months for these values to be restored [15, 16]. We think that the changes in vital capacity and total lung capacity due to all these factors may be responsible for the increase in mean pitch F0 values after open heart surgery.

Limitations of the study

Our work has several limitations. First, the study was conducted at a single center, and the results may not be applicable to other groups because they represent a single center's experience. Second, we did not measure subglottal pressure in the patient population and did not examine pulmonary function tests to determine vital capacity. In conclusion, open heart surgery, which can have a destructive effect on the respiratory system, showed that it was highly correlated with voice quality by affecting the fundamental sound frequency (F0). However, our study is one of the rare studies examining the effect of open heart surgery on voice.

4. Conclusion

Depending on all these factors, deterioration in the frequency and intensity of the voice may be observed after open heart surgery. In our study, the postoperative F0 value was found to be higher than the preoperative value. The difference in fundamental frequency may not as clinically significant, since the mean difference was less than one semitone, and there were very large standard deviations. Although we do not normally expect a significant change in the baseline frequency, the high postoperative F0 value in our patients was thought to be due to the hemodynamic changes of the patients, changes in respiratory support, decreased lung capacity, use of the upper resonator region due to the inability to use the lung capacity fully, and the patient's attempt to make a confidential voice due to pain. We could not detect any difference between preoperative and postoperative evaluation processes in terms of Jitter %, Shimmer % and HNR scales. We consider that the change in F0 value needs evaluations in long-term follow-ups. Since our study has not been done before in terms of evaluating the effects of open heart surgery through sternotomy, we care about its contribution to the literature.

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All authors have contributed equally.
There is no conflict of interest.
The study accomplished in compliance with ethical standards.
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References

1. Hamdan, A.L, Sibai A, Rameh C, et al., Short-term effects of endotracheal intubation on voice, *Journal of Voice*, 2007, 21, 762–768.
2. Byeon, H, The Risk Factors Related to Voice Disorder in Teachers: A Systematic Review and Meta-Analysis, *International Journal of Environmental Research and Public Health*, 2019, 16(19), 3675.
3. Oz, B.S, Iyem, H, Akay, H.T, et al., Preservation of pleural integrity during coronary artery bypass surgery affects respiratory functions and postoperative pain: a prospective study, *Canadian Respiratory Journal*, 2006, 13(3), 145-149.
4. DeVita, M.A, Robinson, L.R, Rehder, J, et al., Incidence and natural history of phrenic neuropathy occurring during open heart surgery, *Chest*, 1993, 103(3), 850–856.
5. Hamdan, A.L, Moukarbel, R.V, Farhat, F, et al., Vocal cord paralysis after open-heart surgery, *European Journal of Cardiothoracic Surgery*, 2002, 21(4), 671–674.
6. Shafei, H, el-Kholy, A, Azmy, S, et al., Vocal cord dysfunction after cardiac surgery: an overlooked complication, *European Journal of Cardiothoracic Surgery*, 1997, 11(3), 564–566.
7. Inada, T, Fujise, K, Shingu, K, Hoarseness after cardiac surgery, *Journal of Cardiovascular Surgery (Torino)*, 1998, 39(4), 455–459.
8. Paltura, C, Yuceant, G.A, The effect of short term endotracheal intubation on voice quality and range, *Journal of Contemporary Medicine*, 2018, 8(1), 26–28.
9. Badak, T.O, Iskesen, A.I, Evaluation of the effects of coronary artery surgery on pulmonary functions by pulmonary function test, *Celal Bayar University Journal of Institute of Health Sciences*, 2021, 8(2), 331–336.
10. Kuran, G, Cavus, G, Vocal quality assessment of patients with pituitary adenomas operated via endoscopic and microscopic approaches, *Turkish Neurosurgery*, 2020, 30(1), 38–42.
11. Akin Şenkal, Ö, Çiyiltepe, M, Effects of voice therapy in school-age children, *Journal of Voice*, 2013, 27(6), 787.e19–25.
12. Subramaniam, V, Kumar, P, Impact of tonsillectomy with or without adenoidectomy on the acoustic parameters of the voice: a comparative study, *Archives Otolaryngology Head and Neck Surgery*, 2009, 135(10), 966–969.
13. Lang, B.H, Wong, C.K, Ma, E.P, A systematic review and meta-analysis on acoustic voice parameters after uncomplicated thyroidectomy, *Laryngoscope*, 2016, 126(2), 528–537.
14. Ng, M.L, Wong, R.K, Wei, W.I, et al., Acoustic changes in Chinese patients with cancer-related unilateral vocal fold paralysis after medialization thyroplasty, *Contemporary Issues In Communication Science and Disorders*, 2008, 35, 17–24.
15. American Thoracic Society; European Respiratory Society. American Thoracic Society/European Respiratory Society statement: standards for the diagnosis and management of individuals with alpha-1 antitrypsin deficiency, *American Journal of Respiratory and Critical Care Medicine*, 2003, 168(7), 818–900. doi: 10.1164/rccm.168.7.818.
16. King, R.C, Reece, T.B, Hurst, J.L, et al., Minimally invasive coronary artery bypass grafting decreases hospital stay and cost, *Annals of Surgery*, 1997, 225(6), 805–809.